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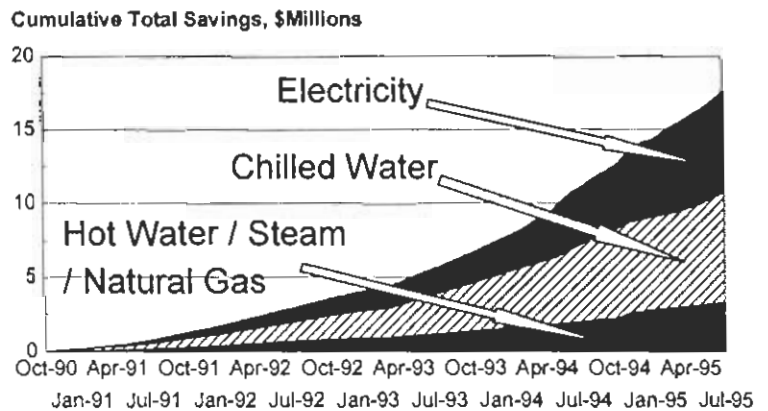
Measuring Energy-Saving Retrofits: Experiences from the Texas LoanSTAR Program

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Texas LoanSTAR Monitoring and Analysis Program

October 1990 - July 1995 Summary of Measured Energy Cost Savings



Texas A&M University
Existing Buildings Research Program

Office of Building Energy Research
U.S. Department of Energy

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February 1996

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TABLE OF CONTENTS

TABLE OF CONTENTS	i
LIST OF TABLES	v
LIST OF FIGURES	vi
PREFACE	viii
DISCLAIMER	ix
ABSTRACT	x
EXECUTIVE SUMMARY	xi
Purpose and Objectives of the Program	xi
Tasking	xi
Development of Monitoring Levels	xii
Measuring the Energy Use	xii
Acquiring and Processing the Data	xii
Monitoring Requirements - Why Did We Monitor What We Did?	xiii
Analysis Approach - How Did We Intend to Calculate the Savings?	xiii
Energy Savings	xiv
1.0 INTRODUCTION	1
2.0 LoanSTAR PROJECT OVERVIEW, OBJECTIVES, AND IMPLEMENTATION	2
2.1 LoanSTAR Overview	2
2.2 Objectives of the LoanSTAR Monitoring and Analysis Program	3
2.3 Implementing the LoanSTAR Program	4
2.3.1 Tasking	4
2.3.1.1 Task 1: Audit Review and Assignment	4
2.3.1.2 Task 2: Selection and Installation of Monitoring Systems	5
2.3.1.3 Task 3: Calibration Laboratory	6
2.3.1.4 Task 4: Testing of Systems Communications, and Computer Support	9
2.3.1.5 Task 5: Monitoring Plans, Analysis, and Reports	10
2.3.1.6 Task 6: Improved Energy Audits	11
2.4 Development of Monitoring Levels	11
2.4.1 Level 0: Facility/Whole-building(s) Utility Data	11
2.4.2 Level 1: Whole-building and Limited Sub-metered Hourly Data	11
2.4.3 Level 2: Moderate Sub-metered Hourly Data	12
2.4.4 Level 3: Detailed Sub-metered Hourly Data	12
2.5 Budgeting for the Measurement of Energy Conservation Retrofits	12
3.0 ACQUIRING, ARCHIVING, HANDLING, AND REPORTING THE DATA	38
3.1 Measuring the Energy Use	38
3.2 General Information on Acquiring, Archiving, Handling, and Reporting the Data	38
3.3 Basics of Electricity Monitoring	39
3.3.1 The Watt-hour Meter	39
3.3.1.1 Connecting a Computer to a Watt-hour meter	39

3.3.1.2 Measuring Demand With a Watt-hour Meter	40
3.3.1.3 The Watt/Watt-hour Transducer	40
3.4 Measuring Thermal Energy.....	41
3.4.1 Thermal Energy Meters.....	41
3.4.2 Thermal Energy Meters Used in the LoanSTAR Program	42
3.4.3 Insertion Flow Meters	44
3.5 Polling and Retrieving Data.....	45
3.5.1 Processing/Plotting Synergistics Data.....	46
3.6 Quality Control	46
3.7 Weekly Report Generation.....	48
3.8 Reporting the Data	48
3.8.1 Monthly Energy Consumption Reports	49
3.9 Data Exploration Software.....	51
3.10 Summary of LoanSTAR Data Management	51
3.10.1 Review of Polling Logs.....	52
3.10.2 Recorder Parameter Set Revision Control	52
3.10.3 Automated Initial Verification	52
3.10.4 Automated Handling of Missing Records.....	53
3.10.5 Generation and Review of Inspection Plots	53
3.10.6 Controlled Data Release	53
3.10.7 Marking, Filling and Reconditioning In Database.....	54
4.0 CHARACTERIZATION OF THE ANALYSIS OF RETROFIT MEASURES	68
4.1 Background	68
4.2 Monitoring Requirements - Why did we monitor what we did?	68
4.2.1 Types of Retrofits.....	68
4.2.2. Criteria	69
4.3 Analysis Approach - How did we intend to calculate savings?	70
4.3.1 Overview	70
4.3.2 Savings Methodology	71
4.3.3 Statistical Models Used.....	73
4.4 Allied Issues Regarding Modeling.....	76
4.4.1. Effect of Short Pre-retrofit Data Sets	76
4.4.2. Uncertainty in Savings Determination	76
4.4.3. Simplified Systems Model Approach	78
4.4.4 Mixed billing and monitored data.....	78
5.0 RESULTS FROM THE FIRST TWO YEARS OF MONITORING	88
5.1 Verifying Energy and Audit Dollar Savings of Retrofits.....	88
5.1.1 Energy Savings.....	88
5.1.2 Demand Savings	88
5.2 Reducing Energy Costs by Identifying O&M Problems.....	89
6.0 RECOMMENDATIONS FROM THE FIRST TWO YEARS OF MONITORING.....	100
6.1 Recommendations from Task 1	100
6.2 Recommendations from Task 2	101
6.2.1 Administrative Guidelines for Task 2.....	101

6.2.2 Equipment Recommendations	102
6.2.2.1 Thermal Metering	102
6.2.2.2 Electrical Metering.....	103
6.2.2.3 Other Instrumentation Problems	104
6.2.3 Equipment Installation	105
6.2.3.1 Thermal Metering	105
6.2.3.2 Electrical Metering.....	107
6.2.3.3 Other Instrumentation	108
6.2.4 Equipment Maintenance	108
6.3 Recommendations from Task 3	110
6.3.1 Equipment.....	110
6.3.1.1 Electrical Metering.....	110
6.3.1.2 Thermal Metering	111
6.3.1.3 Other Equipment	111
6.3.2 Installation.....	111
6.3.2.1 Thermal Metering	111
6.3.2.2 Electrical Metering.....	111
6.3.2.3 Other Equipment	112
6.3.3 Maintenance.....	112
6.3.3.1 Thermal Metering	112
6.3.3.2 Electrical	113
6.3.3.3 Other Equipment.....	113
6.4 Recommendations From Task 4	113
6.4.1 Acquiring the data.....	114
6.4.2 Data quality control.....	115
6.4.3 Hardware issues	116
6.5 Recommendations from Task 5	116
6.5.1 Agency Contact and Site Description	116
6.5.2 Pre-screening of Data.....	117
6.5.3 Modeling and Analysis	117
6.5.4 Savings Calculation	118
6.5.5 Savings Reporting and Follow-up.....	118
7.0 REFERENCES	122
8.0 BIBLIOGRAPHY	128
9.0 ACKNOWLEDGMENTS	135
10.0 APPENDIX.....	136
10.1 Compendium of Analysis Papers.....	136
10.2 Helpful Hints about Polling and Retrieving Data	142
10.2.1 Processing/Plotting Synergistics Data.....	142
10.2.1.1 Preparing Data from Time Series Channels from Raw Synergistics Data with R2A.BAT	143
10.2.1.2 Using GRAPHER to Create an Individual Graph.....	146
10.2.1.3 Creating Graphs Using 101GRAPH.BAT	147
10.2.2 Modification of Routines	148

10.2.3 Creation of Summary Pages From Raw Synergistics Data and Area	
Weather Data	149
10.2.3.1 Modification of Summary Plot Routines	151
10.2.4 Creating a 3-D Graph Using Lotus 123 and Intex Solutions 3D	
Graph.....	151
10.2.5 Using the COLROW3D Columnar to Row Data Processing Routine.....	152

LIST OF TABLES

Table 2.1: Summary of ECRMs for Buildings Monitored as of May 1993	14
Table 2.2: Energy Conservation Monitored in Buildings under the LoanSTAR program as of May 1993	14
Table 2.3: Guidelines for the LoanSTAR Metering Experiments	15
Table 2.4: List of Potential Sensors for Calibration.....	15
Table 2.5: Ranges and Accuracies of the Calibration Facility	16
Table 2.6: Summary of Flow Meter Characteristics	17
Table 2.7: Budget Breakdown for the First Year Monitoring Program	18
Table 5.1: Comparison of Audit and Measured Savings on an Individual Building Basis for the 24 Buildings Currently Reporting Savings as of March 1993.....	92
Table 5.2: Energy Conservation Identified in Buildings Monitored Under LoanSTAR Program as of May 1993.....	93
Table 5.3: O&M Opportunities identified at six sites.....	94
Table 5.4: Summary of Potential O&M Savings at Six LoanSTAR Sites.....	95
Table 6.1: Category I ECRMs.....	120
Table 10.1: Example Output 10192168.DAT From RAW2DAT Program.....	158
Table 10.2: Example Output 10192168.DAT From RAW2DAT Program.....	159
Table 10.3: Example Channel Table For the 10190001.CHT ARCHIVE Program	160
Table 10.4: Example .LOG File From the ARCHIVE Program.....	161
Table 10.5: Summary of GRAPHER Instructions for Graph T1017.GRF	162
Table 10.6: T1017.GRF GRAPHER File	163
Table 10.7: Example Output from the ARCHIVE Program, File 10192168.ACH	164
Table 10.8: Example Input Data File for COLROW3D	165
Table 10.9: Example Output Data File for COLROW3D.....	166
Table 10.10: An Example .LOG File for COLROW3D	167
Table 10.11: Decimal Date Reference Table for COLROW3D	168
Table 10.12: Intex Solutions 3DGRAPH Plotting Instructions for 3D Surface Plot SAMPLEM1.3DP.....	169

LIST OF FIGURES

Figure 2.1: LoanSTAR Monitoring and Analysis Task Planning.....	19
Figure 2.2: Distribution of LoanSTAR Loans by Percent of Functional Area	20
Figure 2.3: Geographic Distribution of LoanSTAR Sites in Texas	21
Figure 2.4: Audit Estimated Retrofit Costs and Savings	22
Figure 2.5: Estimated Cost of Retrofits	23
Figure 2.6: 2 MW of Measured Electric Demand Reduction	24
Figure 2.7: Typical LoanSTAR Level 1 Monitoring	25
Figure 2.8: Typical LoanSTAR Level 2 Monitoring	26
Figure 2.9: Typical LoanSTAR Level 3 Thermal Monitoring.....	27
Figure 2.10: Typical LoanSTAR Level 3 kWh Monitoring	28
Figure 2.11: Preliminary Results for Calibration of RH Sensors	29
Figure 2.12: Diagram of the Liquid Flow Loop Calibration Facility.....	30
Figure 2.13: Preliminary Results from Tangential Paddlewheel Flow meters	31
Figure 2.14: LoanSTAR Monitoring and Analysis Program Network	32
Figure 2.15: DOS-UNIX ASCII Flat File Method for Archiving and Distributing LoanSTAR Data.....	33
Figure 2.16: DOS-UNIX Relational Method for Archiving and Distributing LoanSTAR Data.....	34
Figure 2.17: LoanSTAR Database Structure	35
Figure 2.18: LoanSTAR Centralized Commenting and Logging Facility -- iComment.....	36
Figure 2.19: Before-After Analysis of Energy Conservation and Savings	37
Figure 3.1: Electrical and thermal monitoring diagram for a typical LoanSTAR site.....	55
Figure 3.2: Diagram of an example logger set-up.	56
Figure 3.3: Typical logger set-up to measure three phase whole-building electricity.....	57
Figure 3.4: Typical thermal energy meter set-up.	58
Figure 3.5: Typical hot-tap flow meter installation.	59
Figure 3.6: Weather cross-plots of LoanSTAR vs. National Weather Service.....	60
Figure 3.7: Typical weekly inspection plot for a LoanSTAR site.	61
Figure 3.8: Summary page (page 1) from the August 1993 energy consumption report.....	62
Figure 3.9: Page 2 of the Monthly Energy Consumption Report (MECR).	63
Figure 3.10: Page 3 of the Monthly Energy Consumption Report (MECR).	64
Figure 3.11: Page 4 of the Monthly Energy Consumption Report (MECR).	65
Figure 3.12: Page 5 of the Monthly Energy Consumption Report (MECR).	66
Figure 3.13: LoanSTAR browsing software.....	67
Figure 4.1: Pump and Air-handler Electricity Use at LoanSTAR Building	80
Figure 4.2: Pre-Retrofit Chilled-Water Use with Model and Savings.....	81
Figure 4.3: One, Two and Four Parameter Baseline Models for Savings Measurements	82

Figure 4.4: Examples of Four-parameter Change-point Models for Hot Water and Chilled Water Energy Use.....	83
Figure 4.5: Flow Chart Summarizing Model Fitting Procedure	84
Figure 4.6: Schematic of Savings Estimation Procedure.....	85
Figure 4.7: Schematic of the HVAC and Building Zone Interaction Assumed in the Simplified Systems Model Approach	86
Figure 4.8: Schematic of the Simulation Procedure	87
Figure 5.1: Cumulative Savings from LoanSTAR Retrofits: March 1993	96
Figure 5.2: Electricity Savings from HVAC Retrofits.....	97
Figure 5.3: AHU Electric Demand Reduction	98
Figure 5.4: O&M Identification Procedure Flow Chart.....	99
Figure 10.1: Flow Chart for R2A.BAT Plotting Procedure.....	170
Figure 10.2: Example plot of the first 12 channels from Site 101.....	171
Figure 10.3: Example plot of the remaining channels from Site 101.....	172
Figure 10.4: Flow Chart for the GRAPHER Program.....	173
Figure 10.5: Graph created with T1017.GRF and T101.DAT Data File.....	174
Figure 10.6: Flow chart for 101GRAPH.BAT.....	175
Figure 10.7: Example summary plot for Site 101.....	176
Figure 10.8: Flow chart for summary page UTSUMM.BAT.....	177
Figure 10.9: Basic flow chart for producing 3-D plots.....	178
Figure 10.10: Example .PIC plots using the COLROW3D software packages.....	179

PREFACE

This report has been prepared for the Existing Buildings Research Program of the Office of Building Energy Research at the U.S. Department of Energy. The purpose of this report is to document, for the benefit of others, the monitoring and analysis methods used in the Texas LoanSTAR program. It describes monitoring procedures and data analysis routines and software developed for the Texas LoanSTAR program that are copyrighted for distribution in the public domain. Software mentioned in this report and additional software used in the LoanSTAR program may be obtained by contacting the authors.

This report has been prepared by Drs. Jeff Haberl and Agami Reddy and includes significant input from Drs. David Claridge, W. Dan Turner, Dennis L. O'Neal, and Warren M. Heffington.

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ABSTRACT

In 1988 the Governor's Energy Management Center of Texas received approval from the U.S. Department of Energy to establish a \$98.6 million state-wide retrofit demonstration revolving loan program to fund energy-conserving retrofits in state, public school, and local government buildings. As part of this program, a first-of-its-kind, state-wide Monitoring and Analysis Program (MAP) was established to verify energy and dollar savings of the retrofits, reduce energy costs by identifying operational and maintenance improvements, improve retrofit selection in future rounds of the LoanSTAR program, and initiate a data base of energy use in institutional and commercial buildings located in Texas. This report discusses the LoanSTAR MAP with an emphasis on the process of acquiring and analyzing data to measure savings from energy conservation retrofits when budgets are a constraint.

This report includes a discussion of the program structure, basic measurement techniques, data archiving and handling, data reporting and analysis, and includes selected examples from LoanSTAR agencies. A summary of the program results for the first two years of monitoring is also included.

EXECUTIVE SUMMARY

This report discusses the procedures developed in the Texas LoanSTAR (Loans to Save Taxes and Resources) program for acquiring and analyzing data to measure savings from energy conservation retrofits when budgets are a constraint. This report presents how the data were collected and how savings from energy conservation retrofits in the Texas LoanSTAR program were measured and reported.

Purpose and Objectives of the Program

The LoanSTAR Monitoring and Analysis Program (MAP) was designed to serve the differing needs of the many participants in the \$98 million LoanSTAR revolving loan program. Four primary objectives were to be accomplished by the LoanSTAR MAP. The energy monitoring program's first objective is to determine whether retrofits save as much as estimated in the energy audits. 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. In effect the LoanSTAR MAP was created to serve as a quality assurance measure for agencies purchasing retrofits. The savings reports produced by the MAP were developed to show that real savings from those retrofits were occurring and, when savings did not occur, to investigate and recommend measures to make sure that the savings do occur.

The second objective of the LoanSTAR MAP is to reduce energy costs in a building by evaluating its energy-using characteristics and recommending operations and maintenance (O&M) procedures to reduce energy costs.

The third objective is to increase the cost-effectiveness of future rounds of the LoanSTAR program by screening out ineffective retrofits. Some retrofits prove to be more effective and others less effective than expected. Knowledge gained in the LoanSTAR program is intended to enable engineers who perform audits to make more cost-effective recommendations.

The fourth and final objective of the LoanSTAR MAP is to establish a state-wide end-use data base for institutional and commercial buildings in Texas. Such a data base is expected to supplement existing data bases, such as ELCAP, BECA, and those in use by the United States Department of Energy Information Agency (EIA) and the Electric Power Research Institute's Center for Electric End-Use Data (CEED). These data are intended for use by utility planners, building research scientists, and government policy makers.

Tasking

In order to accomplish these objectives, the LoanSTAR MAP was divided into six tasks with the following responsibilities: Task 1, performing audit reviews and assignments, Task 2, installing hardware and selecting vendors, Task 3, running a calibration facility, Task 4, providing computer support, Task 5, analyzing and reporting

savings, and Task 6, improving energy audits. Each of the six primary tasks also utilized subcontractors as needed to complete the work in a timely fashion.

Development of Monitoring Levels

Four levels of metering were developed for the energy monitoring program. These levels were intended to accommodate the necessary data requirements with the funds available for monitoring the retrofits, as follows:

- 1) Level 0: facility whole-building(s) utility data.
- 2) Level 1: whole-building and limited sub-metered hourly data. Typically, this represents four channels of data from a building, usually electricity and thermal loads.
- 3) Level 2: moderate sub-metered hourly data. This includes Level 1 plus sub-metered data for air-handling units or motor control centers.
- 4) Level 3: detailed sub-metered hourly data. This typically includes 20 or more channels of data and is reserved for the most extensive sites.

Level 1 monitoring applies to retrofits of \$50,000 to \$100,000 and costs about \$3,000 to install. Level 2 monitoring applies to retrofits costing \$100,000 to \$300,000 and costs roughly \$10,000 to \$30,000 to install. Level 3 is reserved for buildings with retrofits costing more than \$300,000 and costs \$30,000 or more to install. These cost levels were developed to keep monitoring budgets within 3% of the retrofit costs. Level 0 costs essentially nothing to install since it relies on monthly utility billing data.

Measuring the Energy Use

The primary uses of energy in buildings involve the time-varying measurements of electricity and thermal energy use, usually on an hourly basis. In the LoanSTAR program, most of the electricity monitoring was accomplished with current transducers, potential transducers, and digital watt-hour transducers, or by piggy-backing on the existing utility meters through the use of a KYZ dry contact pulse.

Thermal energy monitoring, used to measure the chilled water and steam or hot water energy use, was accomplished with thermal energy meters or Btu meters. Btu meters are electronic devices that are used to calculate chilled water or hot water energy use. Each Btu meter requires three input signals: a flow meter signal and a temperature signal for both the supply and return lines.

Acquiring and Processing the Data

The LoanSTAR MAP data management consists of five major functions: 1) polling the data from the remote data acquisition systems; 2) processing the data from various sites into a reasonably generic format; 3) controlling data quality; 4) generating reports; and 5) retrieving data for analysis. By August 1994, the LoanSTAR MAP was retrieving data from over 81 field recorders and 68 National Weather Service (NWS) weather stations. One of the objectives of the data-gathering aspects of the program was to develop public domain routines that could be useful to others. LoanSTAR has faithfully

accomplished this task by developing modular routines to poll and process data, and placing these routines in the public domain.

Monitoring Requirements - Why Did We Monitor What We Did?

As of September 1994, energy savings in 19 LoanSTAR loans (a total of 89 buildings) were being reported, while monitoring was under way at 81 sites. The majority are institutional buildings, while a few are school districts and thermal energy plants. Ranging in size from 50,000 ft² to 500,000 ft², The primary retrofits in these buildings were to the lighting and HVAC systems, which required that both thermal and electrical energy use be analyzed.

If a retrofit was expected to reduce lighting, heating, or cooling energy use, then the energy used by these subsystems was (for the most part) monitored and recorded before and after the retrofit. In most instances, monitoring of whole-building electricity, thermal energy use, and selected electrical submetering on the large electrical loads was sufficient to capture 90% of the energy used by these systems. Typically, the following channels were used during retrofit savings calculations: chilled water use, hot water use, whole-building electricity use, air handler electricity use, pump electricity use, and climate variables (ambient temperature, relative humidity, wind speed and global horizontal solar radiation).

Analysis Approach - How Did We Intend to Calculate the Savings?

In the simplest cases, retrofit savings can be measured by directly comparing the unadjusted pre-retrofit energy use to the post-retrofit energy use. Unfortunately, this simple comparison can introduce as much as 10-20% error in buildings that have varying schedules and/or experienced different weather conditions during the pre/post periods. In the LoanSTAR program, for the larger retrofits, hourly data were measured during the pre-retrofit period to construct a baseline model. This model was then used to predict what the building would have consumed in the post-retrofit period had the retrofit not been implemented.

The basic modeling approaches used in the LoanSTAR program can be grouped into two generic types: regression models and calibrated engineering models. The regression models use billing and/or monitored data and employ one-, two-, three-, and four-parameter change-point models, or multiple regression models. The calibrated engineering models ranged from sophisticated DOE-2 calibrated models to calibrated simplified HVAC system models. In each case it was important to identify the pre-retrofit period, construction period, and post-retrofit period. Then, depending on the type of model, hourly data were then converted to average daily data prior to performing the regressions. Statistical models were then applied and the model that demonstrated the best goodness of fit was chosen. Usually, to ensure completeness, all models were applied to all buildings and the best model was chosen. The statistical models were then used to project the baseline use in the post-retrofit period. Savings were then calculated by comparing the differences between the post-retrofit baseline energy use and the measured

post-retrofit energy use. In cases where substantial post-retrofit data were missing a post retrofit model was created and substituted for the missing post-retrofit data.

Energy Savings

As of September 1994, the cumulative measured savings from the 19 LoanSTAR loan sites that had completed retrofits were \$12.2 million, of which 34.6% is in electricity savings, 47.5% in cooling energy savings, and the remainder (18%) in heating energy savings. The value of the monitoring performed as part of the LoanSTAR program can be appreciated by noting that the program-wide savings agree to within 5% of the audit estimated savings -- a feat rarely accomplished in other programs. O&M savings have increased these values considerably and have also played a significant role in the program. Demand reduction has also been significant across the LoanSTAR sites -- an unexpected feature for variable speed drives. In four of the sites, demand reductions of 30% were observed. The total reduction for all sites as of December 1993 approaches 2 MW, of which roughly 37% is in lighting, 60% in HVAC-related equipment, and 3% in thermal energy storage.

The remainder of this report discusses the procedures developed in the Texas LoanSTAR program for acquiring and analyzing data to measure savings from energy conservation retrofits when budgets are a constraint.

1.0 INTRODUCTION

This report discusses the process of acquiring and analyzing data to measure savings from energy conservation retrofits when budgets are a constraint.¹ This report discusses how the data were collected and how savings from energy conservation retrofits in the Texas LoanSTAR program were measured and reported.

In the first section, the objectives of the LoanSTAR program and how it was structured and implemented are described, including the development of monitoring levels and budgeting. This is followed by a discussion of the basic techniques that were employed to measure the energy savings in the agencies participating in the LoanSTAR program, and a discussion of the procedures that were used to archive, handle, and report hourly data from thousands of data channels.

Next, the analysis procedures that have either been adopted or developed for analyzing the savings from energy conservation retrofits in the LoanSTAR program are discussed, including selected examples of the applications of these procedures from LoanSTAR sites.

Preliminary measured results from the first year of monitoring 24 LoanSTAR agencies are also included. The final section of the report summarizes the lessons learned and makes recommendations for other large-scale monitoring projects.

¹ In the LoanSTAR program the budgets were constrained as follows: 3% of the retrofit costs were to cover the installation of metering equipment, and 2-3% per year were to cover the analysis and reporting. Since the LoanSTAR numbers indicate Texas state interagency transfers these numbers would need to be adjusted to account for overhead and profit.

2.0 LoanSTAR PROJECT OVERVIEW, OBJECTIVES, AND IMPLEMENTATION

2.1 LoanSTAR Overview

In 1988, the Governor's Energy Management Center (GEMC)² 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 (Loans 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. 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 (Verdict et al. 1990).

As part of this program, a statewide energy Monitoring and Analysis Program (MAP) was established. The major objectives of the LoanSTAR MAP are as follows (Turner et al. 1990; Claridge et al. 1991):

- 1) to verify the energy and dollar savings of the retrofits,
- 2) to reduce energy costs by identifying operational and maintenance improvements,
- 3) to improve retrofit selection in future rounds of the LoanSTAR program, and
- 4) to initiate a data base of energy use in institutional and commercial buildings located in Texas.

The LoanSTAR program 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, the 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.

² In 1990 the center was renamed the Governor's Energy Office. In 1993 it was again renamed the Texas Energy Office; it was given its current name, the State Energy Conservation Office, late in 1993.

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 million. Repayments are made semi-annually at an annual interest rate of 4.04%. 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. Total metering costs must not exceed 3% of all retrofit costs.

2.2 Objectives of the LoanSTAR 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 the operation of the building, and so on. This is a quality assurance measure to ensure 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 or 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. Therefore, data gathered in the framework of the LoanSTAR program should be considered a supplement to existing data bases, such as ELCAP, BECA, and data bases used by Energy Information Agency (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 Claridge et al. (1991).

2.3 Implementing the LoanSTAR Program

The LoanSTAR MAP is administered through the State Energy Conservation Office (SECO) of Texas and is 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 the U.S. Department of Energy, the Electric Power Research Institute, Lawrence Berkeley Laboratory, Oak Ridge National Laboratory, Pacific Northwest Labs, National Renewable Energy Laboratory, Princeton University, Massachusetts Institute of Technology, the University of Texas, Pacific Gas & Electric Co., and a Texas utility.³

2.3.1 Tasking

The primary work for the MAP has been divided into six tasks (Figure 2.1) with the following responsibilities: Task 1, performing audit reviews and assignments; Task 2, installing hardware and selecting vendors; Task 3, running a calibration facility; Task 4, providing computer support; Task 5, analyzing and reporting savings; and Task 6, improving energy audits.⁴ Each of the six primary tasks utilizes subcontractors as needed to complete the work in a timely fashion.

2.3.1.1 Task 1: Audit Review and Assignment

The SECO has contracted with 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 SECO. 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 (Heffington et al., 1987; Nutter et al., 1990; Heffington et al., April 1992; Heffington et al., May 1992.)

Figure 2.2 shows the distribution of the LoanSTAR loans by percent floor area of functional use. The largest portion of floor area is in medical facilities, followed by buildings that are being monitored at university campuses. Figure 2.3 shows the geographical distribution of the LoanSTAR sites around the state of Texas. Clearly, the largest number of buildings are in Austin at the State Capitol and University of Texas at Austin campus. The other buildings are spread around the state as shown.

³ This is current as of June 1993.

⁴ Originally, there were 5 tasks. Task 6 was added in 1992.

Figure 2.4 shows the audit estimated retrofit costs and savings. HVAC system retrofits are by far the largest percent of retrofit costs, followed by variable speed drives and lighting retrofits. One interesting feature to point out is the importance of funding boiler and steam system retrofits. These types of retrofits have been very cost effective – with almost twice the savings potential of other retrofits. Table 2.1 gives a summary of energy cost reduction measures (ECRMs) for buildings monitored as of May 1993. The estimated \$32.5 million implementation cost will generate \$9.6 million annual savings for an estimated 3.4 year simple payback. Roughly 199 buildings containing 18.3 million square feet of conditioned space will have been affected 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.

Figure 2.5 lists the estimated costs of the completed retrofits in the program as of May 1993. As indicated, at any given time, different numbers of participating LoanSTAR agencies are at different stages in the program. As of May 1993, 24 sites (36 buildings)⁵ had completed their retrofits and were having their savings reported by the ESL, 11 additional sites had recently completed their retrofits and have yet to report savings. Thirty-four more sites, for a total of 69 sites (199 buildings) are being monitored by the ESL as of May 1993.

As of May 1993, the LoanSTAR program has identified energy source⁶ savings of 2.5 trillion Btu (2.5×10^{12}) as shown in Table 2.2. Electricity represents the largest source of Btu savings at 52.9%, followed by chilled water at 17.4% and steam/hot water at 17.1%. Natural gas savings represent 12.7%.

The installed retrofits have also produced over 2 MW in electric demand savings as well, as shown in Figure 2.6. Over 60% of these savings have been in HVAC retrofits, followed by 37% in lighting retrofits and 3% in thermal storage retrofits.

2.3.1.2 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 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

⁵ The number of sites usually represents a data logger. Since several buildings can be monitored by one logger there are more buildings than sites.

⁶ Btu savings calculated on the basis of source Btus (i.e., 11,600 Btu/kWh, 1,030,000 Btu/MCF, boiler efficiency of 75% and 12,000 Btu/ton-hr).

on the market as of May 1993. Table 2.3 contains guidelines for the energy monitoring levels. These levels include 1) Level 0: facility whole-building(s) utility data, 2) Level 1: whole-building and limited sub-metered hourly data, 3) Level 2: moderate sub-metered hourly data, 4) Level 3: detailed sub-metered hourly data. Additional information about the four levels of monitoring is discussed in section 2.4.

Figure 2.7 shows a typical LoanSTAR Level 1 monitoring setup as installed in the T. S. Painter Building on the University of Texas at Austin campus. This Level 1 monitoring provides whole-building electricity, whole-building chilled water and whole-building steam condensate use. Figure 2.8 shows a typical Level 2 monitoring plan as installed in the UTC Building on the University of Texas at Austin campus. In this case, Level 2 monitoring provides whole-building electricity (kWh), whole-building chilled water, whole-building steam condensate, and sub-metered electricity use for the building's air-handling units and pumps.

Figure 2.9 illustrates a Level 3 thermal monitoring setup as installed in the S. F. Austin building at the Texas State Capitol complex. In general most Level 3 monitoring experiments are complex and require a metering plan that is specially tailored to each retrofit. The S. F. Austin building contains a central boiler/chiller complex that feeds several other buildings and a weather station. Figure 2.10 shows a Level 3 electricity monitoring setup as installed in the S. F. Austin building at the Texas State Capitol complex. The intent of this monitoring plan is to isolate electricity use in the boiler/chiller plant.

In general, a separate monitoring diagram is developed for each LoanSTAR site during the initial site visit by the LoanSTAR field engineer. The purpose of this diagram is to ensure that the intended retrofit's energy use is being recorded properly and to develop a simple diagram that can be understood by all parties involved, including the field engineer, agency contact, and LoanSTAR analyst who will later rely on the diagram to help explain what has been monitored and how it relates to the retrofit.

2.3.1.3 Task 3: Calibration Laboratory

The accuracy of the installed sensors is key to a successful energy monitoring project. Data obtained for such a project must be accurate to maintain confidence and reliability. In order to ensure that accurate data are collected, a National Institute of Standards and Technology (NIST)-traceable calibration laboratory has been established at the Energy Systems Laboratory at Texas A&M University (Turner et al., 1992).

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.

A list of potential calibration sensors is shown in Table 2.4. All of the sensors in the LoanSTAR program are calibrated yearly using the calibration laboratory. This calibration facility includes 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, as shown in Table 2.5. Typically, the calibration accuracy is two to ten times more accurate than the sensors being tested (as recommended by national calibration standards).

Two of the more useful calibration stations have turned out to be the temperature-humidity station and the flow meter calibration facility. The humidity calibration standard consists of a temperature chamber, a multi-bore glass flask and a variety of salt solutions. Saturated salt solutions of known proportions are placed in the flask along with the candidate sensor and several 1,000 Ohm RTD sensors. The temperature of the chamber is then varied and the readings are compared with NIST published data for the salt solutions, using NIST procedures.

The following salt solutions are currently being used: lithium chloride (11% RH); magnesium chloride (32% RH); magnesium nitrate (54% RH); sodium chloride (75% RH); potassium chloride (85% RH); and potassium sulfate (97% RH). The secondary calibration standard for the station is a chilled-mirror dew point sensor.

The measurement of humidity (and its derived variables: enthalpy, specific humidity, dewpoint temperature, etc.) can play an important role in buildings when the analysis of latent cooling loads is undertaken. Unfortunately, the long-term hourly measurement of humidity at remote sites can be characterized as problematic at best. For example, in very humid locations such as the Gulf coast, humidity sensors saturate (and stay saturated) for hours on end. Such sensors require special attention when it comes to calibration. Preliminary results from calibration efforts with bulk polymer-type sensors have been developed. The basic procedure employed involves a constant pressure, sealed flask where the candidate sensors are suspended in the saturated vapor above the salt solution in the bottom of the flask. Then, the entire flask (and sensors) are heated to a beginning temperature and stepped-down through a series of predetermined temperatures, pausing long enough at each temperature for all signals to stabilize.

Figure 2.11 shows the results from tests performed on two RH sensors. Using equations developed by Greenspan (1977), the tests show clearly that one sensor consistently overstates the humidity when compared to the theoretical humidity that is predicted by saturated conditions at a given temperature. Both candidate sensors are bulk-polymer RH sensors with a stated accuracy of $\pm 2\%$ at 25 C (77F) that were taken "off-the-shelf" from LoanSTAR inventories from the same manufacturer. The preliminary tests clearly indicate that temperature and humidity-dependent corrections will need to be developed for each individual sensor to obtain the highest accuracy.

Liquid velocity measurements are calibrated with a dynamic weight flow loop. The flow loop consists of 37,800 liter (10,000 gallon) supply and receiving tanks, a parallel pumping configuration using 3.2, 9.5, and 41 l/s (50, 150 and 650 gpm) pumps, a return pump, assorted valves, and a flow test section, currently with a 15.2 cm (6 inch) pipe as shown in Figure 2.12. The receiving tank is mounted on four Sensortronics Model 65016 (11,342 kg (25,000 lb.) each) load cells. This provides a dynamic weighing system for bulk fluid velocity measurements (ASME MFC-9M-1988; Baker and Hurley 1984; Miller 1989; Olsen 1974). The load cells were calibrated by the Department of Agriculture Weights and Measures Division, State of Texas, using NIST-traceable dead weights. In addition to this primary standard, a series of interchangeable orifice plates is installed to provide a secondary standard. In addition, the calibration facility is equipped with interchangeable 20.3 cm (8 inch) and 25.4 cm (10 inch) pipe test sections as well as a 15.2 cm (6 inch) clear test section. The flow loop is also equipped with a 10.2 cm (4 inch) return line that can also be used for calibration tests.

Both the liquid flow loop station and the temperature-humidity station are being used in a production mode to calibrate sensors for the program. Preliminary tests of some of the sensors with these stations have already provided some interesting and quite unexpected data that confirm the need for a facility such as this.

One of the first problems investigated in the flow loop was the sensitivity of the insertion-type tangential paddlewheel flow meters to the insertion depth into the fluid-carrying pipe (Haberl et al. 1992). These tests showed that care must be taken when installing flow meters in pipes to ensure that they are installed at the proper insertion depth. This problem is further compounded by the fact that different manufacturers recommend different insertion depths. Without careful documentation, the insertion depth can vary slightly from installation to installation. It can also be changed by the agency operators. These flow meters also have an axial alignment requirement; hence, the sensitivity to off-axis installation also needs to be measured.

In Figure 2.13 preliminary results from tests performed on magnetic and non-magnetic paddlewheel flow meters in a 6" pipe are presented. The results show the velocity measurements by one manufacturer's magnetic-type paddlewheel meter were 15% low on average due to an erroneous pulse-per-gallon constant. In addition the signal from the magnetic-type paddlewheel meter went to zero for velocities below 2 ft/s. The failure of the meter below 2 ft/s confirmed the observations that had been made at some of the field installations. However, when the data were closely examined, it was discovered that the flow meter was still rotating and producing electronic pulses but the strength of the pulses had dropped below the sensitivity threshold of the Btu meter.⁷ To remedy this, a pre-amplifier was inserted between the flow meter and the Btu meter that significantly improved the low flow results in the laboratory tests.⁸ In Figure 2.13 the

⁷ Subsequent tests showed that the threshold varies with the type of Btu meter.

⁸ However, such a pre-amplifier is not used by the manufacturer of this flow meter. Tests were performed to confirm the minimum flowrate that this meter would operate under.

“mag meter corrected” symbol represents the results that were obtained once the pre-amplifier had been installed and the pulse-per-gallon reading had been adjusted. As shown, the meter comes within $\pm 5\%$ of the flow rate for velocities above 2 ft/s.

A second type of paddlewheel meter was tested, which uses a “non-magnetic” metering technology. Although this type of technology is about twice as expensive than the magnetic technology, it seems to consistently produce more accurate data, as shown in Figure 2.13. The results from the non-magnetic paddlewheel meter appear to be within $\pm 5\%$ from 2 ft/s and up, and $\pm 10\%$ from 1/2 to 2 ft/s. The pulse-per-gallon factor also appears to be correct. This type of technology also does not suffer from the degradation that the magnetic technology incurs when metal filings accumulate on the magnets and retard the rotation.

Choosing a flow meter for a particular application requires a knowledge of what type of fluid is being measured, how dirty or clean that fluid is, what the lowest expected flow velocities are, and what type of budget one has available, as shown in Table 2.6. This table represents results from an informal survey of flow meter manufacturers and includes installed costs from experiences with the LoanSTAR program.

2.3.1.4 Task 4: Testing of Systems Communications, and Computer Support

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, DASs and the host computer. Public domain software, using open communications protocol, has been developed for polling, translating and analyzing the field data. Data acquisition systems that adequately satisfy the testing were approved for use in the program. The primary functions of this task include the communications bench-test and the software design, development, and testing.

Figure 2.14 shows the LoanSTAR Monitoring and Analysis Program Network (MAPNet) that has been developed for polling, archiving and analyzing building energy data. As of May 1993, 1,020 hourly channels of data are polled weekly from 77 loggers at 69 sites, which account for 199 buildings. One hundred fifty hourly channels of data are also collected from the NWS Aviation Weather Observation, converted to LoanSTAR format and merged with the LoanSTAR data. Once in the MAPNet, the data are kept on a Data General Aviiion AV-4020 RISC server with 64 MB of RAM and 3.5 Gbytes of disk space. Analysts then have access to the data via the campus internet through one of 64 workstations scattered about the campus.

Originally, data were collected with DOS-based computers, processed for missing data and high-low bounds, and then stored as flat ASCII files (.ACS) as shown in Figure 2.15. Inspection Plot Notebooks (IPNs) and Voyager files were then produced on DOS-based computers and distributed to LoanSTAR analysis workstations via the campus internet. Flat ASCII files were also kept on the UNIX-based server where Monthly Energy Consumption Reports (MECR) and Annual Energy Consumption Reports

(AECR) were produced, as well as data being made available for analysis. This system was chosen mainly because of ease of use, and the ability to use existing data processing tools, such as ARCHIVE (Feuerman and Kempton 1987). However, handling hourly data comprising about 1,000 channels from 50 sites became too unwieldy using the flat-file ASCII scheme that required concatenating 52 files to look at one year's worth of data. Hence, a relational system was chosen to update the data management system at this stage of the project.

After a lengthy selection process the Informix relational data base was chosen and installed on the UNIX server. Figure 2.16 shows the basic data flow scheme that resulted. With the relational system, flat ASCII files were loaded into Informix after IPNs were produced with the traditional DOS-based scheme. Once in Informix, the data could then be retrieved and used for any one of a number of processing requirements as shown in Figure 2.17. As of May 1993 there are 1,020 channels of building energy data, which includes over 12 million individual readings. Each week about 162,000 records, or roughly 2.5 million bytes, are added to the data base. To date about 2% of the data have been marked bad.⁹ About 6% of the data have required some sort of correction after they were collected. Most of the corrections to date involve the flow meter corrections.

Another feature that is being developed is a relational commenting system. At various points in the data stream, analysts and LoanSTAR staff have the opportunity to comment on the data and can insert their comments into the permanent LoanSTAR relational database. This process leaves a paper trail for other analysts so that specific facts about a site can be made available without the various parties involved with the installation, maintenance, data collection, programming, and data administration having to meet in person. The system developed is being called iComment, as shown in Figure 2.18. iComment receives comments from a number of different inputs, including the IPN, MECR, AECR, calibration lab, and automatic comments from several routines. iComment then automatically sorts the comments and archives them appropriately. iComment can automatically deliver messages to field engineers in cases where sensors are down and/or need replacing. Before the development of iComment, all commenting was performed on paper, photocopied and distributed, sometimes resulting in missed communications -- a potential problem that can create serious questions about data integrity problems.

2.3.1.5 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

⁹ The use of the term "bad" means that the data cannot be restored and are replaced with -99, the marker for missing data.

the analysis of energy use and site data, and the interaction and feedback to agencies and operators through ongoing analysis of the data.

2.3.1.6 Task 6: Improved Energy Audits

This task seeks to improve the energy auditing methods used in commercial and institutional buildings. The primary focus of this task is to incorporate monitored data as feedback to the energy auditor as the audit progresses, with the goal of improving the accuracy of the audit. This is accomplished through the development of the LoanSTAR Monitoring Workshop and accompanying Workbook, and through the use of prescreening indices. The intention of the workshop (Haberl 1992) was to deliver the basic LoanSTAR data collection and plotting routines to energy auditors in complete enough form that they could be used during the audit process.

Prescreening indices are also under development that allow for the screening of facilities based on monthly utility billing data and a minimum amount of site description information. The prescreening indices are based on the previous work by Haberl and Komor (1989) and basically include weather-normalized W/ft^2 and Btu/ft^2-hr comparative values for energy usage and demand that can point to potential problem areas in a building prior to the site visit.

2.4 Development of Monitoring Levels

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 typically change. Table 2.3 contains the financial guidelines for the energy monitoring levels. These levels include 1) Level 0: facility whole-building(s) utility data, 2) Level 1: whole-building and limited sub-metered hourly data, 3) Level 2: moderate sub-metered hourly data, and 4) Level 3: detailed sub-metered hourly data.

2.4.1 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 is expected to fall within this category.

2.4.2 Level 1: Whole-building and Limited Sub-metered Hourly Data

Level 1 utilizes one- to four-channel Data Acquisition Systems (DAS), and captures hourly whole-building thermal and electric measurements. In some cases, limited sub-metering is also being 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.

2.4.3 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 recorders.

2.4.4 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.

In general, the LoanSTAR analysis relies on before-after energy measurements. Prior to the installation of each retrofit, data loggers are installed in each building to record the baseline energy use. 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, as shown in Figure 2.19. When measured savings do not match audit estimates, a problem flag is generated so that corrective action can be taken to remedy the difference. Feedback to owners and operators also plays an important role in assuring that energy conservation retrofits remain on-track.

2.5 Budgeting for the Measurement of Energy Conservation Retrofits

From the beginning, the LoanSTAR program was designed to put strict limits on the amount of money that could be spent on the monitoring and analysis. This amounted to roughly 3 to 5% of the retrofit cost, which paid for the monitoring equipment, and 2 to 3% of the retrofit cost to pay for the recording of the data, analysis, and reporting.¹⁰ Budget breakdowns for the first year of monitoring are given in Table 2.7.

As discussed earlier, four levels of monitoring were established to roughly conform with data acquisition equipment that was available on the market. Financed at 3%, this converts roughly into the dollar values that are shown in Table 2.3. This means that Level 1 monitoring can be justified in a site where the retrofit cost is in the \$50,000 to \$100,000 range, Level 2 monitoring in the \$100,000 to \$300,000 retrofit cost range, and so forth. This equates to roughly \$3,000 for Level 1, and up to \$10,000 for the installation of a Level 2 system, etc.

Because the LoanSTAR data are also being used to find and resolve O&M problems, it has been shown that 5 to 15% of many building's energy can be saved if these problems can be identified and fixed. Therefore, based on O&M savings Level 1 monitoring can be

¹⁰ Since monies were transferred from one state agency to another there were limited overhead charges. It has been estimated that these would have raised these figure to 6% of the retrofit costs for installation and 4% for annual recording, analysis and reporting. The cost will probably drop as the technology matures and becomes more cost effective.

justified in buildings where the annual energy costs are \$30,000 to \$60,000, and so forth. Throughout the program these guidelines have been strictly adhered to.

Table 2.1: Summary of ECRMs for Buildings Monitored as of May 1993.

ECRM Recommendations	Impl. Cost \$	Total Impl. Cost %	Cost Savings \$	Total Cost Savings %	Simple Payback Yrs.
HVAC System Retrofits	\$10,504,625	32.3	\$3,256,227	34.0	3.2
Boiler and Steam Retrofits	1,439,646	4.4	1,116,516	11.7	1.3
Motor/VSD/VSP Conversion	4,679,163	14.4	1,172,166	12.3	4.0
Chiller & CHW Retrofits	1,936,886	6.0	362,643	3.8	5.3
Lighting Retrofits	4,841,987	14.9	1,605,062	16.8	3.0
EMC Systems	3,368,158	10.4	736,918	7.7	4.6
Pumping Sys. Retrofits	1,752,647	5.4	655,057	6.9	6.0
Others	3,997,383	12.3	662,291	6.9	6.0
TOTALS	\$32,520,495	100	\$9,566,880	100	3.4

Table 2.2: Energy Conservation Measures Monitored in Buildings under the LoanSTAR program as of May 1993.

Purchased Utility Category	Site Energy	Site Energy** (million Btu/yr)	Source Energy* (mil. Btu/yr)	Fractional Site Energy Savings (%)	Fractional Source Energy Savings (%)
Electricity	113,282,528 (kWh/yr)	386,520	1,314,077	26.6	52.9
Natural Gas	305,274 (MCF/yr)	314,432	314,432	21.7	12.7
Steam/Hot Water	318,237 (million Btu/yr)	318,237	424,316	21.9	17.1
Chilled Water	35,986,682 (Ton-hr/yr)	431,840	431,840	29.8	17.4
Totals		1,451,029	2,484,666	100	100

**Btu savings calculated on the basis of site Btus (i.e., 3,412 Btu/kWh, 1,030,000 Btu/MCF and 12,000 Btu/ton-hr)

*Btu savings calculated on the basis of source Btus (i.e., 11,600 Btu/kWh, 1,030,000 Btu/MCF, boiler efficiency of 75% and 12,000, Btu/ton-hr)

Table 2.3: Guidelines for the LoanSTAR Metering Experiments.

Monitoring Level:	Retrofit Costs:	Annual Energy Costs:	Monitoring Budget:
Level 0: Monthly 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 2.4: List of Potential Sensors for Calibration. This table provides a list of possible sensors that might need to be calibrated in a large monitoring program (Turner et al. 1992).

Liquid Flow	Temperature	Hydraulic Pressure	Air Pressure
1. Orifice 2. Venturi 3. Flow Nozzle 4. Turbine 5. Vortex 6. Magnetic 7. Ultrasonic 8. Paddlewheel 9. Impact 10. Mass - Coriolis 11. Mass - Thermal 12. Transducers (kJ or Btu)	1. Thermometer 2. Thermocouple 3. RTD 4. Temperature portion of Humidity sensor 5. Thermistor 6. I.C. Temperature Sensor	1. Pressure Gauge 2. Pressure Transducer	1. Pressure Gauge 2. Manometer 3. Pressure Transducer
Humidity	Electrical Power	Electrical Current	Electrical Voltage
1. Dew/Frost Point Sensor 2. Psychrometer 3. Thin Film Polymer 4. Mechanical (Dimensional) 5. Dielectric Crystal	1. Watt-hour meters 2. Watt transducers	1. Clamp-on Amp Meter 2. Current Transformer	1. Voltmeter 2. Multimeter 3. Potential Transformer
Air Flow	Rotational Speed	Solar Radiation	Illumination Levels
1. Pitot Tube 2. Hot-wire Thermo-anemometer 3. Rotary Device 4. Flow nozzles	1. Contact Tachometers 2. Non-contact Tachometers 3. Strobes 4. Reflective Tachometer	1. Pyranometer 2. Pyrhelio meter	1. Light Meter

Table 2.5: Ranges and Accuracies of the Calibration Facility. This table provides a summary of the intended range and accuracies of each of the calibration stations at the facility (Turner et al. 1992).

Liquid Flow	Temperature	Hydraulic Pressure	Air Pressure
Range: 5 to 950 gpm 0.3 to 59.9 l/s	Range: -40 to 500 F -40 to 260 C	Range: 0 to 500 PSI 0 to 3.5 MPa	Range: 0 to ± 24 inches WG 0 to ± 609 mm WG
Accuracy: $\pm 1\%$ of reading	Accuracy: ± 0.4 °F ± 0.2 °C	Accuracy: $\pm 0.25\%$ Reading	Accuracy: ± 0.01 inches WG ± 0.25 mm WG
Humidity	Electrical Power	Electrical Current	Electrical Voltage
Range: 10 to 95% RH 32 to 125 °F 0 to 52 °C	Range: 0 to 100 Amps 0 to 5 MW	Range: 0 to 1000 Amp	Range: 0 to 600 VAC 0 to 600 VDC
Accuracy: $\pm 1.5\%$ RH, ± 1.0 F, ± 0.65 C	Accuracy: $\pm 0.5\%$ Full Scale	Accuracy: $\pm 0.5\%$ Full Scale	Accuracy: $\pm 0.5\%$ Full Scale
Air Flow	Rotational Speed	Solar Radiation	Illumination Levels
Range: 0 to 8000 ft/m 0 to 46.7 m/s	Range: 0 to 3600 RPM	Range: 0 to 500 Btu/ft ² 0 to 1.5 kW/m ²	Range: 0 to 1000 FC
Accuracy: ± 10 ft/m $\pm .05$ m/s	Accuracy: ± 2 RPM	Accuracy: $\pm 2\%$ Reading	Accuracy: $\pm 1\%$ Reading

Table 2.6: Summary of Flow Meter Characteristics. This table presents a summary of flow meter characteristics, which has been assembled from experiences gained in the LoanSTAR monitoring program and other useful sources.

FLOW METER	D I R T Y	C L E A N	RANGE	LOW F L O W	PURCHASE COSTS (\$)	INSTALL COST (\$)	ACCURACY UNCALIBRATED (INCLUDING TRANSMITTER) (note 1)	APPLICATIONS
ORIFICE PLATE	A	G	THE RANGE OF ALL THE DIFFERENTIAL METERS IS LIMITED BY THE PRESSURE TRANSDUCER IN USE	G	\$800	\$1500	± 1-2 % FULL RANGE SCALE (FRS)	GOOD FOR LOW FLOWS IN CLEAN WATER
VENTURI TUBE	G	G		G	\$1500	\$1500	± 1-2% FRS	GOOD FOR CONTROLS & MONITORING IF PRESENT
NOZZLE	G	G		G	\$2000	\$2000	± 1-2% FRS	GOOD FOR STEAM AND HIGH PRESSURE GASSES
PITOT TUBE	P	G		G	\$500	\$500	± 5% FRS	GOOD FOR SPOT CHECKS IN CLEAN FLUID
ANNUBAR	P	G		G	\$1500	\$500	± 1% OF RATE	VERY GOOD FOR LOW FLOW IN CLEAN FLUID
TURBINE	P	G	1-30 FPS	P	\$1500	\$1500	± 1% OF RATE	VERY GOOD METER IN CLEAN FLOW
VORTEX	G	G	1-30 FPS	G	\$3500	\$1500	± .5-1.5% OF RATE	GOOD MULTI PURPOSE METER
TANGENTIAL PADDLE- WHEEL	A	G	1-30 FPS	P	\$500	\$500	± 2.5% OF RATE	GOOD FOR MONITORING
INSERTION TURBINE	P	G	1-30 FPS	P	\$1500	\$500	± 1% OF RATE	GOOD FOR MONITORING
TARGET	A	G	1-30 FPS	P	\$1500	\$500	± 1.5-5% FRS	GOOD FOR MONITORING
ULTRASONIC TIME OF FLIGHT DOPPLER	G G	G G	.5-30 FPS .5-30 FPS	A A	\$2000-\$3500	\$500	± 5 % FRS ± 5% FRS	GOOD FOR SPOT CHECKS
MAGNETIC	G	G	.5-30 FPS	G	\$3000	\$1500	± 1% FRS	GOOD METER IF BUDGET IS NOT A FACTOR
MASS FLOW	A	G	.5-30 FPS	G	\$3500	\$1500	± .2-1% FRS	GOOD IN LOW CLEAN FLOW AND SMALLER PIPES

G - GOOD A - AVERAGE P - POOR

NOTE: 1. VALUES FROM MILLER 1989.

2. OTHER VALUES IN THIS TABLE ARE APPROXIMATE AND ARE GIVEN AS REFERENCE
VALUES. PRICES AND CHARACTERISTICS WILL CHANGE AS CONDITIONS DICTATE

Table 2.7: Budget Breakdown for the First Year Monitoring Program.

Task	Person-months	Personnel (\$)	Travel, supplies. (\$)	Total (\$)
1	29	\$103,000	\$2,500	\$105,500
2	37	\$103,000	\$4,500	\$107,000
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 LoanSTAR Monitoring Analysis and Review Committee were \$110,000.

2) Includes \$81,000 for computer hardware and software, and includes a matching contribution by Texas A&M.

3) Estimated hardware to monitor \$26 million in retrofits is \$780,000.

4) Because the LoanSTAR program was carried out by a Texas state agency these costs do not include overhead and profit.

Figure 2.1: LoanSTAR Monitoring and Analysis Task Planning.

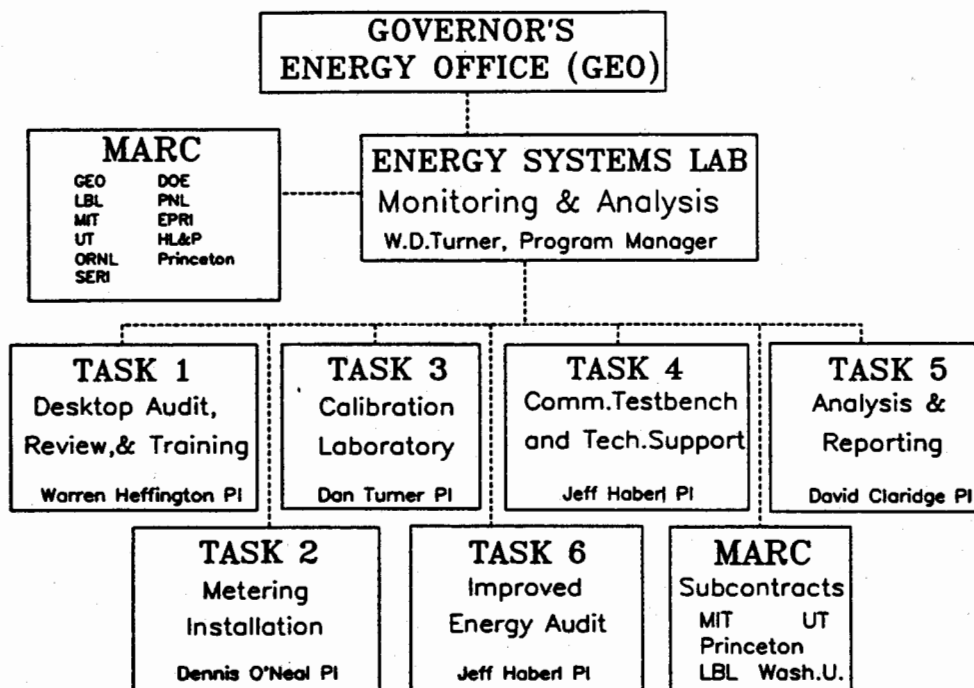


Figure 2.2: Distribution of LoanSTAR Loans by Percent of Functional Area.

Percent Area by Functional Use
Buildings Monitored as of April, 1993

Total Area Monitored Under LoanSTAR Program: 18.27 Million sq.ft.

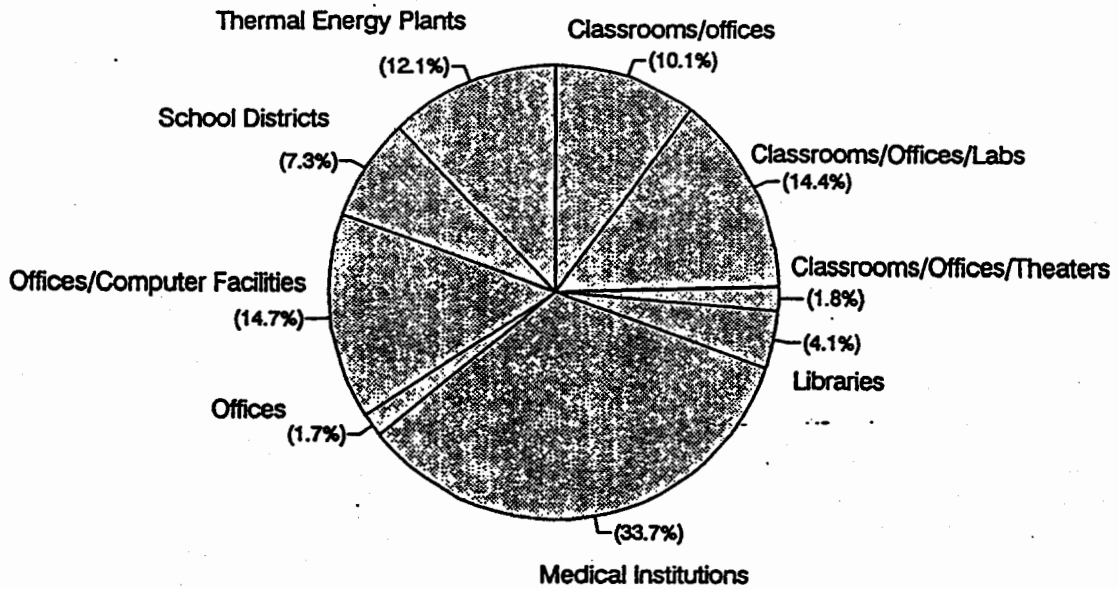


Figure 2.3: Geographic Distribution of LoanSTAR Sites in Texas.

SITES MONITORED UNDER LOANSTAR PROGRAM AS OF MAY 1993

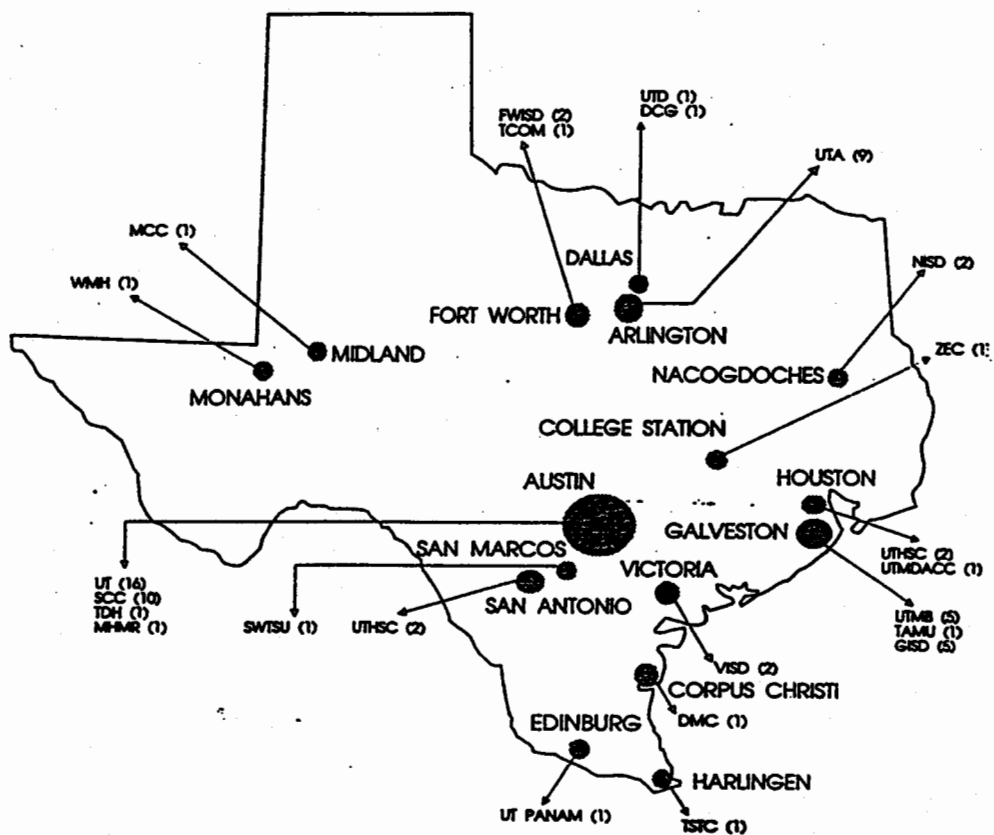


Figure 2.4: Audit Estimated Retrofit Costs and Savings.

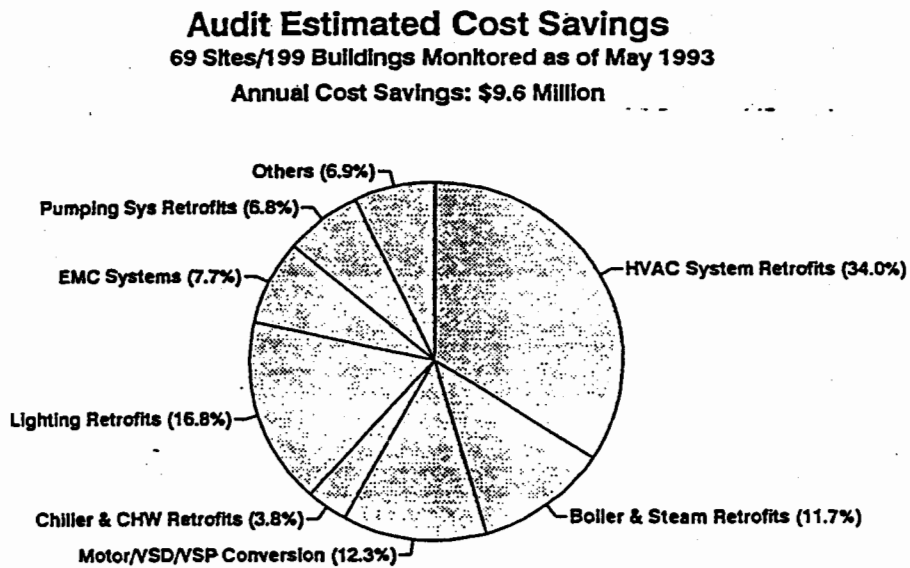
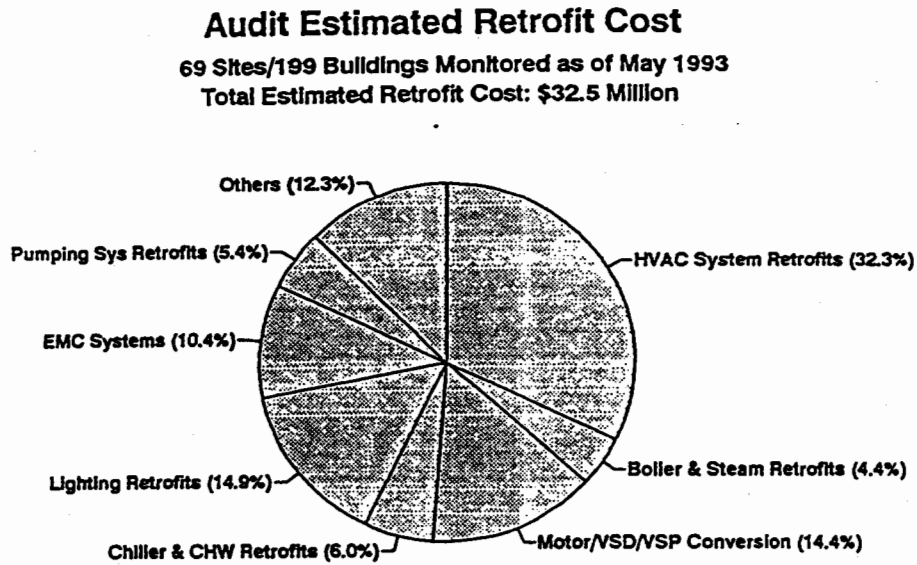


Figure 2.5: Estimated Cost of Retrofits.

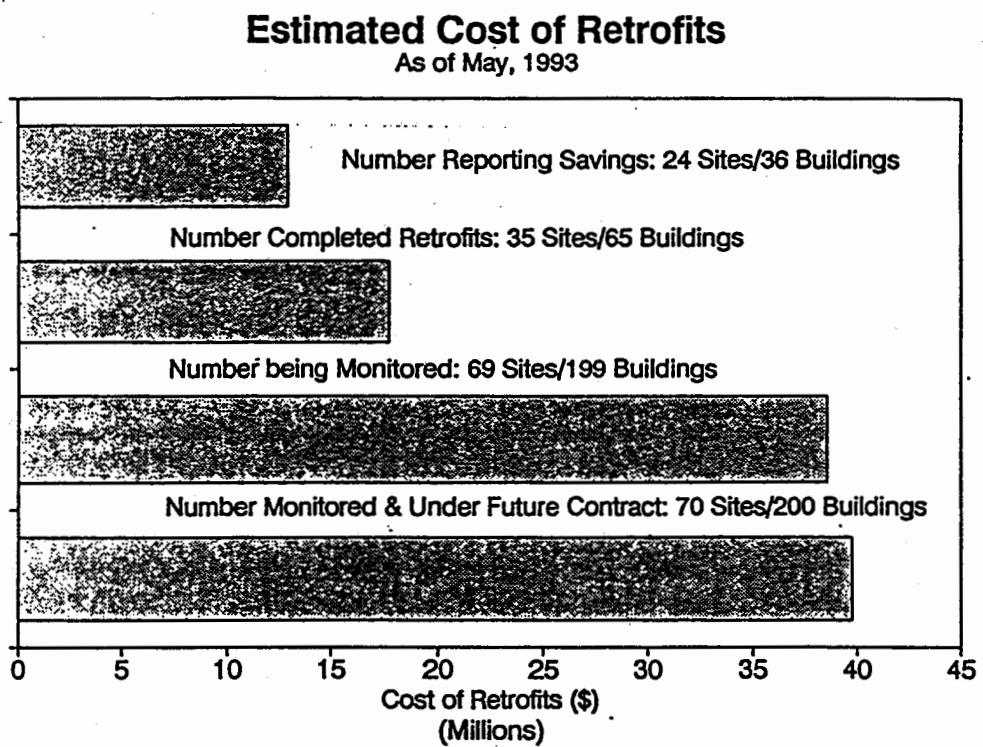


Figure 2.6: Total of Measured Electric Demand Reduction.

Total Measured Reduction in Electricity Demand (2 MW)

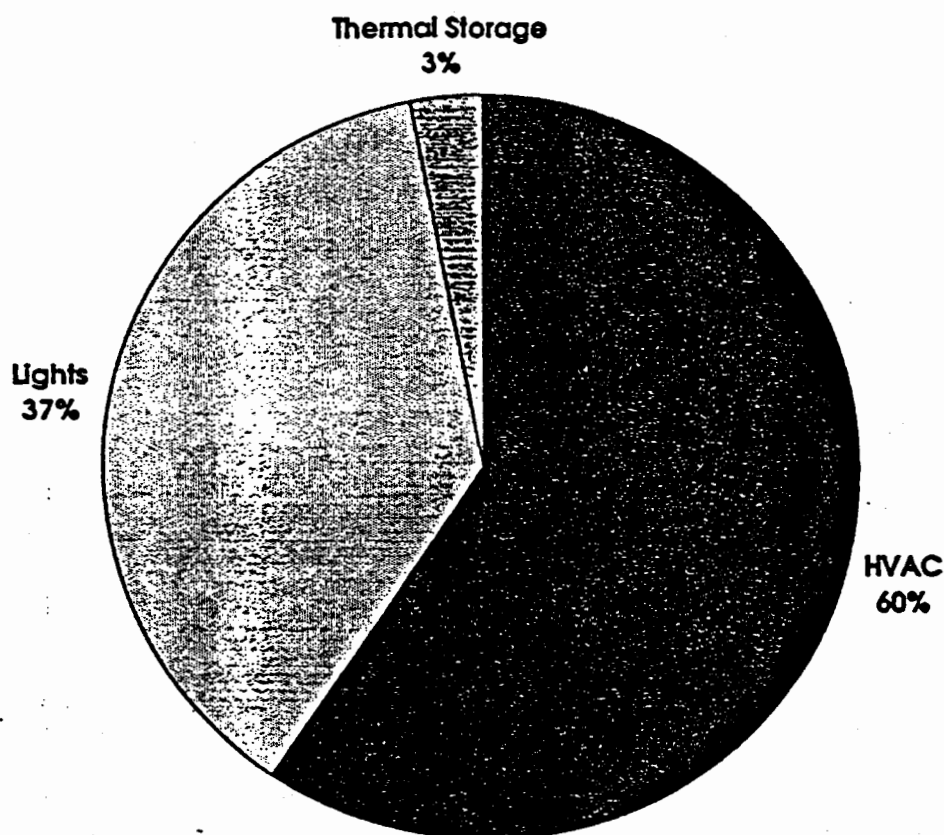


Figure 2.7: Typical LoanSTAR Level 1 Monitoring. This diagram illustrates a typical Level 1 monitoring setup as installed in the T.S. Painter Building on the University of Texas at Austin campus. This Level 1 monitoring provides whole-building electricity use, whole-building chilled water use, and whole-building steam condensate use. Channel numbers (e.g. CH 8) are usually included for each site to help identify data channels.

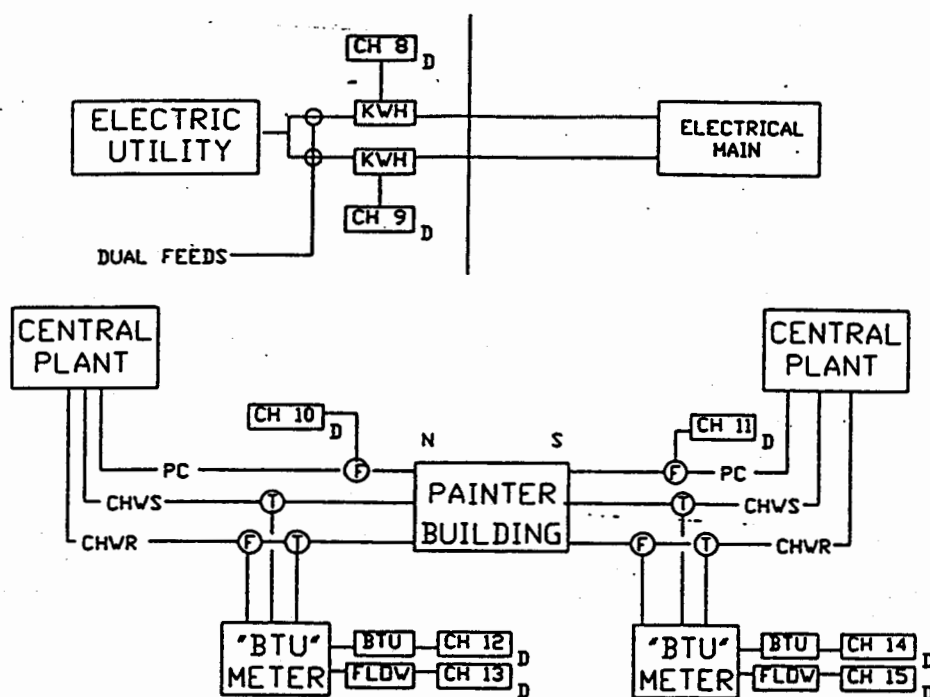


Figure 2.8: Typical LoanSTAR Level 2 Monitoring. This figure shows a typical Level 2 monitoring experiment plan as installed in the UTC Building on the University of Texas at Austin campus. In this case Level 2 monitoring provides whole-building electricity (kWh), whole-building chilled water use [Btu, flow (F), temperature (T)], whole-building steam condensate use (PC or AC), and sub-metered electricity use for the building's air-handling units (AHUs) and pumps (CHWP).

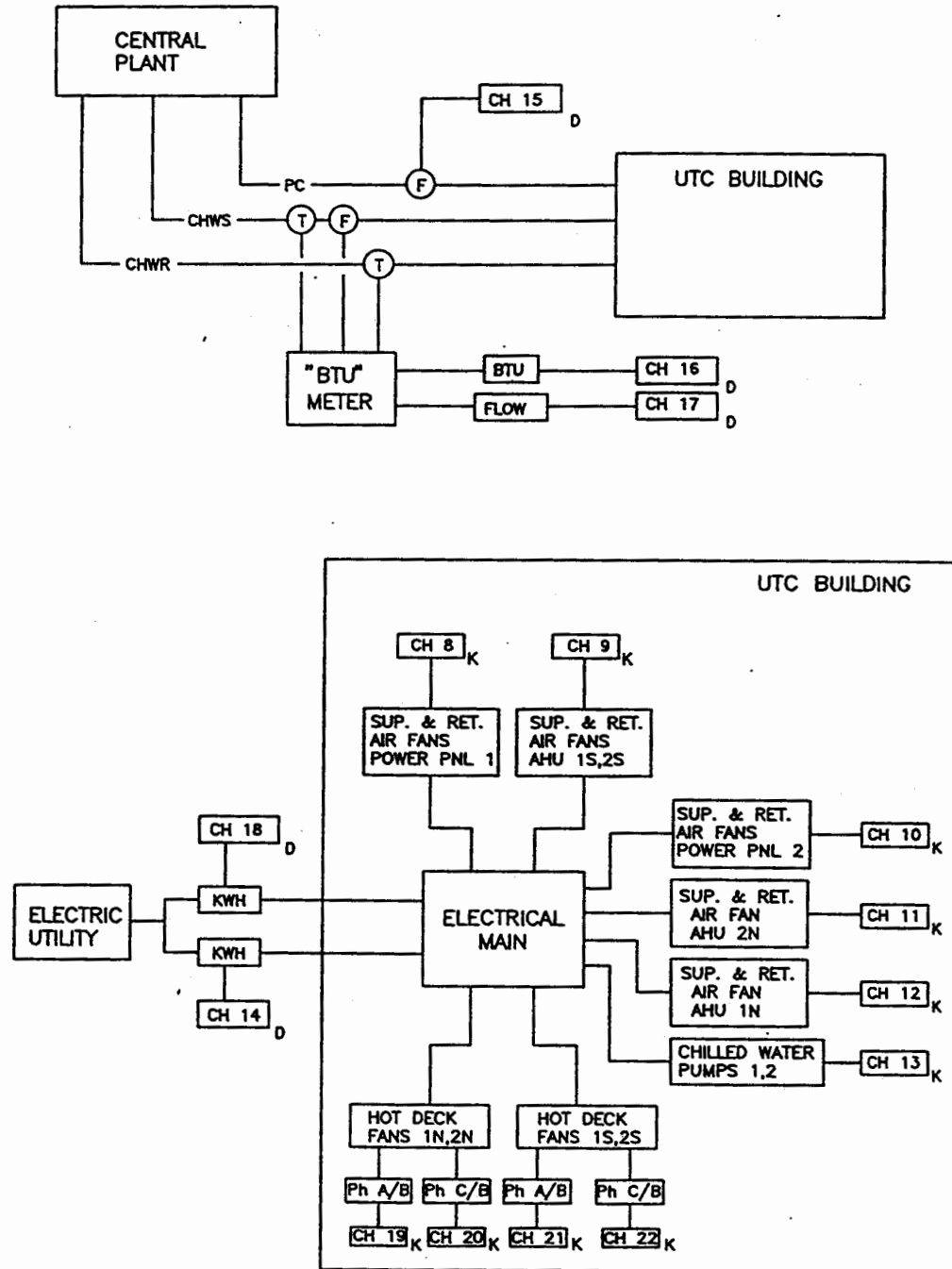


Figure 2.9: Typical LoanSTAR Level 3 Thermal Monitoring. This diagram illustrates a Level 3 thermal monitoring setup as installed in the S. F. Austin building at the Texas State Capitol complex. In general most Level 3 monitoring experiments are complex and require a metering plan that is specially tailored to each experiment. The S. F. Austin building contains a central boiler/chiller complex that feeds several other buildings and a weather station.

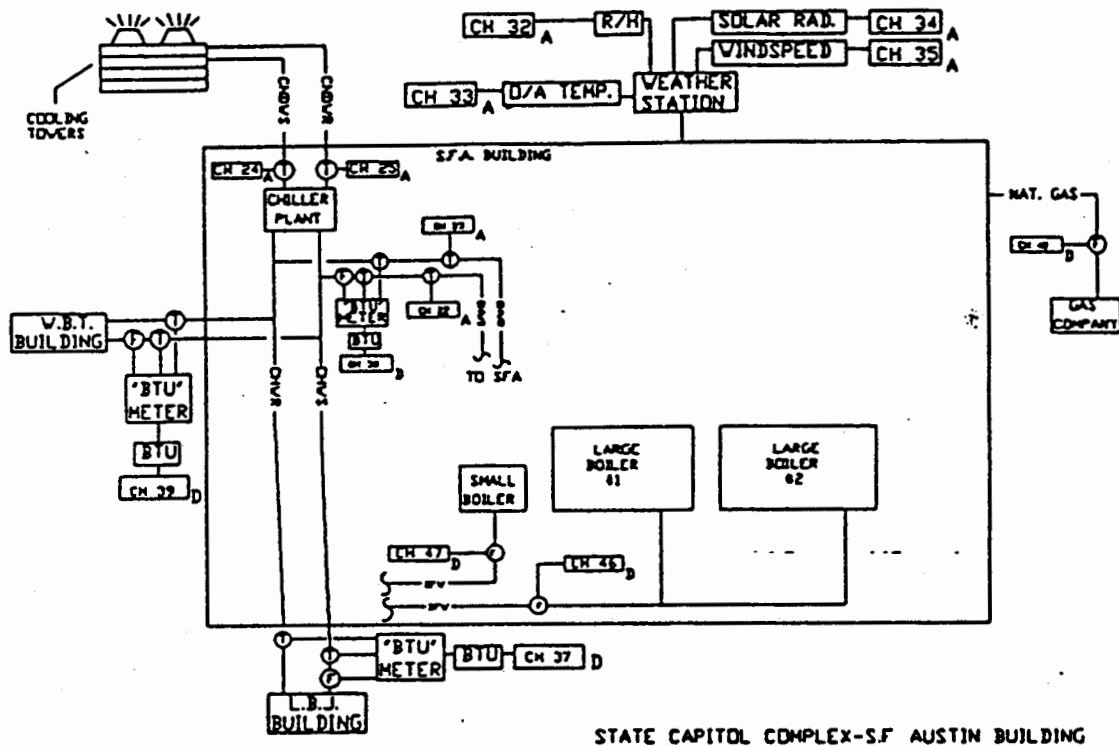


Figure 2.10: Typical LoanSTAR Level 3 kWh Monitoring. This diagram illustrates a Level 1 electricity monitoring setup as installed in the S. F. Austin building at the Texas State Capitol complex. The intent of this monitoring plan is to isolate electricity use in the boiler/chiller plant.

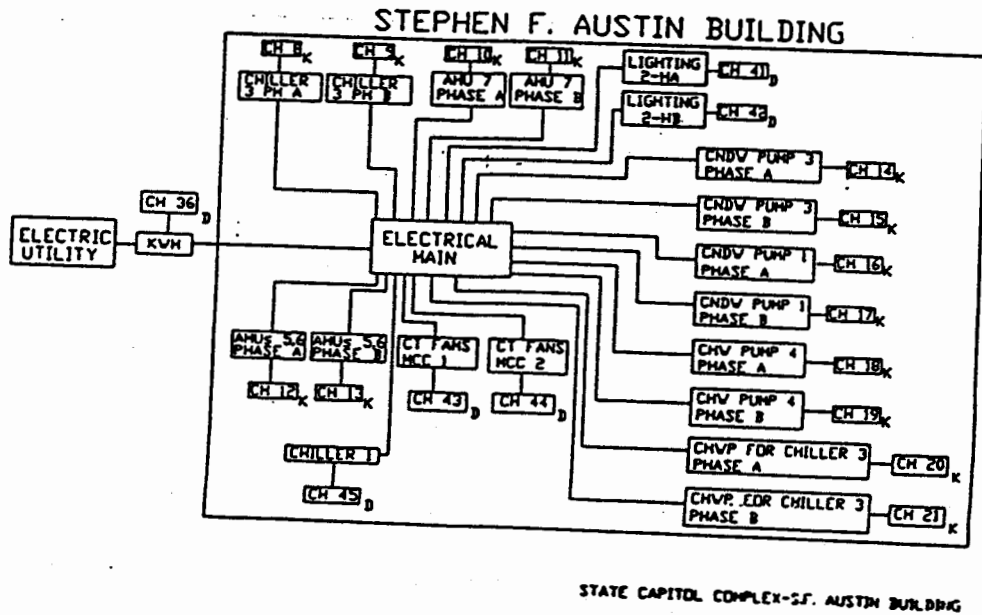
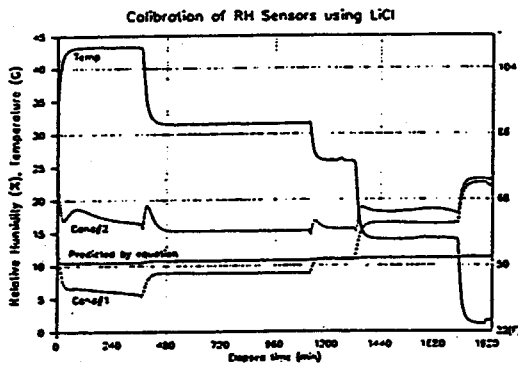
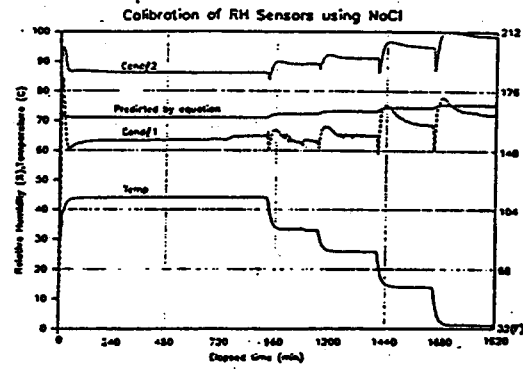


Figure 2.11: Preliminary Results for Calibration of RH Sensors . These figures contain results from tests performed with three salt solutions over a varying range of temperatures as recommended by Greenspan (1977) and Huang (1991). Figure 2.11a presents the results for the calibration of two candidate sensors using lithium chloride (LiCl) over a varying range of temperatures. Figure 2.11b presents the results for calibrations using magnesium chloride (MgCl), and Figure 2.11c presents results using sodium chloride (NaCl). Time series data are presented to illustrate the long length of time needed to perform these calibrations.

Preliminary Results for Calibration of RH Sensors Using LiCl.



Preliminary Results for Calibration of RH Sensors Using NaCl.



Preliminary Results for Calibration of RH Sensors Using MgCl.

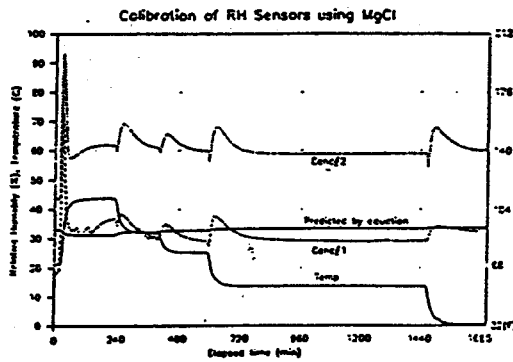


Figure 2.12: Diagram of the Liquid Flow Loop Calibration Facility. This figure is a diagram of the dynamic weight, liquid velocity flow loop that is in the upper portion of the schematic diagram of the calibration facility. Water at varying flow velocities is drawn from the supply tank, pumped through the 6.1 m (20 ft) long test section, and diffused into the receiving tank where the changing weight of the water is compared to the manufacturer's flow velocity.

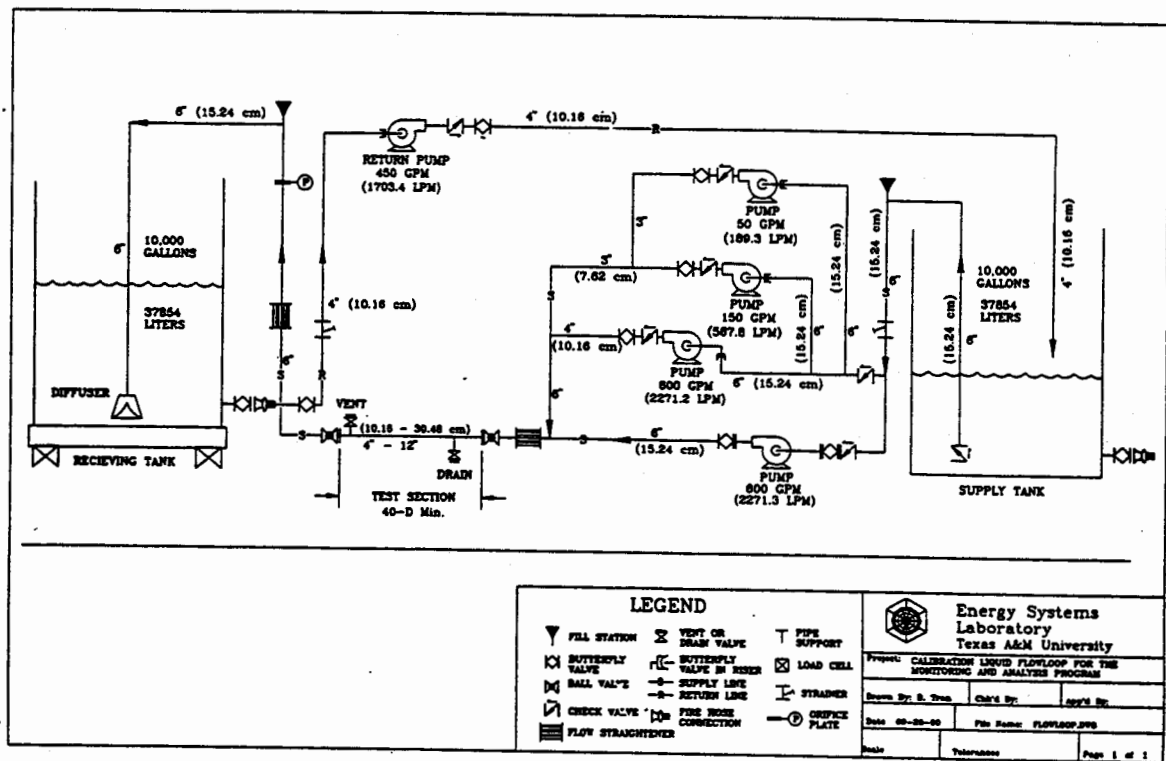


Figure 2. 13: Preliminary Results from Tangential Paddlewheel Flow meters.
 Results from preliminary tests conducted on three magnetic-type paddlewheel flow meters and one non-magnetic-type paddlewheel flow meter are shown in these figures.
 All tests were conducted with the manufacturer's k-factor.

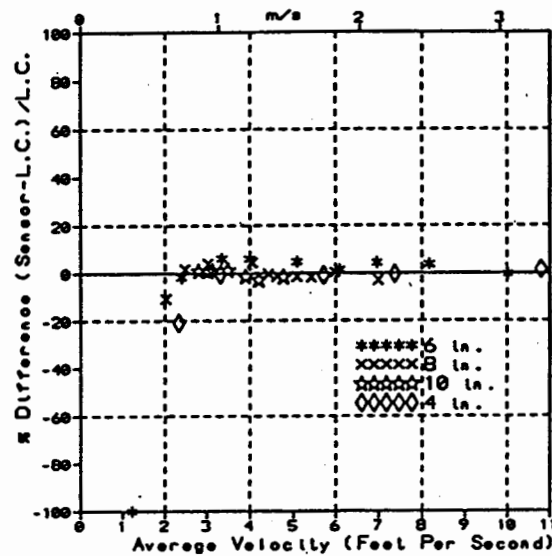


FIGURE 3A: RESULTS OF TESTS OF TANGENTIAL PADDLEWHEEL FLOW METERS. THIS FIGURE SHOWS THE RESULTS OF TESTS THAT WERE PERFORMED ON MAGNETIC-TYPE TANGENTIAL PADDLEWHEEL FLOW METERS USING A DYNAMIC WEIGH FLOW LOOP (ROBINSON ET AL. 1992)

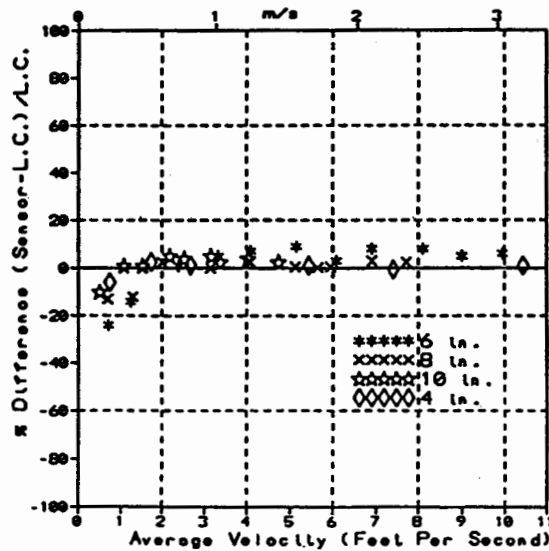


FIGURE 3B: RESULTS OF TESTS OF TANGENTIAL PADDLEWHEEL FLOW METERS. THIS FIGURE SHOWS THE RESULTS OF TESTS THAT WERE PERFORMED ON NON-MAGNETIC-TYPE TANGENTIAL PADDLEWHEEL FLOW METERS USING A DYNAMIC WEIGH FLOW LOOP (ROBINSON ET AL. 1992)

Figure 2.14: LoanSTAR Monitoring and Analysis Program Network. This figure shows the LoanSTAR network that has been established for polling, archiving and analyzing building energy data at the Texas A&M University campus.

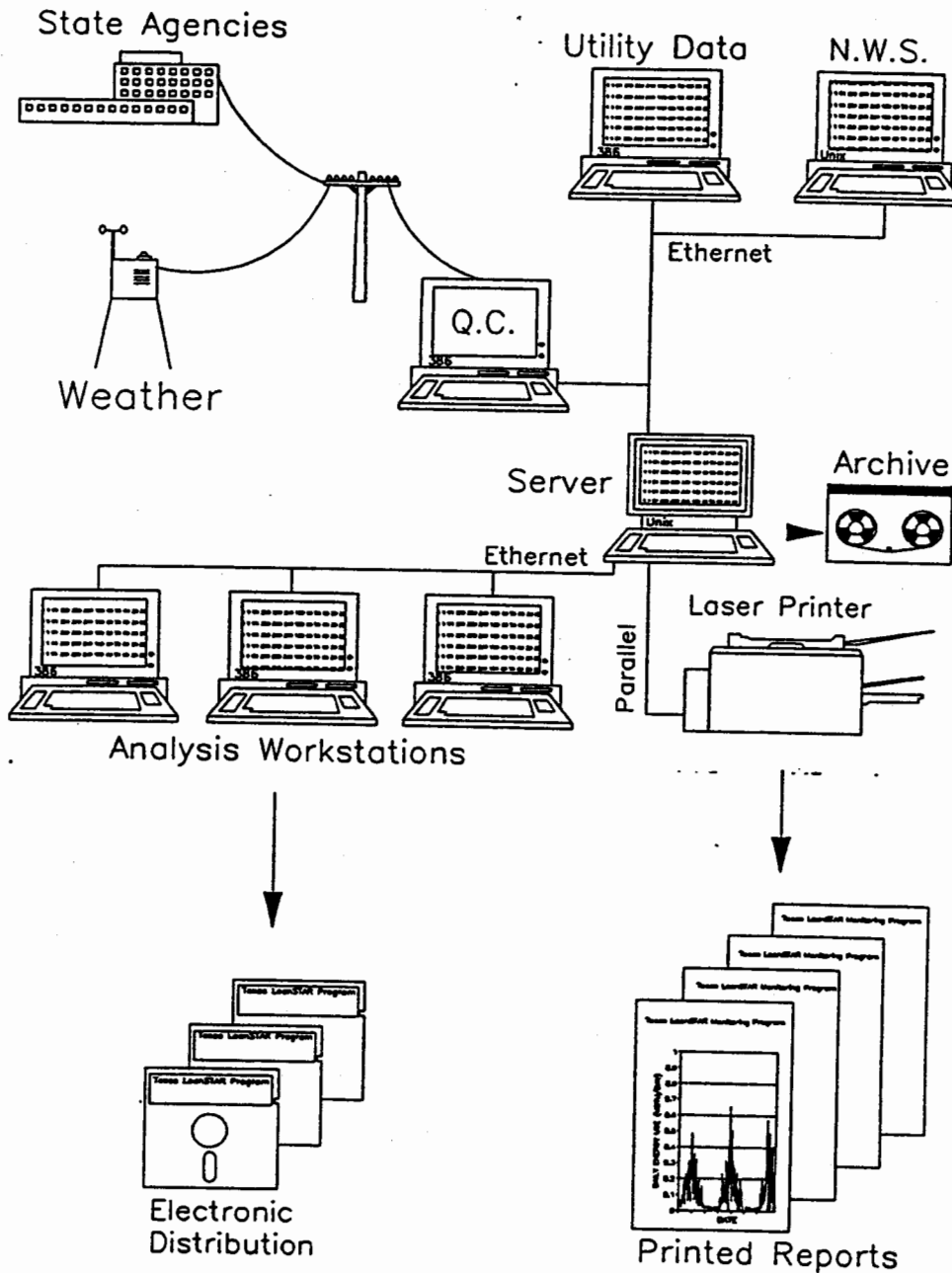


Figure 2.15: DOS-UNIX ASCII Flat File Method for Archiving and Distributing LoanSTAR Data.

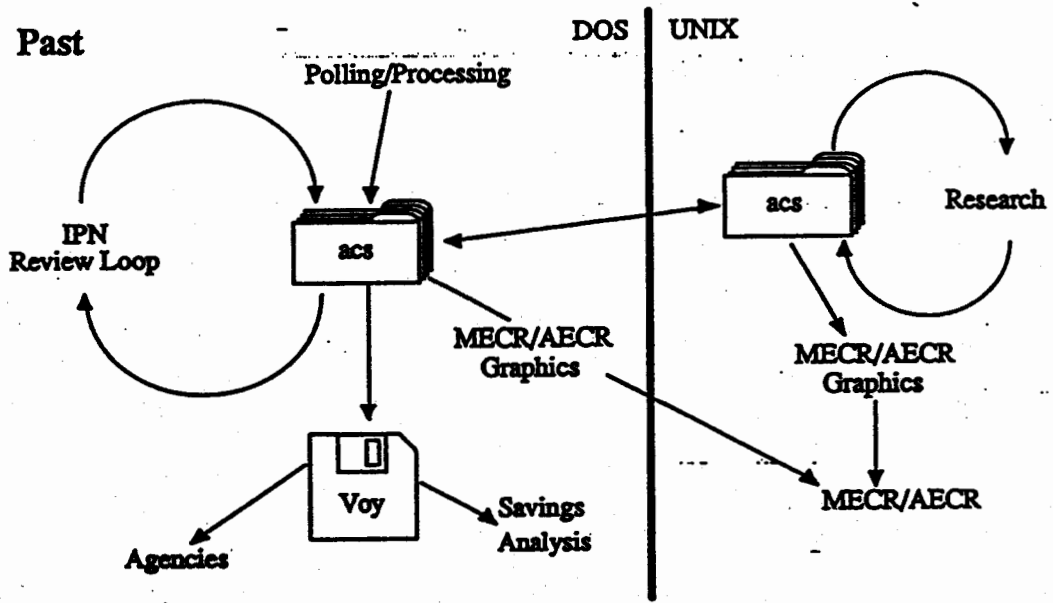


Figure 2.16: DOS-UNIX Relational Method for Archiving and Distributing LoanSTAR Data.

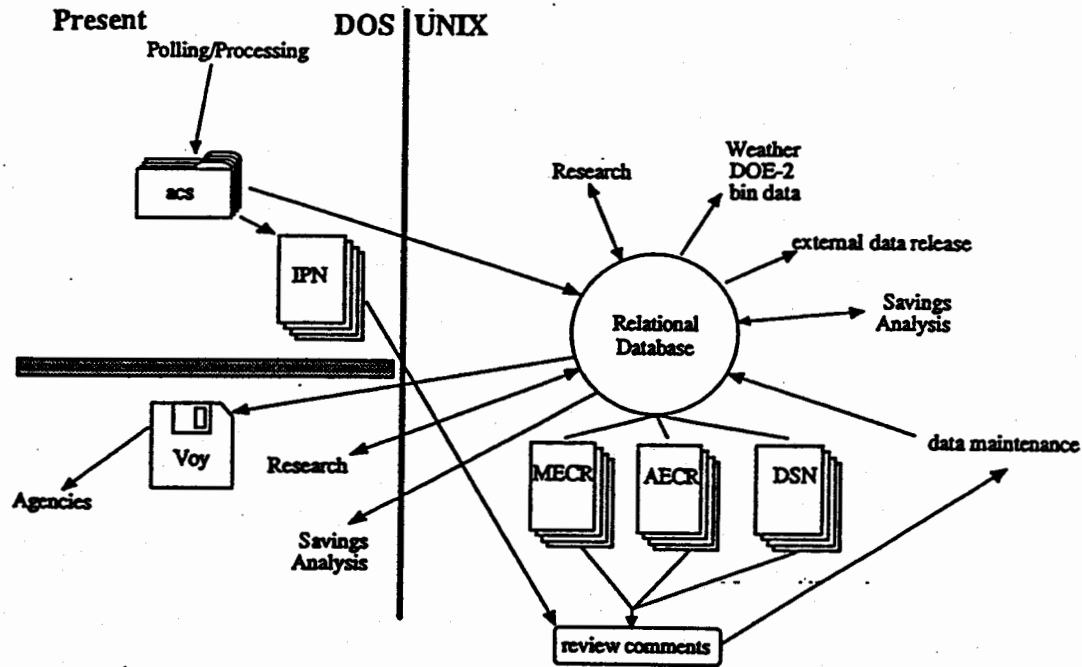


Figure 2.17: LoanSTAR Database Structure.

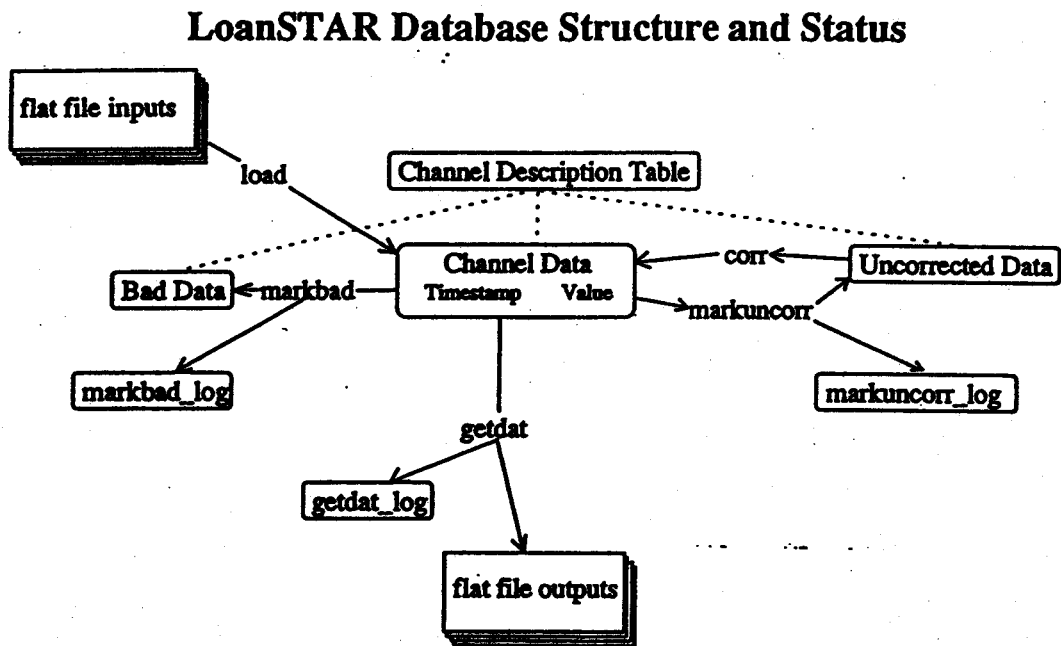


Figure 2.18: LoanSTAR Centralized Commenting and Logging Facility -- iComment.

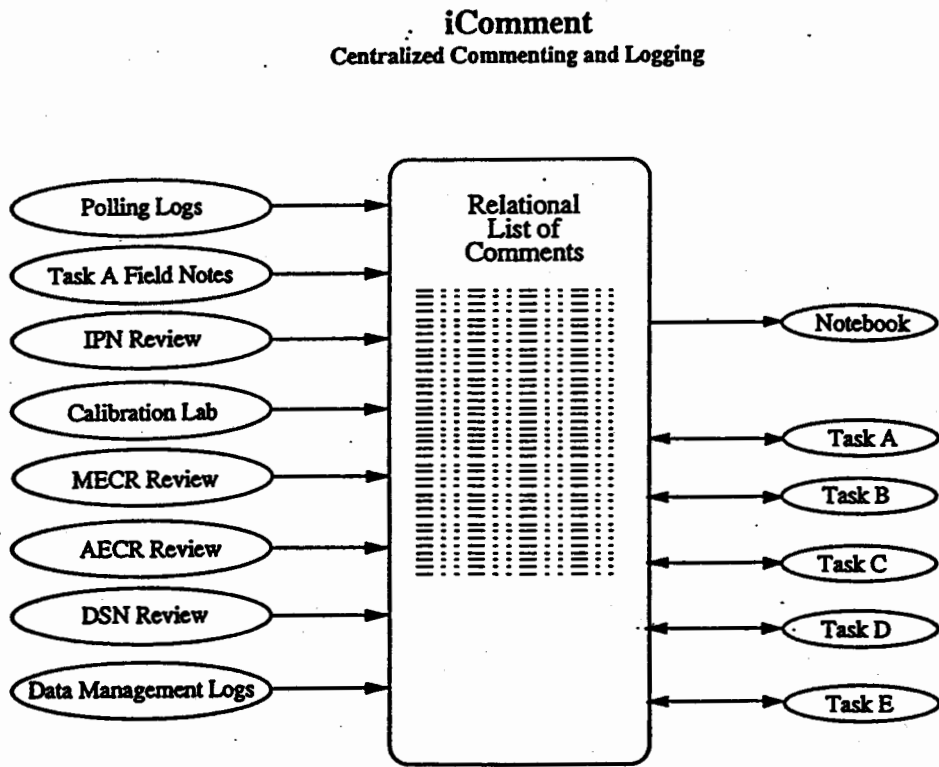
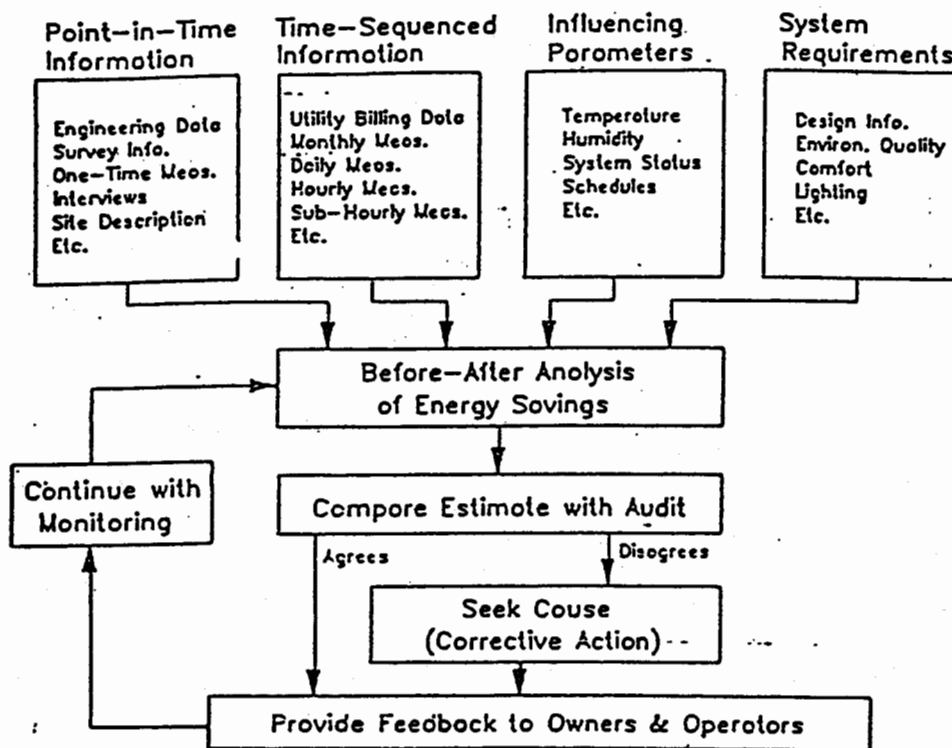


Figure 2.19: Before-After Analysis of Energy Conservation and Savings.



3.0 ACQUIRING, ARCHIVING, HANDLING, AND REPORTING THE DATA

3.1 Measuring the Energy Use

This section discusses measuring energy use, including general information on acquiring, archiving, handling, and reporting the data, the basics of electricity monitoring, and measuring thermal energy.

3.2 General Information on Acquiring, Archiving, Handling, and Reporting the Data

One of the main activities of the LoanSTAR program is the measurement of hourly electricity and thermal energy use for the purpose of determining before/after energy savings. To accomplish this, it was necessary for LoanSTAR staff members to visit each site and determine how the primary energy feeds to the building would be measured. This resulted in a monitoring diagram for each site similar to that shown in Figure 3.1. In this figure, electrical and thermal monitoring for a UT Austin site is shown. The upper diagram is the electrical monitoring diagram, and the lower site is the thermal monitoring diagram. These diagrams serve as one of the primary documents that show where sensors are located and what channels they are assigned.

At each site, loggers needed to be installed and set up to record specific data on each channel. An example logger set-up is provided in Figure 3.2. This diagram illustrates an example logger that is set up to measure one single phase electricity channel (on power channel 0), one digital thermal Btu and flow channel (on digital channels 0 and 1), one analog temperature channel (on analog channel 0), and one analog humidity channel (analog channel 1). In general LoanSTAR loggers were installed in electrical vaults or mechanical rooms. Figure 3.3 illustrates how three phase electricity is monitored with three current transducer (CT) channels and one 4-wire potential transducer (PT) using the Synergistics logger (Photocopied with permission: Synergistics 1990).

Thermal energy monitoring usually requires physically penetrating the chilled water, hot water and/or steam condensate lines in the building and installing flow meters as shown in Figure 3.4. This figure shows a detail of how thermal energy monitoring of chilled water is achieved with the use of a Btu meter, two temperature probes and a flow meter. Penetration of the "live" chilled water pipes was accomplished without having to drain the entire building's piping network through the use of "hot taps" as shown in Figure 3.5. Hot taps are a standard industry practice for penetrating a live fluid carrying pipe and require a welder and pipe cutting equipment. This figure shows a typical hot-tap flow meter installation used in the LoanSTAR program.

The remainder of this section describes in detail how energy use was recorded from electricity meters, thermal energy meters and other meters of importance and how the data were retrieved, inspected, archived and presented.

3.3 Basics of Electricity Monitoring

The monitoring of electrical energy (a time-varying function) requires a few more steps than the monitoring of electric power (an instantaneous function). In order to measure the energy use of a building or an appliance, it is necessary to have a recording meter that measures and records the amount of power used over a period of time. In the early days of electrical metering this was accomplished with some very ingenious mechanical devices. Beginning in the mid-1980s the direct metering of electrical energy through the use of affordable, easy-to-use microprocessor-based field data acquisition systems became a day-to-day reality. However, in order to get a sense of what is involved, it is helpful to know about the basic components--many of which are still in use today.

From the start, the measurement and recording of electrical energy was accomplished with Watt-hour meters, and pulse-initiating telemetering circuits. Then, in the 1970s, this task was simplified somewhat when Watt/Watt-hour transducers became commercially available, and more recently, with the advent of microprocessor technology, digital Watt/Watt-hour meters. This next section reviews the basics of obtaining digital data from power/energy measurements. The reader is referred to the authoritative *Handbook for Electricity Metering* by the Edison Electric Institute (EEI 1981), and the paper by Schuster (1985) for additional details. A significant amount of material for the next section of this workbook has come from these texts and from the LoanSTAR Monitoring Handbook (Haberl et al. 1992).

3.3.1 The Watt-hour Meter

A Watt-hour/demand meter acts very much like the speedometer and odometer on an automobile. It is composed of a combination of sub-components: a very slow-speed motor whose rotational speed is proportional to the power that passes through it, a magnetic brake to retard the spinning rotor when power is withdrawn from the meter, a series of mechanical registers to record the number of revolutions, and a meter that records the peak electric demand (i.e. - number of revolutions in a specific time interval). Basically, as the power is increased, the rotor spins faster and the Watt-hour meter records more revolutions. A measurement of the energy used during any given period of time can then be obtained by subtracting two consecutive Watt-hour meter readings (revolution counts). Such meters form the basis for almost all of the electrical metering that is performed in this country. The basic principle upon which they work was set forth in 1884 by Ferraris who showed that torque (rotation) can be produced in an electrically conductive rotor when it is exposed to two alternating-current fluxes in such a way that they produce rotational motion in one direction on the rotor.

3.3.1.1 Connecting a Computer to a Watt-hour meter

The basic method that is used to generate an electronic time-series data record of the energy that passes through a Watt-hour meter is to send a series of on/off pulses to a digital recorder. Originally, this was accomplished with pen and ink charts, which gave way to magnetic tapes that were collected and transferred to a mainframe computer periodically. More recently, such information is recorded by microprocessor-based data acquisition systems where it is transferred (sometimes automatically) over phone lines to

a central facility. In almost all cases, the time-series record consists of a record of pulses where each pulse is equal to some predetermined number of Watt-hour disk revolutions and hence the amount of energy that has passed through the meter during that period of time.

The energy-accounting gear train of the Watt-hour meter is fitted with either a two-wire or three-wire pulse initiator (either electronic, optical, or mechanical) to generate these pulses. Most Watt-hour meters that are fitted with pulse initiators use the 3-wire configuration. The difference between 2-wire and 3-wire systems is due to physical problems that arose with the original mechanical pulse receivers. If the pulse initiator was not carefully installed and adjusted, there was a chance that it would chatter and over-register the number of pulses. This egregious characteristic was removed by adding a third wire, which serves as a latching mechanism since the pulse generator must not only switch on/off but also switch between circuits in between each pulse--thus eliminating the chatter. A 2-wire telemetering connection can always be made to a 3-wire pulse initiator by simply using one of the contacts and adjusting the energy/pulse ratio. However, one must ascertain before hand whether or not contact chatter will be a problem.

3.3.1.2 Measuring Demand With a Watt-hour Meter

In most larger commercial buildings both the electricity energy use and peak electric demand are usually recorded for billing purposes. In order to accomplish this, the Watt-hour meter is equipped with a demand meter, which retains a reading of the peak electric power level that passed through the meter until the demand reading is reset at the end of each billing period. This was originally accomplished through the use of a thermal demand element, which later gave way to a mechanical gear-driven demand meter. In thermal demand meters, a pair of bi-metallic coils are attached to the demand indicator shaft. Movement of the shaft is produced by creating a temperature difference between the coils that is proportional to the power measured. This is accomplished by reversing the currents in one heater when compared to the other. Thermal demand meters are still being used today. However, one should be careful when such meters are exposed to widely varying ambient temperatures because the demand readings can be affected by temperature of the meter.

An indicating-type mechanical Watt-hour demand meter is actually a "Watt-hour meter within a Watt-hour meter". It records the energy used during a pre-specified period, pushing the maximum demand pointer to a new value when the demand for the current period exceeds any previous period, and then resets itself to zero at the end of a predetermined demand period; beginning the cycle over again. Some versions also include a cumulative-type demand meter that displays the current peak demand and adds the demand to another register each time it is reset.

3.3.1.3 The Watt/Watt-hour Transducer

A replacement for the Watt-hour meter became a reality in the 1970s with the commercial availability of the Watt/Watt-hour transducer. This solid state device produced dramatic improvements in the accuracy and stability of electrical metering and

paved the way for microprocessor-based electrical power and energy metering. The Watt/Watt-hour meter provides a direct analog or digital output signal that is proportional to the energy being consumed.

Watts are calculated electronically and output as either an analog DC signal or pulsed output that uses a basic time-division-multiplier principle. Conversion of the energy consumption to analog or pulsed output utilizes two different processes. In each process a carefully controlled triangular wave form is compared to a varying sinusoidal wave form to produce a pulse-width and pulse-amplitude modulation. In other words, the width of each pulse is proportional to the input voltage, and the amplitude of each pulse is proportional to the input current. The output from the modulator is a DC current signal that is proportional to the input wattage. The output from the modulator can also be sent to the pulse initiator section to produce a pulse that is proportional to the input wattage.

The basic unit that is inside integrated solid state digital Watt/Watt-hour meters that are used in certain data acquisition systems utilizes a similar principle to the Watt/Watt-hour transducer. In brief, an input reference voltage from a potential transformer (PT) is supplied that provides a low voltage signal that is proportional to each of the high voltage phases being monitored. This is combined with low voltage input current signals to produce digital wattage output signals that are proportional to the energy used by each circuit being monitored.

The primary advantage with such a multi-channel, integrated, solid state Watt/Watt-hour meter is that it only requires PTs and CTs to attach it to a building's electrical system, which eliminates the need for a separate Watt/Watt-hour transducer for each load being monitored; and since it is directly combined with the microprocessor that records the data, it can be re-configured in software for different loads, which makes it ideal for portable applications. Continuous power factor measurements can also be taken with such equipment. A more complete description of the circuitry inside the data logger developed for the United States Department of Energy is provided in the paper by Schuster (1985).

3.4 Measuring Thermal Energy

Heating and cooling energy use for buildings with hot and chilled water systems can be measured using thermal energy meters. These meters require the input of temperature sensors and flow meters. Some thermal energy meters can report both energy rates and flow rates. This section discusses some of the thermal energy and flow meters used in the LoanSTAR program. Special features and limitations of equipment from several different manufacturers are mentioned.

3.4.1 Thermal Energy Meters

A thermal energy meter is typically an electronic device that is used to calculate chilled water or hot water energy used in a building or facility. Each thermal energy meter requires three input signals: a flow meter signal, and one temperature signal each for the supply and return lines. Each thermal energy meter has its own requirements for the type

of flow meter and temperature sensors needed for proper operation. A schematic of a typical thermal energy meter setup is shown in Figure 3.4.

The calculation procedure performed by the thermal energy meter is based on the following equation:

$$E_T = m \times C_p \times \Delta T \quad (3.1)$$

where

$$m = \rho \times \bar{V} \times D^2/4 \quad (3.2)$$

E_T = thermal energy usage

m = mass flow rate of the fluid (usually water)

C_p = specific heat of the fluid at a given temperature

ΔT = difference between entering and leaving fluid temperatures

ρ = density of the fluid

D = inside pipe diameter

\bar{V} = average (bulk) velocity of the fluid stream

Most flow meters don't measure mass flow directly, but measure the velocity of the fluid which allows for the calculation of the volumetric flow rate. The flow rate is then multiplied by a constant, which converts the flow rate into a mass flow rate for the fluid being measured. A modified form of equation (3.1) that includes the volumetric flow rate is given as:

$$E_T = KQ\Delta T \quad (3.3)$$

where K is the "k-factor" constant containing ρ and c_p for the fluid being measured, and some other constants needed for units conversions. The symbol Q is the volumetric flow rate (i.e. $\bar{V}\pi D^2/4$). For example, the value of K for water is approximately 500, for E_T in units of Btu/hr, Q in gpm, and ΔT in units of degrees F.

The ΔT value is very straightforward, and is taken as the difference between temperature of the supply and return lines. The volumetric flow rate is a function of pipe size and fluid velocity through the pipe.

3.4.2 Thermal Energy Meters Used in the LoanSTAR Program

Three brands of thermal energy meters have been used throughout the LoanSTAR program. They are designated as brands A, B, and C for the remainder of this section. The main differences between these meters are the flow meter and temperature sensor requirements, and the ability to specify scaling factors based on pipe size and flow meter calibration. Brand A is field scaleable, while brands B and C are not.

Brands B and C must be scaled by the manufacturer. The purchaser specifies pipe diameter, flow meter model, type of fluid and estimated maximum volumetric flow rate. The manufacturer then programs the appropriate scale factors into "ROM" chips within the meter electronics. Many times the meters were programmed incorrectly because the diameter was incorrectly estimated beforehand, or the manufacturer mistakenly programmed the wrong size into the meter. Mistakes of this type were usually not discovered until after the thermal energy meters were installed. Excessive time delays resulted from removing and shipping these meters back to the manufacturer for reprogramming.

Brand A meters require no information about the site when ordering except temperature range being measured (either hot or cold) and the fluid being measured. They have DIP switches that allow the scaling factors to be specified in the field. This model also has another DIP switch that lets the user scale the output signals.

The temperature sensors used with these meters are included when the meter is purchased. Brands A and C sensors are interchangeable. This means any one sensor is identical to the next and can be used in either the supply or return line. The brand B thermal energy meters are individually calibrated to the temperature sensors that are labeled "hot" and "cold." Recalibration efforts and repairs are more difficult when the sensors are not interchangeable.

A summary of meter features for the three thermal energy meters used in the LoanSTAR program is listed below.

Features	Brand A	Brand B	Brand C
Cost	\$450	\$275	\$1,700
Field Scaleable	yes	no	no
Output Signals	Flow, Btus	Flow, Btus	Btus
Temp Sensors	Thermistor	Solid State	RTD
Interchangeable Temp Sensors	yes	no	yes
Flow Meter Signal	Pulse	Pulse	Pulse or Analog
No. of water lines meter is capable of monitoring	1	1	2

The output signal from all three meters is a simple digital pulse (i.e., a contact closure) that is detected by the data logger. The scaling of each pulse is dependent on the pipe size, flow meter characteristics, and thermal energy meter electronics configuration.

Another factor to consider when assessing the validity of the data produced by these thermal energy meters is calibration. The brand A manufacturer produces a test device that simulates input from a flow meter and two temperature sensors. Brands B and C do not offer such a device; however, the temperature sensors can be checked by measuring

resistance or milliamps produced by the sensor at a given temperature. The brand C temperatures are easily checked by measuring the resistance of the RTD sensors and using a table to calculate temperature. Brand B temperature sensors produce a 1 milliamp current per degree Kelvin signal, but the manufacturer states that direct measurements are accurate to only ± 5 degrees F.

As always, a reasonableness check should be made with the energy measured by these meters. One easy check is to calculate the energy used per square foot. In the LoanSTAR program, measured building hot water and chilled water use ranges between 3 and 30 Btu/ft²-hr.

3.4.3 Insertion Flow Meters

The insertion flow meter consists of a sensor with a paddle wheel or turbine that is immersed into the pipe flow. The paddle wheel or turbine spins at a rate proportional to the fluid velocity. This rotation produces an electronic signal that is transmitted to the thermal energy meter or other logging device. These meters can be installed in pipes under pressure through the use of "hot taps," thus avoiding a system shut-down. A schematic of a typical insertion meter installed in a pipe is shown in Figure 3.5.

There are several advantages to using insertion flow meters. They are relatively inexpensive and are easily removed for calibration or repair. A special insertion tool is all that is required to install or remove these meters.

The insertion flow meter is the meter of choice for the LoanSTAR project. Three different brands of meters have been installed in the field and tested in the calibration laboratory. Again, these meters will be referred to as brands A, B, and C.

Brand A contains an axially-mounted stainless steel turbine that is immersed in the fluid flow. This model is capable of withstanding the high temperatures found in hot water distribution systems and boiler feed water and condensate lines. One drawback to this model is its high expense. Another difficulty with this flow meter is that it requires periodic inspection with an oscilloscope to diagnose any problems it may have in the pipe. For instance, if one of the blades has broken, the turbine will continue to rotate and produce a signal, making it appear that nothing is wrong with the turbine. However, the signal would no longer represent the true flow through the meter.

Brand B is the least expensive model used. It consists of a plastic tangential paddlewheel with embedded magnets. When the paddle wheel rotates, a sinusoidal voltage with a frequency proportional to fluid velocity is generated. Testing at our calibration facility has shown this meter to be accurate to the manufacturer's stated accuracy at flow rates above three feet per second. Extra drag due to the magnetic fields may contribute to the loss of accuracy at low flow rates. These magnets also tend to collect any iron filings that may be circulating through the water system. Removal of several flow meters that had been in use for six months showed significant amounts of iron filings attached to the paddle wheel. These filings can eventually prevent the paddle

wheel from rotating. Another problem with this brand is that at low flow rates the signal generated is very low, thus making detection with some thermal metering equipment difficult.

Brand C is the flow meter most commonly used on the LoanSTAR project. It is similar to brand B, except there are no magnets on the tangential paddle wheel. The meter uses an RF signal that is projected across the path of the paddlewheel. Each tooth contains a non-magnetic metal core that breaks the RF signal as it passes between the antenna and receiver. The sensor produces a square wave frequency that is detected at the thermal energy meter or logger. Calibration tests show this meter to be accurate to the manufacturer's specifications at flow rates as low as 0.5 ft/s. The cost of this meter is about twice that of brand B.

A summary of the three meter features is shown below:

Features	Brand A	Brand B	Brand C
Cost	\$1,600	\$300	\$500
Sensor	Turbine	Paddle Wheel	Paddle Wheel
Temperature Range	N/A	32 - 220°F	-4 - 220°F
Fluid Velocity Range	N/A	1 to 30 ft/sec	1 to 30 ft/sec
Output	4 - 20 mA	Frequency	Frequency

A variety of thermal energy meters and flow meters is available for use on building energy monitoring projects. New equipment is continually being evaluated to see if it will provide a significant improvement in cost, operation, or reliability over current equipment.

3.5 Polling and Retrieving Data

Since 1989, the number of buildings being monitored, and consequently the amount of data collected, has increased dramatically. The first year of the project saw hourly data collection from one building in College Station. Since October 1990, over 200 buildings from around the state have been added at irregular intervals. The first set of buildings added was at the University of Texas at Austin (12 buildings), followed immediately by the State Capitol Complex (9 buildings), also in Austin. After this initial rush of LoanSTAR Program buildings, collection of hourly National Weather Service (NWS) data from locations throughout Texas began in November 1990. As of May 1993, the LoanSTAR MAP is collecting data from 77 sites located in various cities throughout Texas as well as weather data from 50 NWS stations.

LoanSTAR MAP data management includes five major functions: polling the data from the data acquisition systems (DAS), processing the data from all the various sites into a reasonably generic format, controlling data quality, generating reports, and retrieving data for analysis. Information regarding polling, processing, and report

generation can also be found in the following papers and reports: López and Haberl, (1992); Claridge et al., (1992); and Haberl et al. (1990a, b, 1992).

The first step in this data management scheme is the entry of data into the system. This includes both the retrieval of building data from the remote data loggers and the acquisition of NWS data. At LoanSTAR, each building is polled weekly. Using IBM PC-based communication software, the LoanSTAR MAP currently downloads data as basic ASCII columnar text. Each remote DAS collects hourly or fifteen minute consumption information, which is stored in onboard volatile memory. Because these systems have a finite amount of memory, the DAS is polled once per week to avoid older data from being overwritten by newer data and lost. As each site is polled, the data set is saved as one file per site per week. Therefore, every week, one new raw data file per site containing 168 hourly records is created and saved. Prior to processing, these files are stored in a temporary directory on the polling PC. After the data have been processed, the raw files are archived to tape.

The NWS data records were initially collected by the Texas A&M Meteorology Department using satellite technology. The MAP has been allowed to transfer weather data over the campus internet for internal use in analysis at a minimal cost. The Meteorology Department is actually collecting data from NWS locations nationwide; therefore, some initial filtering is done by the Meteorology Department's computers to extract only Texas sites before the package is transferred. This relieves the strain on the campus network and obviously reduces the disk space required on the LoanSTAR computer system. The NWS data set requires substantial processing to be usable by the LoanSTAR analysis teams. As with the building data, the raw files are archived onto tape. In both cases, if problems are identified somewhere in the processing stream at a later date, all raw data are still readily available for reprocessing. NWS data is also being collected from Accowearth in State College, Pennsylvania.

3.5.1 Processing/Plotting Synergistics Data

Included in an appendix at the end of this report are some helpful hints about what to do with the data once they have been collected from a logger. The routines used to process and plot data collected from Synergistics loggers in the Texas LoanSTAR Program over the last three years on a weekly basis are described there. Instructions and sample code are available on disk for developing inspection and summary plots, as are 3-D plots using a combination of public domain data processing tool kits and inexpensive commercially available plotting software. The routines discussed are available in the workbook by Haberl et al. (1992).

3.6 Quality Control

Processing of the weekly data sets and essential quality control are performed through a combination of public domain utilities, commercial software, and routines written in-house to knit the data streams together. It should be noted that a goal of LoanSTAR MAP has been to use inexpensive existing software wherever possible to decrease potential costs for those who wish to duplicate our methods and also to reduce our development

time. This methodology has caused an interesting assortment of modules to evolve over the past three years. The routines written by the LoanSTAR staff are generally programmed in either GAWK or C++. GAWK (FSF, 1989) is a public domain version of AWK, a powerful UNIX file processing language. GAWK is available in both DOS and UNIX versions.

The cornerstone of the processing and quality control areas is a public domain DOS program called ARCHIVE, which was developed at Princeton University (Feuermann and Kempton, 1987). ARCHIVE is a general purpose program for manipulating and checking columnar data. With ARCHIVE, a channel table is created to describe the columnar data to be processed. Static lower and upper bounds can be associated with any channel in the channel table. For readings outside the specified range, ARCHIVE will flag the data entry in a diagnostic log file as well as replace the suspect value with some predefined "bad data" marker in the output data. This allows an automated method for assuring that data are reasonable. For example, a dry-bulb temperature channel for a site in most parts of Texas might have a lower bound of -10 and an upper bound of 120. Obviously, it is quite useful to have a program check the 168 hourly readings each week rather than doing this by hand. ARCHIVE can also perform simple data translations. For example, linear transformations can be used to convert from one unit to another. In fact, a linear translation is used to attach the site number to every record in the output. ARCHIVE produces two files as output: a diagnostic log file and the actual output data. The log files are inspected every week to insure data quality.

After passing through ARCHIVE, the data file is scanned for missing hours. It is not terribly uncommon for a data logger to lose power in the field. Usually these loggers have battery backups that perform a minimal amount of work: refreshing the internal memory. This allows the logger to keep any data it has collected up to this point, but the logger does not collect any new data until the power is restored. This in turn creates gaps in the data set. For purposes of merging weather data and certain types of analysis, it was determined early in the project that missing hours should be added back into the data with a "bad data" marker inserted for all data values. Therefore, the data file is filtered through a generalized AWK script to scan for missing hours and put them back in as necessary. While the concept of scanning and replacing missing hours is easy to understand, a generalized program must take into account day boundaries, month boundaries, year boundaries, leap year boundaries, and several other special conditions. As with ARCHIVE, the output of this script consists of two files: a diagnostic log file, which reports the number of hours added back in, and the actual output. This file is the final version in which all LoanSTAR hourly data are kept. These processed files are archived to two tapes and also transferred to the MAP's UNIX file server over the campus Internet. Storing the data on a large file server allows immediate access to all the data across all sites, as well as provides access to powerful tools such as the UNIX version of AWK, C, C++, and commercial statistics packages such as SAS (SAS, 1990).

NWS data are translated into the LoanSTAR format through the use of several UNIX shell scripts and supporting AWK scripts that convert the incoming data into a format

readable by ARCHIVE. The weekly weather data set is then processed in a fashion similar to LoanSTAR building data with one important difference: the weekly file contains the hourly records from all Texas weather sites. This was done to keep the overall processing scheme as efficient as possible. C++ routines are used to extract particular locations from the weekly data set. As shown in Figure 3.6, this scheme has proven particularly useful for creating verification cross plots between LoanSTAR weather data and the National Weather Service data.

3.7 Weekly Report Generation

While simple automated quality control checks have been implemented, a key function of the whole process is the production of weekly verification plots. These plots are circulated between the project's Principal Investigators and research staff in a bundle referred to as the Inspection Plot Notebook (IPN). Figure 3.7 shows several sample verification plots. The plots allow possible problems with the data to be identified by visual checks. Graphical presentation of the data on a weekly basis adds tremendously to the quality control and is much less time consuming than scanning the actual ASCII data columns. Because the data are subjected to a long stream of software filters prior to the production of the plots, any potential problems are usually brought to the attention of the Database Manager, who determines if a processing problem could have corrupted the data. If this is not the case, then a genuine data problem may have occurred (for example, a metering problem), and an appropriate message is forwarded to the field engineers.

These weekly plots are currently produced with a commercial graphics package, along with supporting AWK scripts and a controlling DOS batch file. Three different kinds of pages are created for the notebook: times series readings of all channels; summary pages that include scatter plots of some channels (thermal channels and motor control center electricity consumption) versus temperature and derived time series readings of the primary data types (whole-building electricity consumption and thermal channels); and scatter plots of LoanSTAR weather data versus NWS data (as in Figure 3.7). The batch files and supporting scripts allow these pages to be produced from the processed data on a weekly basis with a simple command. The LoanSTAR MAP currently produces roughly 950 of these small graphs, 80 pages in all, each week. The start-up time was substantial, as is the computing time required each week. Additionally, the logistics of actually printing, copying, filing, and routing the IPN each week should be addressed. All told, the entire process requires 20-30 person-hours every week. This does not include the time spent by the Principal Investigators and project staff reviewing the plots themselves. It is estimated that the MAP requires an additional 50 person-hours each week for review of the IPN, although this value is hard to quantify because the interested parties have different methodologies and goals.

3.8 Reporting the Data

Using consumption data to provide near-term feedback to owners and operators in order to increase operating efficiency has only emerged in the last few years. Methods that provided real-time feedback on energy cost to home-owners were investigated in the 1970s (Seligman et al. 1978), but failed to catch on as concerns about energy cost waned.

However, the benefits of regular feedback have been shown in several case studies (Haberl and Claridge 1987; Haberl and Vajda 1988; Haberl and Komor 1990; Katzev and Johnson 1987; Kempton and Komor 1990; Kinney and Romano 1990). Different forms of feedback have been found to be useful, including weekly time series plots of consumption, three-dimensional time series plots, three-dimensional residuals of measured minus modeled consumption, and plots of savings resulting from specific operational improvements implemented.

The Texas LoanSTAR MAP staff installs data acquisition equipment to monitor the energy use of each large building at the whole-building level, with consumption often submetered for a short period of time before the retrofits are installed and monitoring continued subsequent to the retrofits.

As noted, the monitoring determines the retrofit savings in the program, but the second major objective of the monitoring program is to use the monitored data to identify additional measures that can be implemented to make the buildings operate even more efficiently. There are questions the program addresses.

- Is the retrofit working properly?
- Are the building systems working properly?
- Can changes in operation or maintenance lower operating costs?

Determining the answers to these questions requires a thorough understanding of the data collected and of the building and systems from which the data are collected. While the audit reports and site description information are very useful in developing an understanding of the building, a crucial part of the process is meetings and discussions with the facility engineer and building operators. Furthermore, if operation and maintenance measures are identified, the cooperation of the facility engineer and building operator is essential before any operational savings can be realized. Part of the communications process is transmittal of the data collected from the building to the operators in a format they can easily understand. Traditional engineering reports and papers are not current enough to be useful, and the format and language would typically obscure key information from most operators. Out of necessity, we have developed several forms of largely graphical reporting that are used with the facility engineers and operators of the buildings being monitored. The three forms described in the next section are 1) monthly energy consumption reports, 2) computer filters of the data with browsing software, and 3) weekly inspection plots. All three of these reporting forms are also used by program staff, building operators, facility engineers, and program managers for a variety of other purposes.

3.8.1 Monthly Energy Consumption Reports

A six-page energy consumption report is sent monthly to each facility monitored. This report contains two pages of tables and text and four pages with graphs of consumption data for the previous month.

The first page of the report provides a concise summary of current energy consumption retrofit savings and a comments section. Figure 3.8 shows the first page of the August 1993 report for a 324,000 ft² (30,100-m²) engineering center with a dual-duct VAV retrofit that became operational during March of 1991. The report shows that the building uses electricity, chilled water, and hot water. All three are supplied from a central plant and were not metered at the building until data acquisition equipment was installed to acquire pre-retrofit data. Peak 60-minute electricity demand is reported instead of the standard 15-minute demand, because 60 minutes is the integration period for the data collected. The original report contains the names, addresses, and phone numbers of individuals at the facility who can be contacted regarding unusual data, building schedules, etc., and the name of a person with the monitoring project to whom questions about this report can be directed. The retrofit seems to be working well – although the savings are lower than projected by the audit report. The comments section provides individualized feedback to the agency and building operators on items noted by the project staff. For example, savings were also observed during the construction period. Total measured savings of \$411,225 have accrued as of August 1993.

The second page of the report plots daily chilled-water (or other cooling energy) consumption as a function of daily average dry-bulb temperature and hot water (or other heating energy) as a function of average dry-bulb temperature. Figure 3.9 shows an example taken from the August report (shown in Figure 3.8) for the engineering center. Note that the consumption is plotted using M,T,W,H,F,S,U to indicate days of the week for the current month, with the January-February consumption plotted using dots, and the consumption for August of 1992 plotted as "+". This helps identify changes in consumption patterns. The use of letters also helps identify outliers and determine whether specific events occurred on weekdays, weekends, holidays, etc.

The third page of the report gives time series plots of the hourly chilled water and hot water consumption for the month. Figure 3.10 is an example taken from the August report. The right hand axes on page 2, 3 and 4 were included to serve as a figure of merit that can be used to compare hourly or daily use across different sites. Data after August 17, 1993 are missing due to a hardware problem – one of the reasons why it is important to inspect, identify, and remedy problems as soon as possible.

The top half of the fourth page of the report shows a time series plot of the hourly electricity consumption for the building and also shows submetered electricity consumption (Figure 3.11). The whole-building consumption (top line) shows well-defined weekday/weekend differences. Submetered data are shown for the air handlers, super computer room, and a derived channel for the lights and receptacle loads. The air handler electricity use clearly shows the VAV. The bottom half of page four shows the local ambient dry-bulb temperature and relative humidity. The two-week break between semesters from August 17 - 28 is clearly visible in the electricity data on page 4 (Figure 3.11).

Page five (Figure 3.12) gives two views of a three-dimensional surface plot of the whole-building electricity consumption taken from the August consumption report. This figure provides more detail on daily patterns and day-to-day variation than is readily apparent in the two-dimensional plots given on page 4 of the reports. Obviously, the whole-building electricity data are missing from July 1 - 15. The "canyons" show the typical weekend drop in consumption. The view in the top part of this figure tends to make unusually high consumption during any part of the period evident. The last page of the report provides a written summary of the building envelope construction characteristics, HVAC system(s), building use and HVAC schedules, lighting, and planned or installed retrofits and status. This page normally changes only when retrofits or schedules change.

3.9 Data Exploration Software

After the first consumption report is sent to the agency and operators, the agency contact person is called and a session is scheduled where personnel from the monitoring program meet with facility engineers and operating personnel to discuss the report format, answer questions, and obtain feedback on the report, including suggestions for improvements, etc. During these meetings there are inevitably requests for different graphs that are not included in the report.

To accommodate these requests a computer loaded with data exploration software (LC 1990) is taken to these meetings. This software was originally developed to help organize and examine meteorological data but is capable of handling most kinds of time series and geographically distributed data. It provides multiple window viewing and zoom-in capabilities by utilizing a cross-indexed, compiled data base structure, as shown in Figure 3.13. All data collected from each building monitored at the site are loaded in compiled form for browsing with the software.

The software package cost is comparable to popular word processors, and facilities personnel are encouraged to purchase a copy if they are interested in exploring the data in greater detail than presented in the monthly reports. For these sites, an updated, compiled file of the building data is sent with the consumption report each month for this type of data exploration.

3.10 Summary of LoanSTAR Data Management

In summary, the LoanSTAR MAP data management includes five major functions: polling the data from the recorders, processing the data from all the various sites into a standard format, controlling data quality, generating reports, and retrieving data for analysis. Given the large volume of measured data and the critical nature of the analyses performed on those data, the task of controlling data quality is critical. Techniques developed by LoanSTAR to ensure data integrity can be applied directly to any program.

The principal techniques for providing data verification and validation include:

- 1) review of polling logs
- 2) recorder parameter set revision control
- 3) automated initial verification
- 4) automated handling of missing records
- 5) generation and review of inspection plots
- 6) analytical review of data
- 7) controlled data release
- 8) marking, filling and reconditioning in database.

3.10.1 Review of Polling Logs

LoanSTAR sites are instrumented with Synergistics C-180 series data recorders. In 1992 the ESL developed specialized software (POLLC180) for automatically polling these recorders. The POLLC180 system calls, connects, and extracts time-series records (TSRs) with minimal human intervention. As it processes a set of recorders, POLLC180 writes an activity log. Each week the data polling administrator examines the log files generated by the polling system for the preceding period. Examination of this log identifies dead loggers and some types of sensor problems. The ESL is also collecting data for several other sites from Campbell Scientific data recorders and is working on an equivalent of POLLC180 for use with them as well as other loggers. Routines have also been developed for converting EMCS data into LoanSTAR format (Claridge, et al 1991)

3.10.2 Recorder Parameter Set Revision Control

The key to decoding information stored in each data recorder is the "parameter set" containing information such as channel types and scaling factors. The parameter set is initially defined by the site installation team, but *changes* over the life of the experiment. When sensors are changed, or other equipment is modified, repaired, or recalibrated, there is usually a change to the parameter set. One lesson of the LoanSTAR program is that data recovery and analysis requires an iron-clad historical record of every parameter set affecting each data set. For any program, a rigorous policy of retaining each parameter set and pertinent information must be implemented. A software tool such as the Revision Control System (RCS) is an excellent example of an automated procedure for controlling such information.

3.10.3 Automated Initial Verification

After the operator has verified reception of raw data by the automated polling system, the raw data are uploaded to the main server for further manipulation. These operations transform the raw data into table entries in the relational database management system (RDBMS). The transformation extracts the data from the raw file and syntactically translates them into a format appropriate for the RDBMS. Site and channel-specific rules from the channel-ID table (CHIDS) in the RDBMS assist in the translation process. These rules include elementary verification procedures, such as "reasonableness" range checks (Ex: Relative humidity of 110% is "unreasonable") and component-sums (Ex: whole-

building electric should equal the sum of all the electric subsystems). Suspicious records are flagged in the log for handling by the operator.

3.10.4 Automated Handling of Missing Records

It is not uncommon for a data recorder to lose power in the field. Battery backups support the internal memory during an outage but the logger does not collect any new data until the power is restored. This causes gaps to exist in the data set. Gaps cause problems with merging weather data and certain types of analysis, so LoanSTAR implemented a protocol whereby missing records are filled into the data with the -99 flag (Invalid Data) for all data values. Rather than storing "missing" data into the RDBMS (which would waste space), ESL techniques actually fill the missing records on demand during a data extract. While the concepts of scanning and replacing missing data are easy to understand, a general program must account for day boundaries, month boundaries, year boundaries, leap year boundaries, daylight savings, and several other special conditions. Any program will directly benefit from LoanSTAR's development work in this area.

3.10.5 Generation and Review of Inspection Plots

The final phase of the raw data translation process is the preparation of inspection plots. After all data has been initially verified through range-checks and other automated procedures and missing data has been filled, inspection plots are prepared according to site-specific procedures stored in the RDBMS. In the LoanSTAR methodology, three different kinds of plots are created: time series readings of all channels, scatter plots of some channels versus temperature, and scatter plots of LoanSTAR weather data versus nearby National Weather Service data. Samples of these plots as used in the LoanSTAR Inspection Plot Notebook (IPN) are shown in Figures 3.6, 3.7, 10.2, 10.3, and 10.7.

The plots allow possible problems with the data to be identified by visual checks. Because of the long stream of filters that the data are subjected to prior to the production of the plots, any potential problems are usually brought to the attention of the Database Manager, who determines if a processing problem could have corrupted the data. If this is not the case, then a genuine data problem may have occurred (for example, a metering problem), and an appropriate message is forwarded to the field engineers. Archives of all comments are also kept in the relational data base.

3.10.6 Controlled Data Release

Maintaining the integrity of released data is one of the main goals of the LoanSTAR program. In order to meet this need the ESL developed a procedure for controlling and tracking all data releases. All distributed data are extracted as needed from the RDBMS -- it is important to note that the powerful database developed by the ESL allows all historical program data to be maintained on-line, ready to meet any analysis or technology-transfer requirement.

Data are extracted into columnar format using the program "GETDATC", which writes a complete log of every request, (including site, channels, time ranges,

identification of the requester). If any inaccuracy affecting that set of data is later detected and resolved, the log can be used to track down and update the recipients of any updated data.

The importance of this facility is that it resolves the issue of "Well, MY copy of the data clearly shows that . . ." Requesters are encouraged to obtain new copies of data as needed for analysis, and not to keep static local copies. Since the ESL's RDBMS is network accessible via the NSF Internet, technology transfer and analysis requests can be filled real-time to almost anywhere in the world.

3.10.7 Marking, Filling and Reconditioning In Database

The ESL's database design partitions the data -- "original", as received in the initial load, and "reconditioned", updated to allow for any needed adjustments, such as rescaling due to sensor drift. Unrecoverable data sets (perhaps due to a sensor failure) can be reconditioned as "bad" (-99). Data requests are filled by supplying reconditioned data for site-channel-date ranges that have been reconditioned, and original data for ranges that have not been reconditioned. This partitioning provides a critical validation aid -- the original data, as well as log of all reconditioning steps, is available at all times for further analysis. The ESL's advanced system eliminates much of this difficulty of maintaining accurate records. No system relying on static updates (including most PC-based database implementations) can deliver information so accurately and completely.

The "reconditioning" technique also allows for the inclusion of "synthesized" data. Missing pieces of data are synthesized as necessary by feeding existing data into the appropriate software including the EModel software (Kissock 1993), which then derives a data set representing the building's expected behavior during the period of missing data. Synthesized data can provide for certain types of savings analyses (or graphing) that require contiguous data.

In the next section, the analysis of the retrofit measures is discussed. The focus of the section includes a description of why we monitored what we did and how we intended to analyze it.

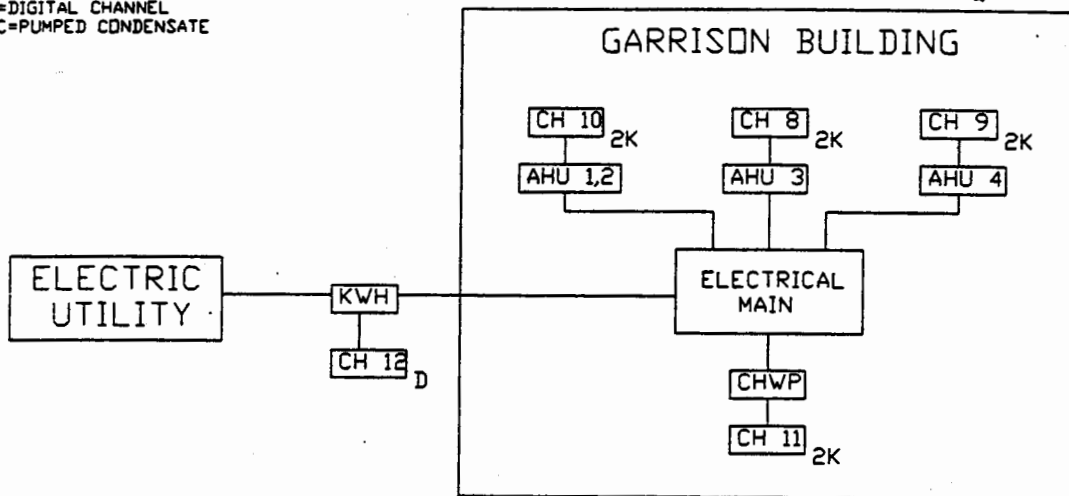
In section 10.2 of the appendix additional helpful hints are provided about polling and retrieving data, including special processing required for data obtained from Synergistics loggers. Specific routines are also presented for producing the inspection plots, and special purpose 3-D plots.

Figure 3.1: Electrical and thermal monitoring diagram for a typical LoanSTAR site. This figure shows the electrical and thermal monitoring diagram for the UT Austin site. The upper diagram is the electrical monitoring diagram, and the lower diagram is the thermal monitoring diagram.

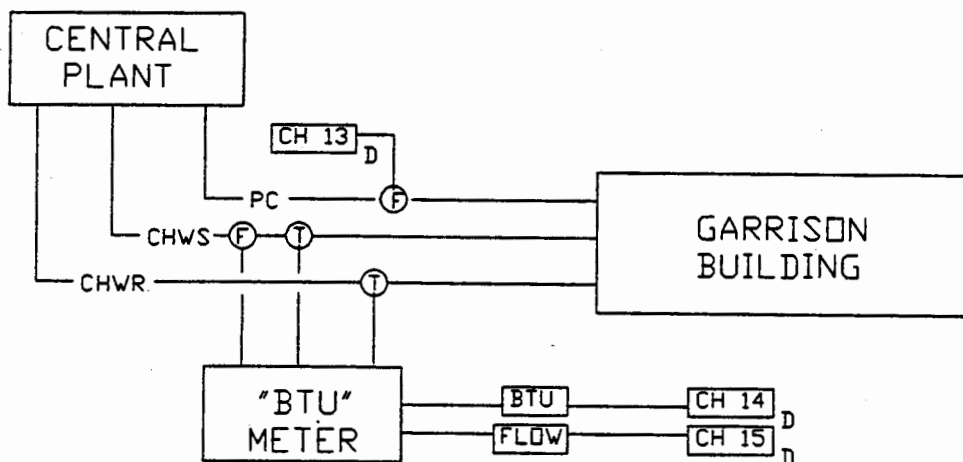
"KWH" MONITORING DIAGRAM

LEGEND

K=KWH CHANNEL
 A=ANALOG CHANNEL
 D=DIGITAL CHANNEL
 PC=PUMPED CONDENSATE



THERMAL MONITORING DIAGRAM



UT AUSTIN-GARRISON BLDG

Figure 3.2: Diagram of an example logger set-up. This diagram illustrates an example logger which is set up to measure one electricity channel, one digital thermal Btu channel and one digital flow channel, one analog temperature channel, and one humidity channel.

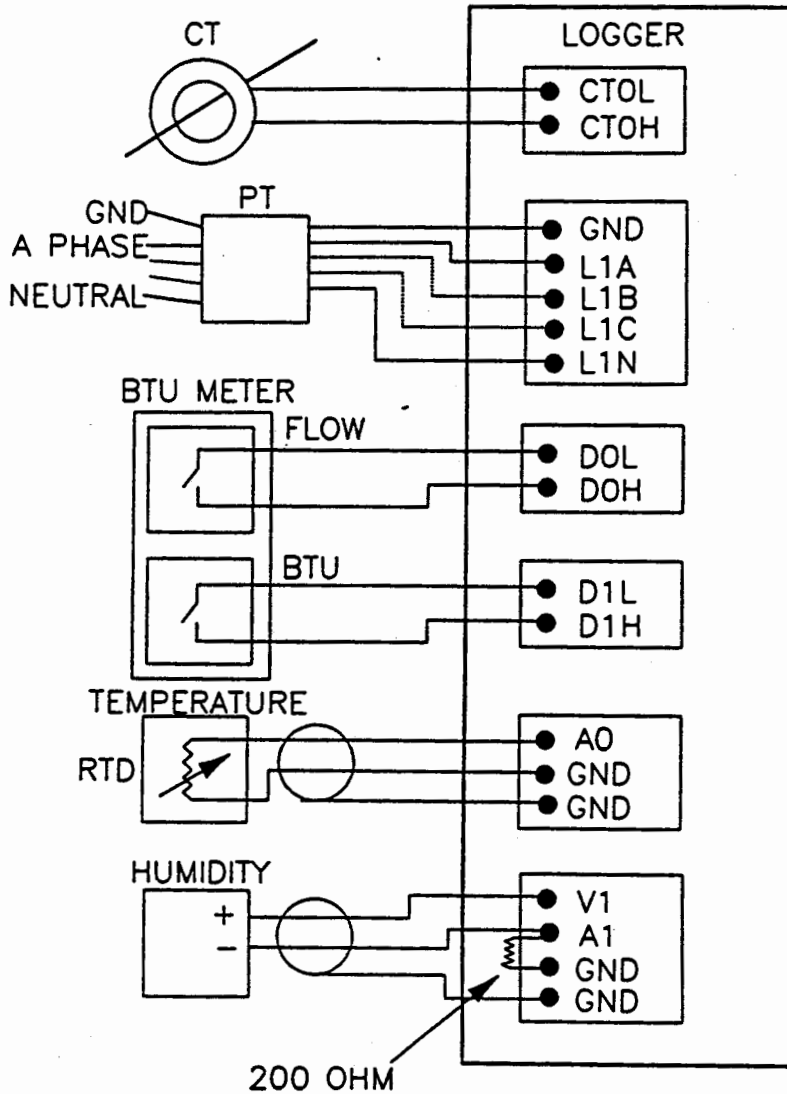


Figure 3.3: Typical logger set-up to measure three phase whole-building electricity. This figure illustrates how three phase electricity is monitored with the Synergistics logger (Photocopied with permission: Synergistics 1990).

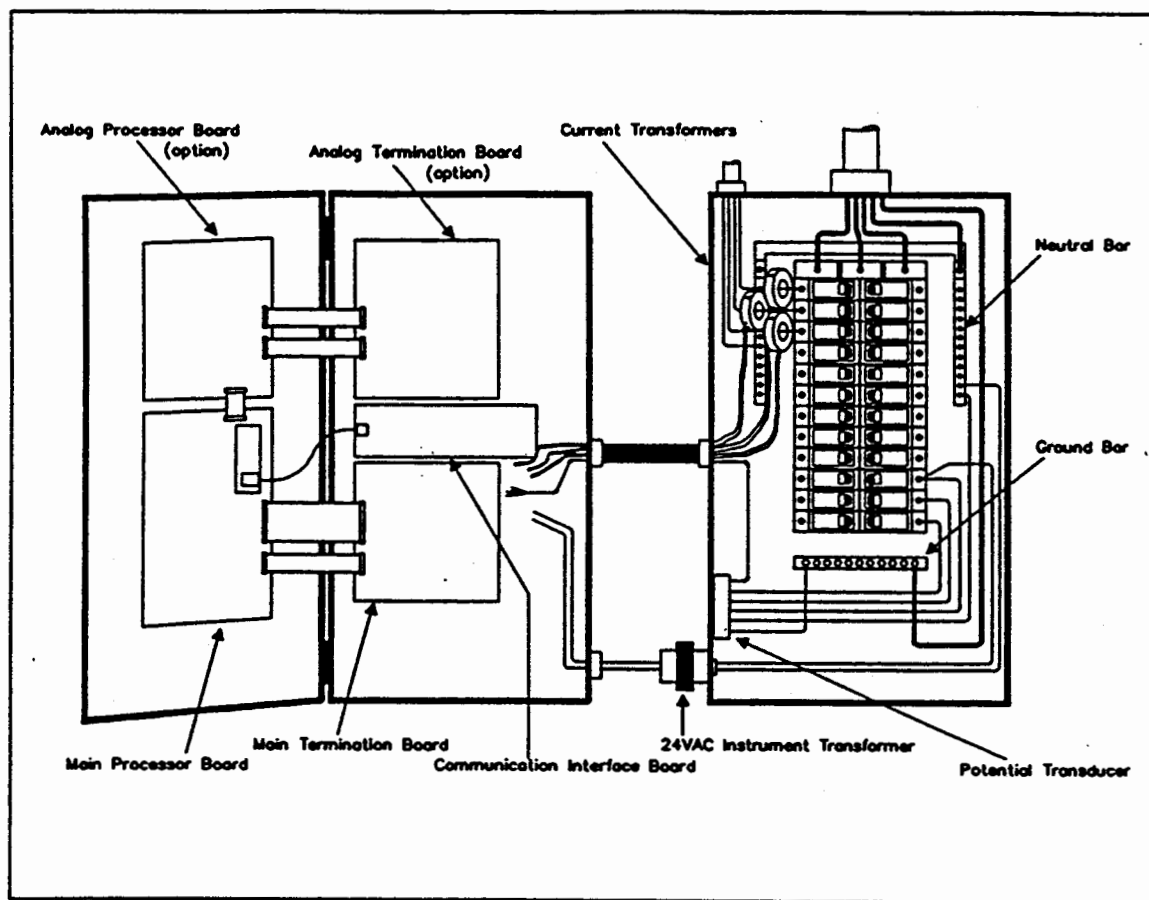


Figure 3.4: Typical thermal energy meter set-up. This figure shows a detail of how thermal energy monitoring of chilled water is achieved with the use of a Btu meter, two temperature probes, and a flow meter.

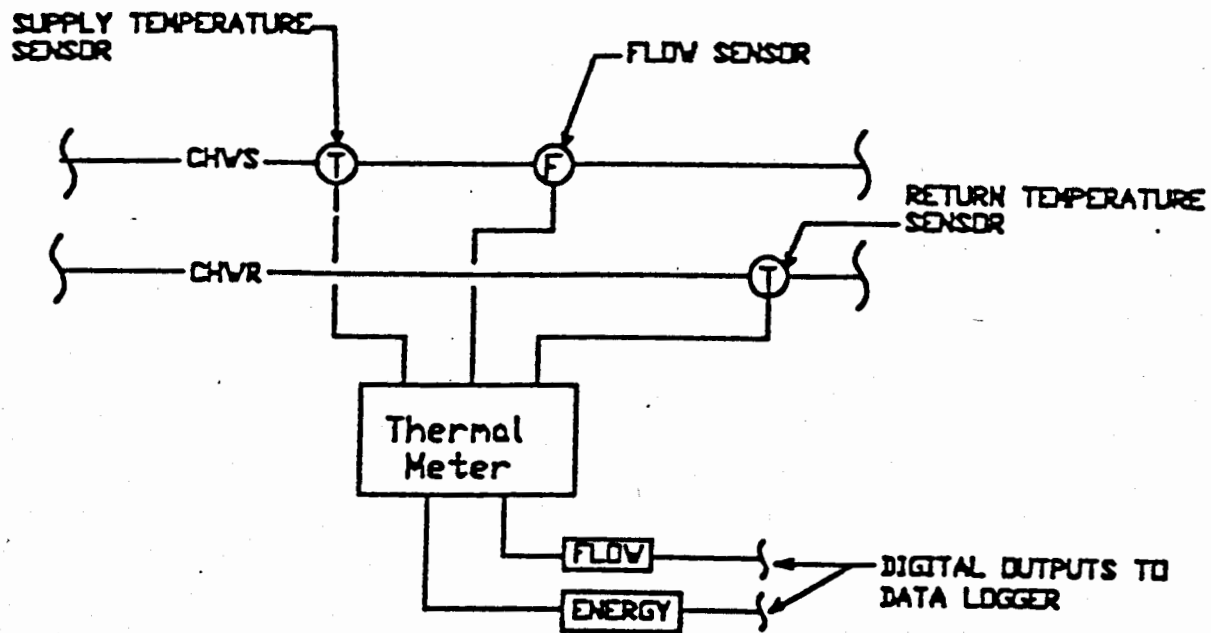


Figure 3.5: Typical hot-tap flow meter installation. This figure shows a typical hot-tap flow meter installation used in the LoanSTAR program. Hot-tap flow meters were chosen to avoid having to shut down the chilled water or hot water system during installation.

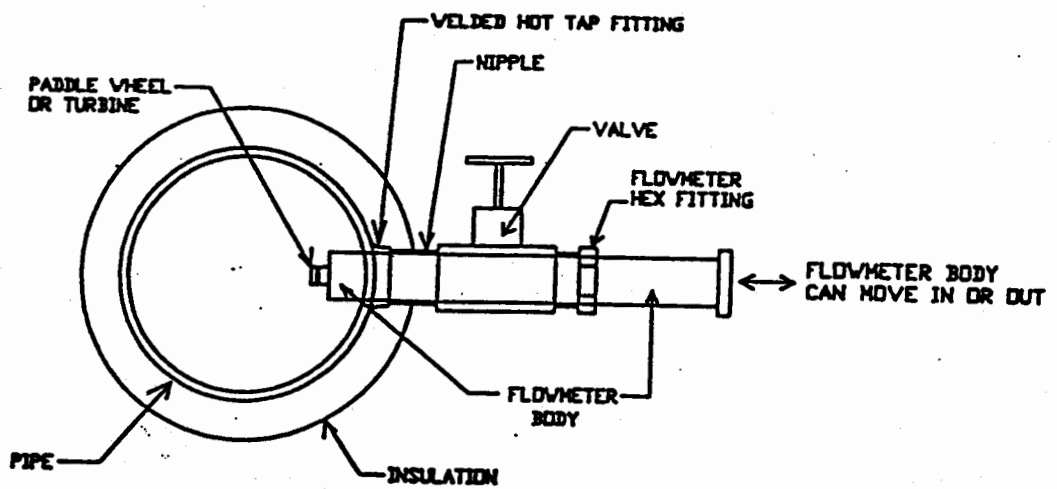
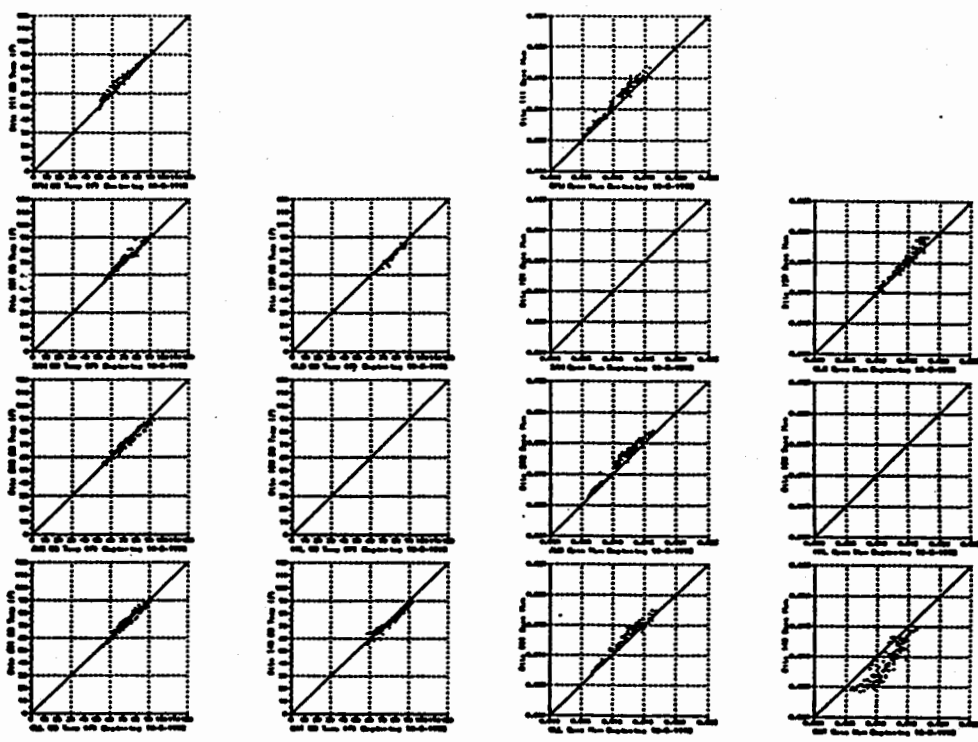


Figure 3.6: Weather cross-plots of LoanSTAR vs. National Weather Service. This figure shows cross-plots of weather data from the LoanSTAR sites (y-axis) vs. the National Weather Service (NWS, x-axis) for Dallas/Ft. Worth (DFW), Houston International Airport (IAH), Austin (AUS), College Station (CLL), Galveston (GLS), Harlingen (HRL), and San Antonio (SAT). Cross plots of dry-bulb temperature (DB) occupy the left side of the figure, and cross plots of specific humidity occupy the right side of the figure (Spec. Hum.).



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Figure 3.7: Typical weekly inspection plot for a LoanSTAR site. This figure shows the summary page from the weekly inspection plot of the Zachry Engineering Center (Site 001).

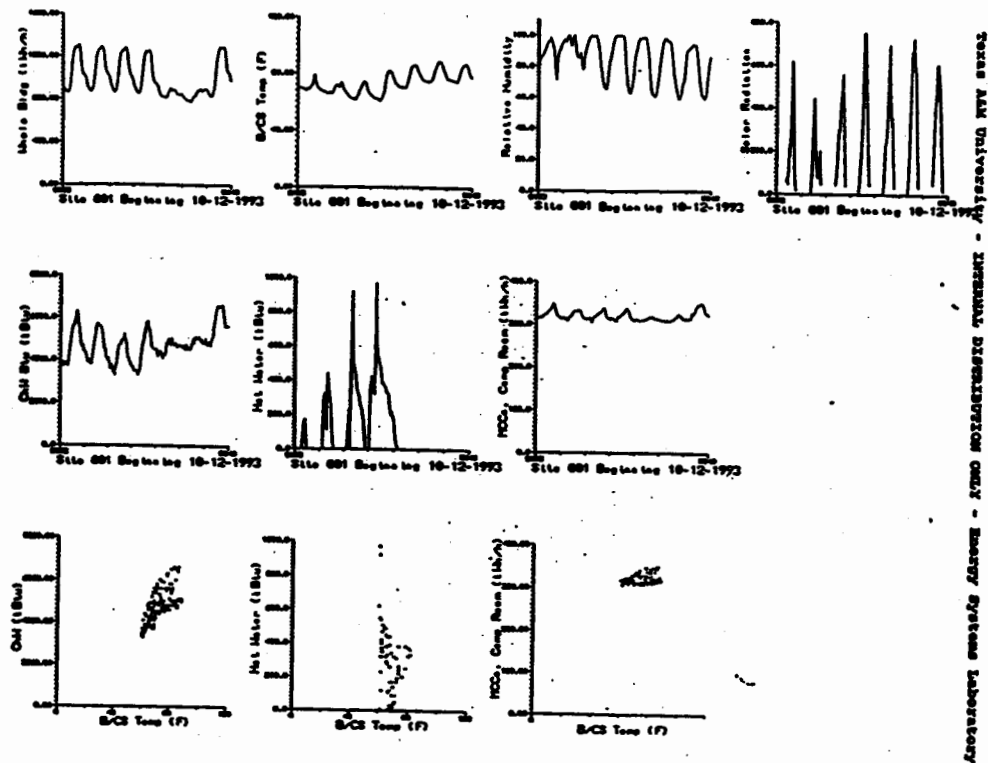


Figure 3.8: Summary page (page 1) from the August 1993 energy consumption report for the Zachry engineering center at Texas A&M University.

Zachry Engineering Center Texas A&M University 324,400 square feet	
<u>Site Contact</u> Mr. Charles Darnell, Jr. Physical Plant Administration Texas A&M University (409)-845-5318 Gene Stewart (409)-845-5511	<u>LoanSTAR Metering Contact</u> Aamer Athar 053D WERC Texas A&M University College Station, TX 77843-3123 (409)-845-9213

Summary of Energy Consumption				
	Measured Use	% hours reported	Unit Cost	Estimated Cost
Electricity	706194 kWh	100	\$0.02788	\$19689
Peak 60 Minute Demand	1301 kW	100	-	-
Chilled Water	4345.9 MMBtu	100	\$4.670	\$20295
Hot Water	87.0 MMBtu	53	\$4.750	\$413

Peak 60 minute demand was recorded at 1200 Tuesday 8/31/93.
There were 744 hours in this month.

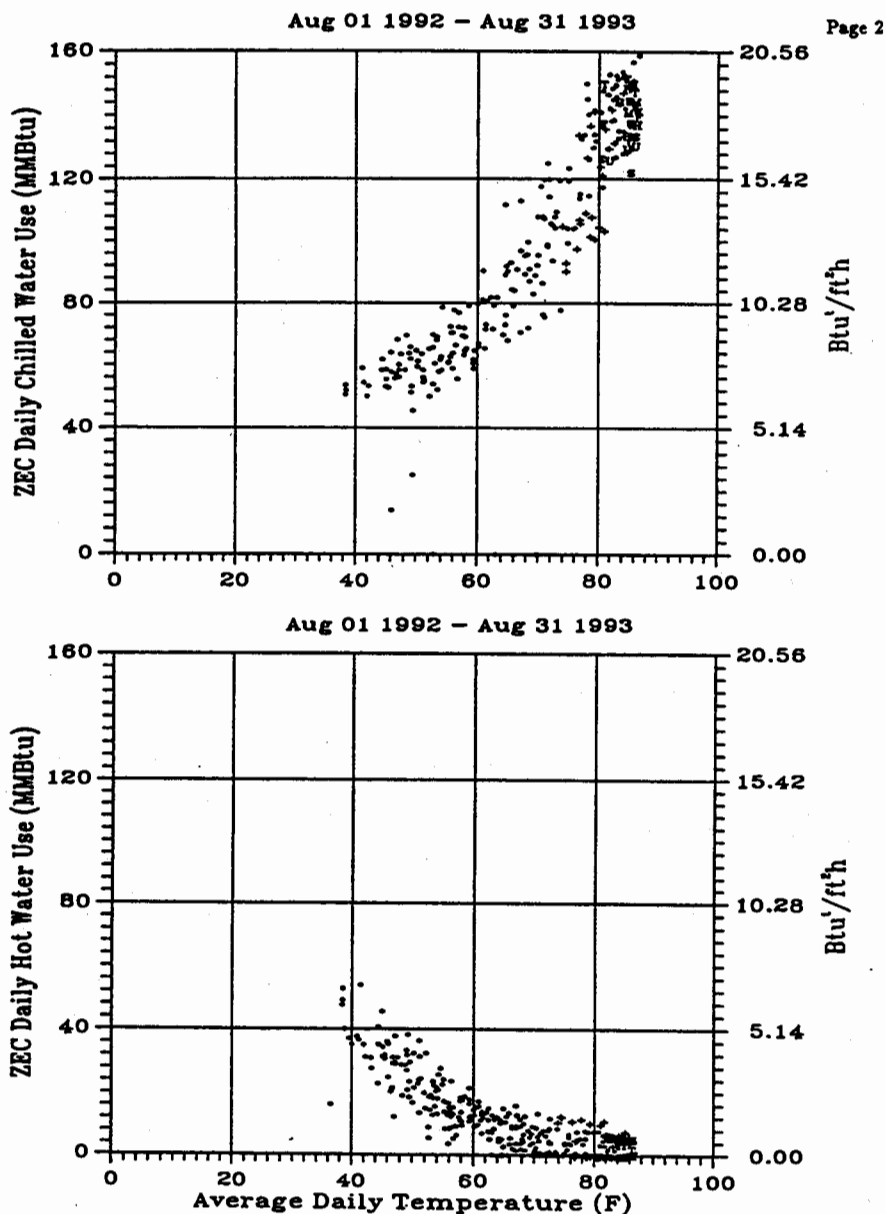
Monthly Retrofit Savings				
	Measured Savings		Audit Estimated Savings	
Electricity (kWh)	118164	\$3294	162730	\$4524
Chilled Water (MMBtu)	682	\$3185	2215	\$10344
Cond./H.W. (MMBtu)	114	\$542	956	\$4541
Monthly Total		\$7021		\$19409
Total to Date*	(34 months)	\$411225	(30 months)	\$582268

*Measured savings include construction period. Audit estimated savings do not.

Comments

★ Hot water consumption data are missing from 8-17-93 to 8-31-93 due to a hardware problem.

Figure 3.9: Page 2 of the LoanSTAR MECR contains cross plots of daily thermal energy use vs. average daily temperature with the current month annotated as shown.



Data points for the current month are shown as letters. Points from this month last year are shown as +.
 Monday through Sunday are represented as M,T,W,H,F,S,U. All other points are shown as *.

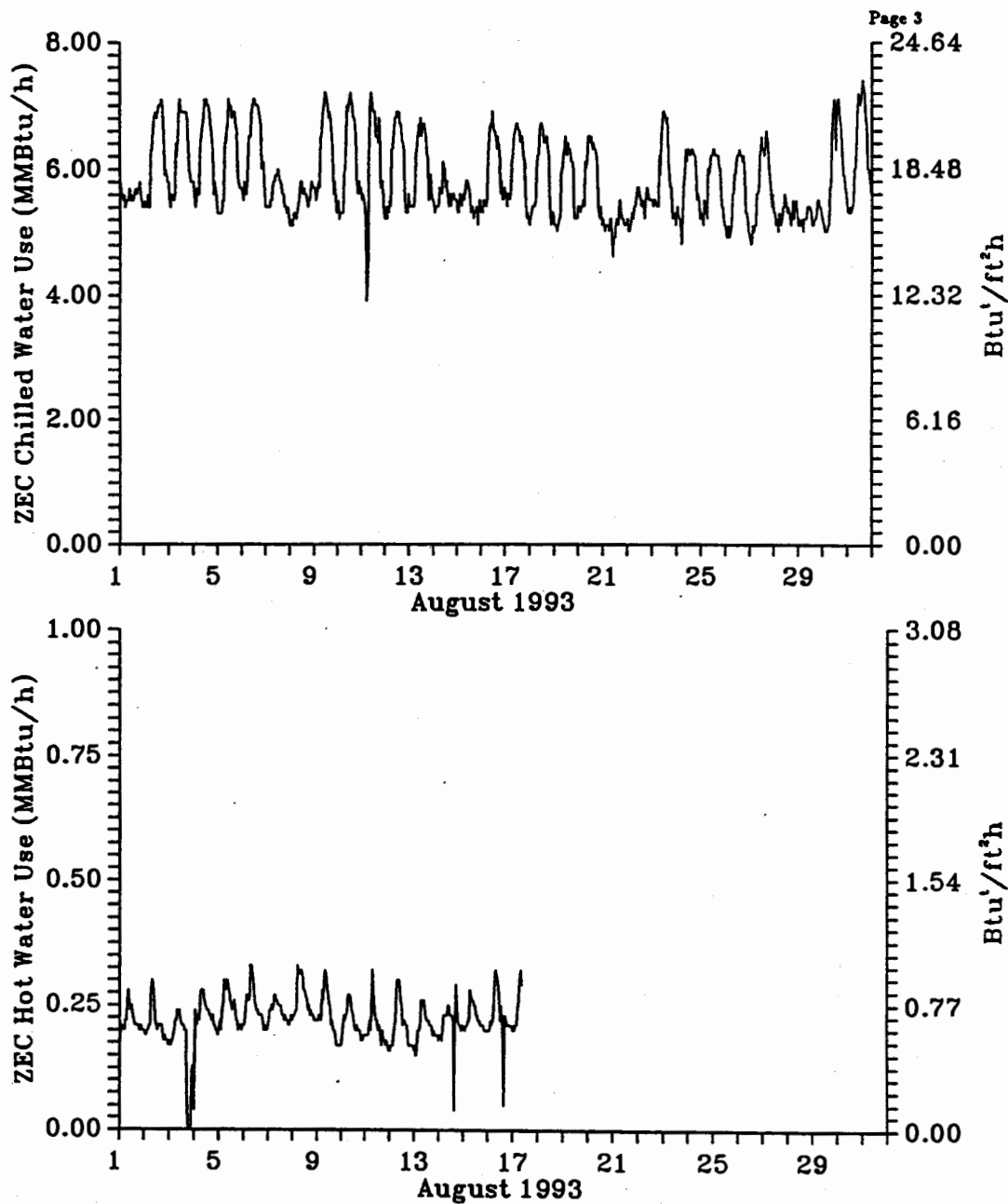
Zachry Engineering Center - Texas A&M University - August 1993

Texas Energy Office
 LoanSTAR Monitoring & Analysis Program

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Figure 3.10: Page 3 of the LoanSTAR MECR contains time series traces of thermal energy use, typically chilled water and hot water or steam use.



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Figure 3.11: Page 4 of the LoanSTAR MECR contains time series traces of electricity use and environmental data. In the upper plot, whole-building electricity is shown along with sub-metered data for lights and equipment, motor control centers, and a central computing facility. The lower plot is a time series trace of hourly dry-bulb temperature and humidity recorded on the roof of the building.

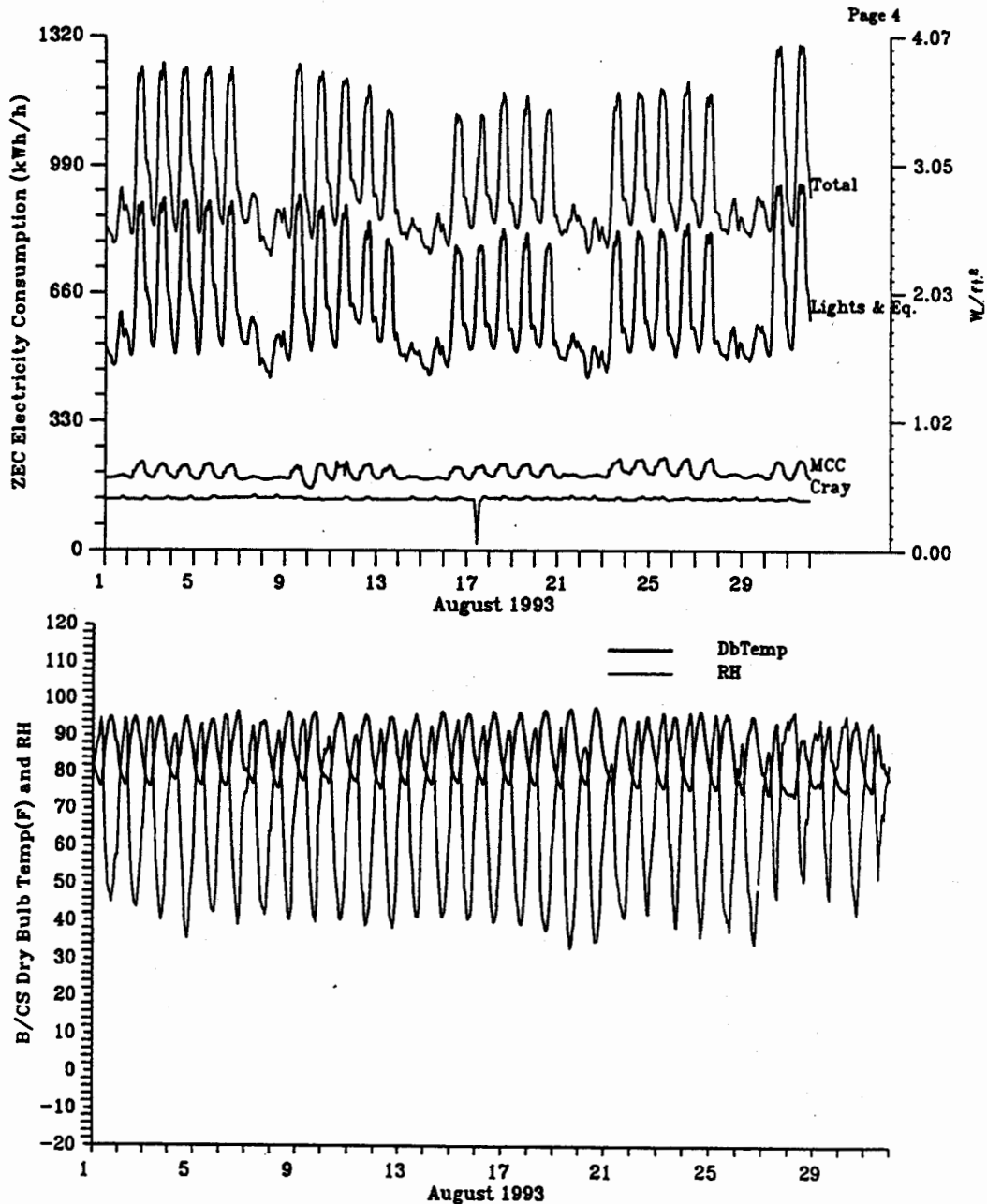
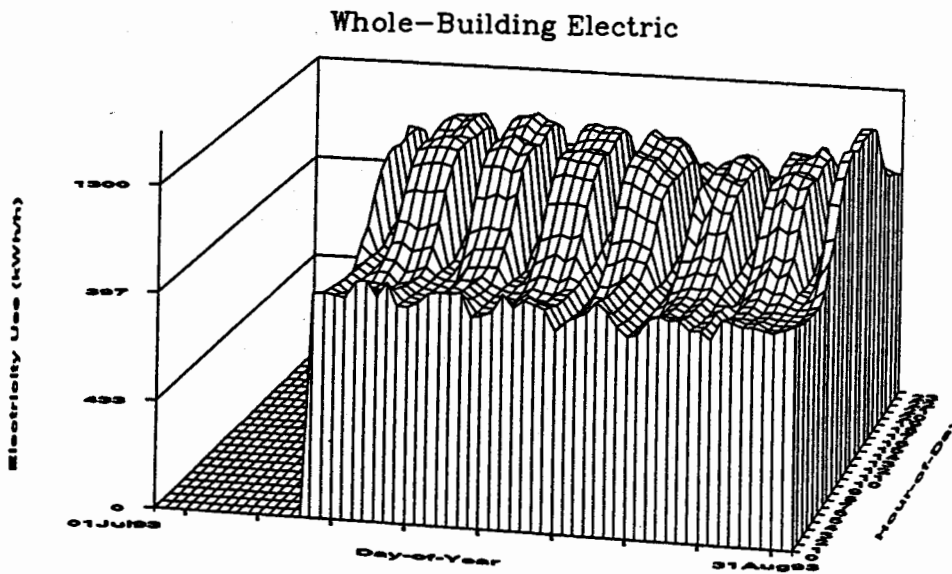
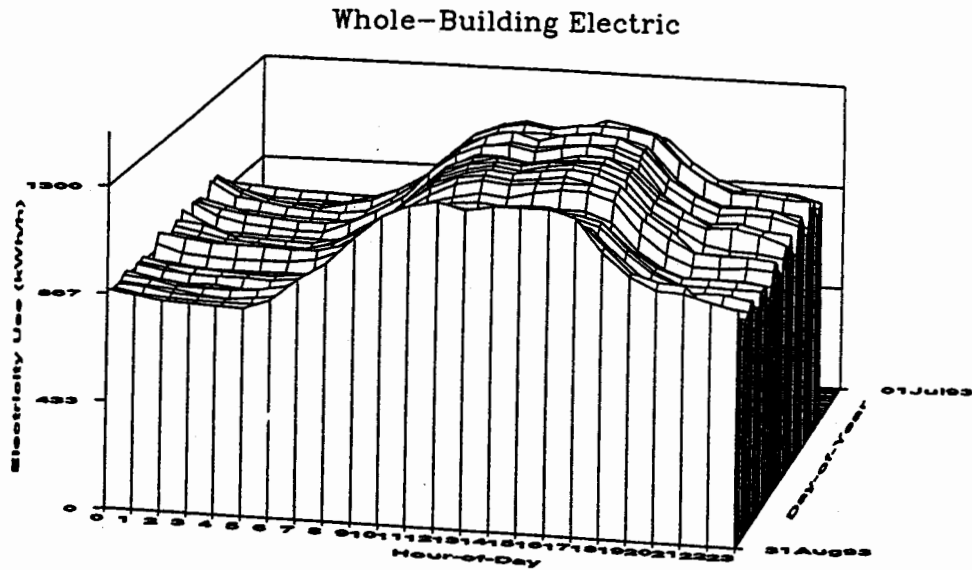


Figure 3.12: Page 5 of the LoanSTAR MECR contains two views of 3-D plots of whole-building electricity.

Page 5



Sundays are marked with an "S"

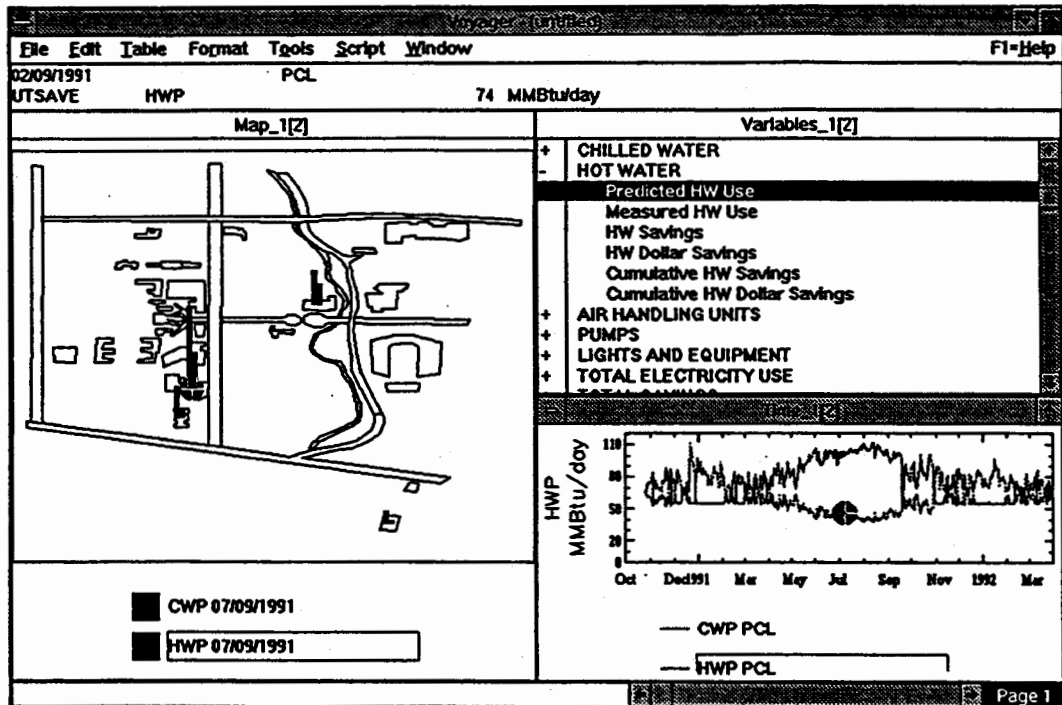
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Figure 3.13: LoanSTAR browsing software. This figure shows a multi-window view from the Voyager software package that is used for browsing through LoanSTAR data.



4.0 CHARACTERIZATION OF THE ANALYSIS OF RETROFIT MEASURES

4.1 Background

Let us start by reiterating the major objectives of the Monitoring and Analysis Program (MAP) of LoanSTAR. These are to:

- (a) verify energy and dollar savings of the retrofits,
- (b) reduce energy costs by identifying operational and maintenance improvements at monitored facilities,
- (c) improve retrofit selection in future rounds of the LoanSTAR program, and
- (d) provide a detailed data base of energy use in commercial/institutional buildings located in Texas.

The scope of this chapter (as well as that of this report) is limited to objective (a) above. Though the loan repayment schedule is based on the energy savings estimated by the energy audits, the purpose of objective (a) is primarily to assure retrofit effectiveness, i.e. to determine whether the actual or measured savings from the retrofits are in effect as large as those estimated during the audit process. This constant verification can avoid expensive oversights and ensure the proper operation of the building after the retrofit stage is complete. Section 4.2 briefly describes the types of energy retrofits performed in the LoanSTAR program and discusses monitoring requirements to properly identify associated energy savings. Section 4.3 presents the methodology by which retrofit energy savings in the framework of the Texas LoanSTAR project are estimated. Other important allied issues are addressed in section 4.4.

4.2 Monitoring Requirements - Why did we monitor what we did?

4.2.1 Types of Retrofits

Savings monitoring requirements for any site depend upon the type of energy conservation retrofits and the level of audit verification required as described in sections 2 and 3. The projects funded by LoanSTAR primarily include retrofits to lighting, HVAC systems, electric motors, energy management control systems (EMCS), boilers, energy recovery systems, thermal storage and co-generation systems. As of April 1993, energy savings in 24 LoanSTAR sites representing 38 buildings are being reported, while monitoring is underway in 69 sites representing 199 buildings. From Figure 2.2 presented earlier, we note that the majority of monitored buildings are institutional buildings, while a few school districts and thermal energy plants have also come on-line. The buildings located on university campuses vary in size from 49,000 ft² to 484,000 ft² and house classrooms, offices, laboratories, computer facilities, auditoriums, workshops and a major campus library. Such buildings are provided with electricity, chilled water, and steam (or hot water) from centralized campus utility plants that are separate from the buildings.

The types of retrofits in all monitored buildings, the estimated implementation costs, completion status, and cost savings that can be realized in dollars, in percent of total cost and as simple payback, were previously discussed in Table 2.1. These values are audit estimated values and their comparison with measured savings is discussed in section 5.1. The primary retrofit in all these buildings was the conversion of constant volume air handling units to variable air volume air handling units. The resulting energy savings in whole-building chilled water use, whole-building hot water use, and electricity use of air handlers and chilled water pumps are individually estimated and reported. We note from Table 2.1 that lighting and EMCS retrofits are the second most important types of retrofits.

4.2.2. Criteria

The general philosophy of monitoring design in the framework of LoanSTAR is described in this section. Depending on the number of channels being monitored, ensuring the quality of the data may be a formidable task. Meters must be correctly calibrated when installed and recalibrated at frequent intervals to avoid "drift". Detecting bad data can also be difficult. Though certain quality control measures can be automated, proper control requires an inordinate amount of analyst time. Given the financial constraints of the MAP (only 3% of the retrofit cost can be used for monitoring), the objectives of LoanSTAR are better served by taking fewer channels of good data at the whole-building level rather than at the disaggregated end-use level.

To provide the best measure of energy savings, the energy use of each type of equipment being retrofitted should be separately monitored. For example, if constant air volume (CAV) air handlers are being converted to variable air volume (VAV), the total electricity used by the air-handlers should be metered. This can often be accomplished by metering the electricity used by the main distribution panel (often called a motor-control center) which distributes electricity to all of the air-handlers in the building.

If the energy savings generated by lighting retrofits are to be exactly measured, then all of the electrical feeds to the lighting fixtures must be identified and metered. In practice, this is often difficult and expensive because lighting circuits are usually distributed throughout the building. A less expensive method is to meter the whole-building electricity use and the air-handler electricity use separately. The difference between the two channels (provided no large appliances are situated outside the building, something which is easily verified) is the lighting and equipment (LE) use. Comparing LE use immediately before and after the retrofit will yield a good estimate of the electricity saved by the retrofit. Over a long period of time, however, this estimate of savings may be less accurate as other electrical equipment may be added to or removed from the building.

If a retrofit is expected to reduce the heating and cooling energy use, these energy uses should also be metered. In buildings where heating and cooling are generated on-site, metering the energy supplied to the heating (say, in the form of natural gas volume)

or the cooling (say, electricity in the case of a vapor compression chiller and natural gas in the case of an absorption chiller) equipment is adequate if similar operational strategies are maintained before and after the retrofit. If the building subscribes to district heating and/or cooling (like institutional buildings do) then whole-building heating and/or cooling can be measured separately by individually metering heating and cooling energy as they enter and leave the building. This involves measuring the fluid flow rate AND the temperature difference between both streams. It must be stressed that both these quantities should be monitored and retained as separate channels because this allows for corrections (such as flow rate) to be made at a later time when manufacturer calibration factors are found to have gone astray. This occurred in the LoanSTAR program (Haberl et al., 1992) and hence the absolute need to retain both these channels.

Typically, the following channels are used during retrofit savings calculations: chilled water use, hot water use, whole-building electricity, air handler electricity use, chilled water pump electricity use, and climatic variables hourly averaged (ambient dry-bulb temperature, relative humidity, wind speed and global horizontal solar radiation).

4.3 Analysis Approach - How did we intend to calculate savings?

4.3.1 Overview

One way of estimating retrofit savings is to compare directly the unadjusted pre-retrofit energy use to the post-retrofit energy use. Though this method may yield a first-order evaluation, it has generally been found to be too simplistic because the effect of the retrofit on energy use may be largely or entirely masked by changes between the pre- and the post-retrofit periods of certain important parameters influencing energy use (the most important often being the climatic variables and the building operating mode). Consequently, in order to incorporate the effects of such changes into the energy savings calculation, a theoretical model capable of predicting the energy use of the building under pre-retrofit operation needs to be developed. Though pre-retrofit utility bills may be a source for such a model, most of the institutional LoanSTAR buildings do not have such data. Consequently the pre-retrofit monitored data provides both a base-line and a source of developing the model.

Modeling approaches can be grouped according to two generic types:

(A) the regression model approach, sub-divided into two categories:¹¹

(A1) models using billing OR monitored data (Fels, 1986; Claridge et al., 1990; Kissock et al., 1992), which are by far the most widely used;

(A2) models using a mix of billing AND monitored data (Liu et al., 1992) whose need arose in certain of our smaller LoanSTAR buildings;

(B) the calibrated engineering model approach, which can again be sub-divided into two categories:

¹¹ Some analysts may prefer classifying regression models according to either time scale (monthly, daily, hourly), model type (simple or multiple) or model functional form (linear, change point, quadratic, spline).

- (B1) detailed simulation codes like DOE-2 (Hsieh et al., 1991; Bronson et al., 1992); and
- (B2) simplified HVAC systems models (Katipamula and Claridge, 1993).

Whenever appropriate, model development using the regression approach is used because it is generally the least demanding in effort and user-expertise, yields adequate results and permits uncertainty associated with savings to be quantified using accepted statistical procedures. The calibrated detailed simulation model approach is more tedious and requires knowledge of how the mechanical systems of the building are operated and a certain proficiency in using the particular building energy code. It is typically resorted to during analysis of monitored data for determining retrofit savings only when the quality or length of the data period is not adequate to enable proper regression model identification. The simplified model approach (developed until recently essentially for residential building energy use, Subbarao, 1988) falls between the two approaches both in the level of user-expertise and length of data period. This approach is described in section 4.4.3.

The Texas LoanSTAR program requires that data acquisition equipment to monitor building energy use be installed for a suitable period before the retrofits are carried out (Claridge et al., 1991) and remain in the building possibly throughout the retrofit life. Consequently, estimates of the retrofit energy savings can be based on the regression model approach. There are, however, buildings for which, due to a variety of reasons, the pre-retrofit data are either too short or even entirely spurious. As discussed at more length in section 4.4.1, statistical models for weather related savings calculations based on fewer than about 3 months of data are usually unreliable. Only in such instances is the calibrated simplified systems model approach considered for use in the LoanSTAR program (Katipamula and Claridge, 1993). This approach has yet to reach a stage of maturity in methodology development where it can be used routinely and with confidence by people other than highly skilled analysts. Consequently, unless otherwise specified, the majority of the discussion that follows pertains to regression model approach.

4.3.2 Savings Methodology

The methodology currently used to report retrofit savings in LoanSTAR buildings basically involves the following steps (Kissock et al., 1992a, b):

- (i) **Identification of the pre-retrofit, construction, and post-retrofit periods** This is done both from log books and inspection of the hourly time series plots of air handler electricity use. Changes in consumption patterns are very distinct during these three stages and consequently there is little ambiguity, as illustrated by Figure 4.1. In buildings with constant volume AHUs the pre-retrofit period, air-handler electricity use is almost constant, while electricity use behavior during the construction period is many times erratic. Finally, after the VAV retrofit is complete, air-handler use follows a regular but varying pattern depending upon the building heating and cooling loads.

- (ii) Preliminary data handling The entire data set from each building is usually comprised of hourly averaged or hourly summed observations. In most cases these channels are screened and converted into daily averaged data. This is the time scale presumed in all subsequent steps because of the following reasons: 1) it retains the resolution required to observe variation in energy use with climatic conditions and building operating mode; 2) it avoids the complexity introduced by the thermal mass effects of the building shell and the strong diurnal scheduling patterns of lighting and equipment (LE); and 3) it significantly reduces the amount of data to be manipulated and interpreted as compared to hourly data, while remaining large enough for robust statistical analysis. In those special cases where daily data do not provide sufficient detail, hourly data are retained.
- (iii) Regression model identification In order to measure savings statistical models of pre-retrofit energy use of each energy type influenced by the retrofit are developed. Typically, this would include daily cooling energy use, heating energy use, and electricity use. The functional form of each model is determined both by our physical understanding of how a particular type of energy use should vary with time and also by the equipment operating schedules. For example, electricity use of a CAV air handler is independent of weather conditions, but can vary from a weekday to weekend if on/off schedules are implemented. Therefore, this use is normally modeled as the mean electricity use during each type of operational period. LE use can also be reasonably modeled by mean models, one for the weekday and one for weekends. Classical techniques (such as a t-test) are often used to determine whether differences in building use during weekdays and weekends are statistically significant and hence warrant separate models. The same techniques of day-typing, that is, grouping the daily data set into separate subsets and identifying models for each day-type, is also done for other holidays, such as Christmas, Thanksgiving, and for university buildings, spring and summer breaks (Katipamula and Haberl, 1991).

Changes in quantities such as cooling and heating energy are primarily influenced by the local weather conditions, internal loads and mode of building operation or day-type. Because day-types are in effect dictated by internal loads, regression models with weather parameters usually requires a day-type separation prior to modeling. The types of models used in the LoanSTAR program, their deficiencies and how these are currently being improved are discussed in section 4.4.

- (iv) Predicting energy use of non-retrofitted building The set of pre-retrofit regression models (identified using daily data) are then used to predict daily energy consumption of the retrofitted building under pre-retrofit conditions, but with building operation and weather conditions corresponding to each day of the post-retrofit period. Because the building has already undergone retrofits, the use of a model is unavoidable and leads to model prediction uncertainties, which subsequently impact the uncertainty of retrofit savings.

- (v) Calculation of savings Finally, the savings over a certain number of post-retrofit days are calculated by subtracting the daily measured energy consumption from the daily energy consumption predicted by the pre-retrofit model and summing the daily savings over the time period in question.

The entire procedure for computing total savings of either chilled water, hot water or electricity can be summarized by:

$$\sum_{j=1}^m E_{Save,j} = \sum_{j=1}^m \bar{E}_{Pred,j} - \sum_{j=1}^m E_{Meas,j} \quad (4.1a)$$

or

$$E_{Save,Tot} = E_{Pred,Tot} - E_{Meas,Tot} \quad (4.1b)$$

where

- j = subscript representing a particular day over the post-retrofit period,
- m = number of post-retrofit days over which savings are estimated,
- $E_{Save,j}$ = energy savings over day j ,
- $\bar{E}_{Pred,j}$ = model predicted daily energy use of non-retrofitted building,
- $E_{Meas,j}$ = measured post-retrofit daily energy use, and
- Tot = subscript denoting total over the entire retrofit period.

Figure 4.2 illustrates this methodology by a series of three plots. The upper plot depicts a scatter plot of chilled water use as a function of outdoor dry-bulb temperature (which as discussed in section 4.3.3 as the main regressor variable). A linear regression model is then fit to the pre-retrofit data points. The 95% uncertainty bounds of the regression line are also shown. In the middle plot, the same linear model is plotted in conjunction with measured post-retrofit data points. The differences between each daily point and the regression line represents the energy savings on that particular day. Summing the daily values over m days yields the net energy savings during a certain time interval as shown in the lower plot.

4.3.3 Statistical Models Used

It is clear from the above discussion that the regression model identification phase is crucial in the entire retrofit savings process. Currently, most regression models are linear, and of the first-order. This was based on 1) preliminary findings and previous experience supported by heat transfer and thermodynamic principles that energy flows in buildings could be well represented by linear first order functional forms (Fels, 1986; Rabl, 1988; Subbarao, 1988), and 2) a desire to keep the statistical identification simple (proper non-linear regression requires a much higher level of expertise).

The present generation of LoanSTAR models presumes ambient temperature to be the sole regressor variable (Kissock et al., 1992 a & b). Specifically, T in our daily models is calculated as follows:

$$T = \frac{\text{daily max. temp} + \text{daily min temp.}}{2} \quad (4.2)$$

Though a mean daily T value could be calculated from the 24 hourly monitored values, it was decided to use the above definition because of consistency. In all LoanSTAR sites we rely on the National Weather Service to provide the minimum and maximum daily temperatures. This service is available for most U.S. cities.

In some buildings in the LoanSTAR program, the simple regression model has been found to be adequate. However, studies underway reveal that adding other variables would improve the models in terms of increasing the adjusted R^2 and decreasing the coefficient of variation (CV). Implications of such models in terms of 1) multicollinearity between regressor variables which could lead to unstable parameter estimates (Manly, 1986; Draper and Smith, 1981, Ruch et al., 1993; Wu et al., 1992), 2) uncertainty intervals of savings estimates, and 3) the higher measurement uncertainty of monitoring equipment (say, that of specific humidity), which are currently under assessment.

Returning to simple regression models with T as the sole variable, it is well known that energy use in buildings often exhibits a three parameter change-point behavior (Fels, 1986; Ruch and Claridge, 1991; Kissock et al., 1992 a & b). In residential buildings, where concurrent heating and cooling is typically not required, the presence of a three parameter change point is easily explained by the thermostatically controlled heating or cooling system (Fels, 1986). In commercial buildings, this simple explanation does not always suffice. This is because interior zones may require cooling while the exterior zones may call for heating. This, coupled with the facts that latent loads become substantial during hot, humid days and that HVAC supply air temperatures are often controlled (or reset) non-linearly with ambient temperature, results in four parameter change-point behavior.

Temperature driven regression models adopted for LoanSTAR analysis can be subdivided into three groups (See Figure 4.3):

(a) Mean or one-parameter models, (for example, air handler electricity use for constant volume dual duct systems in buildings is reasonably independent of weather, and a mean daily value has been found to be adequate for most commercial buildings; in the LoanSTAR program);

$$E = \alpha_1 \quad (4.3)$$

(b) One parameter linear regression models for cooling and heating energy use

$$E = \alpha_1 + \alpha_2 T \quad (4.4)$$

(c) Segmented linear regression models, which can be further sub-divided into:

- Three-parameter or PRISM change-point models (Fels, 1986)

$$E = \alpha_1 + \alpha_2 (T - \alpha_3)^+ \quad (\text{heating}) \quad (4.4)$$

$$E = \alpha_1 + \alpha_2 (\alpha_3 - T) \quad (\text{cooling}) \quad (4.5)$$

- Four parameter or 4-P change-point models (Ruch and Claridge, 1991)

expressed as:

$$E = \alpha_1 + \alpha_2 (T - \alpha_4)^- + \alpha_3 (T - \alpha_4)^+ \quad (4.6)$$

where

(⁻) indicates that the quantity within the parentheses should be set equal to zero when it is positive (i.e., negative only values are permitted),

(⁺) indicates that the quantity within the parentheses should be set equal to zero when it is negative (i.e., positive only values are permitted),

In the four parameter model when α_1 is the energy consumption at the change point temperature, α_2 and α_3 are the cooling and heating slopes (Figure 4.4). In the four parameter model when α_3 is constrained to be zero, we get the three-parameter change point model, which is the basis of the heating-only or cooling-only PRISM model (Fels, 1986). In this light, the three-parameter model can be viewed as a special (but important for residential buildings) case of the more general 4-P model.

Identification of model types (a) and (b) is relatively straightforward and can be done in standard packages (for example, we use SAS, 1989 and STATGRAPHICS, 1991). Though linear segmented models are special cases of a much larger set of models, called spline functions (Pindyck and Rubinfeld, 1981), these commercial packages do not allow segmented linear regression modeling to be investigated in a framework convenient enough for building energy analysis. This is because the change point needs to be known and specified in order to use classical spline regression. Because this is not known a priori for buildings (in fact, this is one of the parameters being identified by regression), these commercial packages fall short of the necessary analysis.

Another deficiency in these packages is the lack of proper error diagnostics for spline regression models. Consequently, specially written computer programs, like PRISM (Fels, 1986) or in-house LoanSTAR programs, like 4-P (Ruch and Claridge, 1991) or EModel (Kissock et al., 1993), are used. The computational algorithm of the 4-P model involves a search method where the residual sum of squares over each of the two segments is computed separately for each incremental variation in the change point temperature. These two values of the sum of squares are then added together. The particular value which minimizes this sum is said to correspond to the sought-after change-point temperature (Ruch and Claridge, 1991), as shown in Figure 4.4. Extensions

and improvements in the 4-P model to handle both single variable and multi-variable cases are currently also being studied.

4.4 Allied Issues Regarding Modeling

4.4.1. Effect of Short Pre-retrofit Data Sets

Ideally, a full year or more of energy use and weather data should be used to construct regression models. The data can then be said to contain the entire range of variation in both climatic conditions and operating modes of the building and HVAC system. However, in many cases, a full year of data is not available and one is constrained to develop models using less than a full year. How temperature-dependent regression models of energy use fare in such cases is discussed by Kissock et al. (1993). The first step was to construct temperature-dependent linear regression models of daily energy use from one-, three-, and five-month data sets. Then the annual energy use predicted by these models was compared to the annual energy use predicted by a model based on an entire year of data.

It was found that annual heating energy use can be more than 400% greater than the annual energy use predicted by models from short data sets. In addition, in the climate of Central Texas, models of heating energy use have prediction errors 4-5 times greater than those of cooling energy models.

Two characteristics of data sets that influence their ability to predict annual energy use were identified:

(a) As expected, longer data sets provide a better estimate of annual energy use than shorter data sets. In the sample of buildings chosen, the average cooling prediction error of short data sets decreased from 7.3% to 3.0% and the average annual heating prediction error decreased from 27.5% to 12.9% as the length of data sets increased from one month to five months.

(b) More important than the length of the data set, however, was the range of outdoor temperatures represented by it. Cooling models identified from months with above-average temperatures tend to over-predict annual energy and vice-versa. The converse seems to hold for heating models. Either way, limited temperature ranges represented in short data sets can lead to large errors in energy use predictions.

The best predictors of both cooling and heating annual energy use are models from data sets with mean temperatures close to the annual mean temperature. The range of variation of daily temperature values in the data set seems to be of secondary importance. One-month data sets in spring and fall, when the above condition applies, are frequently better predictors of annual energy consumption than five-month data sets from the winter or summer periods.

4.4.2. Uncertainty in Savings Determination

In statistics, ascertaining the uncertainty of a prediction is as important as the prediction itself. Hence determining the uncertainty in our retrofit savings estimate is imperative. Model identification has a direct bearing on determining the uncertainty because the same issues equally affect the nature and magnitude of errors. The uncertainty in savings can be attributed to measurement errors (both in the independent and dependent variables) and to errors in the regression model. The former are usually well known to engineers and the methodology of estimating their effect can be adequately covered using classical engineering textbooks, for example, Bendat and Piersol (1986). Errors in regression models, on the other hand, are more complex and arise from several sources. Reddy et al.(1992) have classified these into three categories which are very briefly mentioned below:

- (a) Model prediction errors, which arise due to the fact that a model is never "perfect". Invariably a certain amount of the observed variance in the response variable is unexplained by the model. This variance introduces an uncertainty in prediction even when the range of variation in the regressor variable is within the range over which the model was identified.
- (b) Model mis-specification errors which are due to 1) inclusion or non-inclusion of certain regressor variables (neglecting humidity effects, for example); 2) assumption of a linear model when the physical equations suggest non-linear interaction among the regressor variables; and 3) incorrect order of the model, i. e., either a lower order or a higher order than the physical equations suggest.
- (c) Model extrapolation errors, which arise when a model is used for prediction outside the region covered by the original data from which the model has been identified.

It is difficult to handle category (c) in a purely statistical manner. Insights gained from studies such as that described in section 4.4.1 are the only way that such effects can be reduced. The net effect of categories (a) and (b) is often improper residual behavior which may partially or even entirely invalidate the major assumptions made during least-squares regression, namely that the residuals have: 1) zero mean; 2) constant variances, i.e., heteroscedasticity is not present; 3) a lack of correlation, i.e., no serial correlation or autocorrelation is present; and 4) a near-normal distribution.

The method of least squares can be used to estimate the parameters in a linear regression model regardless of the form of the distribution of errors, and so the last assumption 4) is not relevant in our current savings calculation methodology. Assumption 1) is also not a serious criterion because it is satisfied in most cases. The normal method for dealing with heteroscedasticity is to perform a weighted regression with the observations inversely weighted with their variance (Draper and Smith, 1981). Data from the individual LoanSTAR buildings do not seem to generally exhibit strong heteroscedasticity, and consequently this issue may also be overlooked.

Most of the models developed at the daily time scale seem to suffer from autocorrelated residual behavior. The practical implications of neglecting serial correlations in the data are that equations presented in elementary statistical textbooks for model prediction uncertainty will underestimate the true model uncertainty. We would then be placing more confidence in our savings estimates than is strictly warranted. A study by Ruch et al.(1993) has addressed this issue and suggested that a hybrid model of ordinary least squares (OLS) and an autoregressive (AR) model be used, which, though akin to OLS in predictive ability, has much more realistic error diagnostics than OLS. The statistical theory of the hybrid model approach developed from fundamental statistical concepts and described in Ruch's paper is validated with measured data from four buildings. In every case, the hybrid model provided far more accurate error estimates of the model prediction than did ordinary OLS. The flow chart summarizing the model fitting procedure is shown in Figure 4.5.

4.4.3. Simplified Systems Model Approach

In some buildings, the pre-retrofit monitoring data period was so short that a proper statistical model could not be developed. Even more drastic was the fact that, in a couple of buildings, retrofits were completed before the monitoring instrumentation was even installed. Hence, the simplified calibrated model (Katipamula and Claridge, 1993) was developed which is based on the ASHRAE TC 4.7 Simplified Energy Analysis Procedure (SEAP). This method, as illustrated by Figure 4.6, involves developing one model for the dual-duct variable air volume (VAV) and one model for the dual-duct constant air volume (CAV) system. If no pre-retrofit data are available, the VAV model is first calibrated (i.e., its input parameters tuned so that model-predicted hourly energy use fits the hourly measured energy use as closely as possible) with the post-retrofit monitored data. The calibrated loads from the post-retrofit VAV model are then used with the CAV model to predict the energy use of the building in the pre-retrofit condition. Savings are then calculated by comparing the results of the CAV-predicted energy to the VAV predictable energy use.

Figure 4.7 is a schematic of how the simplified model views the interaction between the HVAC system and the building zones. The building is divided into two zones: an exterior or perimeter zone and an interior or a core zone. The core zone is assumed to be insulated from the envelope heat losses/gains, solar heat gains, and infiltration heat loss/gain; the conduction gains/losses from the roof are lumped with the external zone. Given the internal load schedule, the building description and the climatic parameters, the building loads can be estimated for each hour of the day and for as many days of the year as is needed. Subsequently, using parameters describing HVAC control and operation (hot or cold deck temperatures, economizer cycles, etc.), the heating and cooling energy use of the building are estimated. The simulation process is sketched in Figure 4.8.

4.4.4 Mixed billing and monitored data

Another approach, this one statistical rather than engineering model-based, has been developed (Liu et al., 1992) to determine savings under special circumstances, called mixed billing and hourly monitored data. Such circumstances arose in two schools, and

similar retrofits in many more schools are underway, hence the need to devote time and effort to handle such cases. Here the monitoring began after part of the retrofit was already completed (which is not an uncommon occurrence). Specifically, a gas-based absorption chiller was replaced by a vapor compression chiller which supplemented the cooling provided by already existing roof-top units. Monitoring began after the chiller retrofit was completed. However, after a few months an additional retrofit was made, namely an EMCS was installed. Hence, gas use in the school decreased, but use and demand of electricity increased due to the chiller retrofit which, however, was tempered by the EMCS system. The objective of the analysis is to determine the energy savings due to chiller retrofit and due to the EMCS individually. The methodology involves developing statistical models for each energy type which are then calibrated for the strong seasonal schedules present in schools using gas and electric utility billing data. The methodology is currently being refined but preliminary indications are positive.

Figure 4.1: Pump and Air-handler Electricity Use at LoanSTAR Building. The pre-retrofit, construction and post-retrofit periods are clearly identified by changing energy patterns.

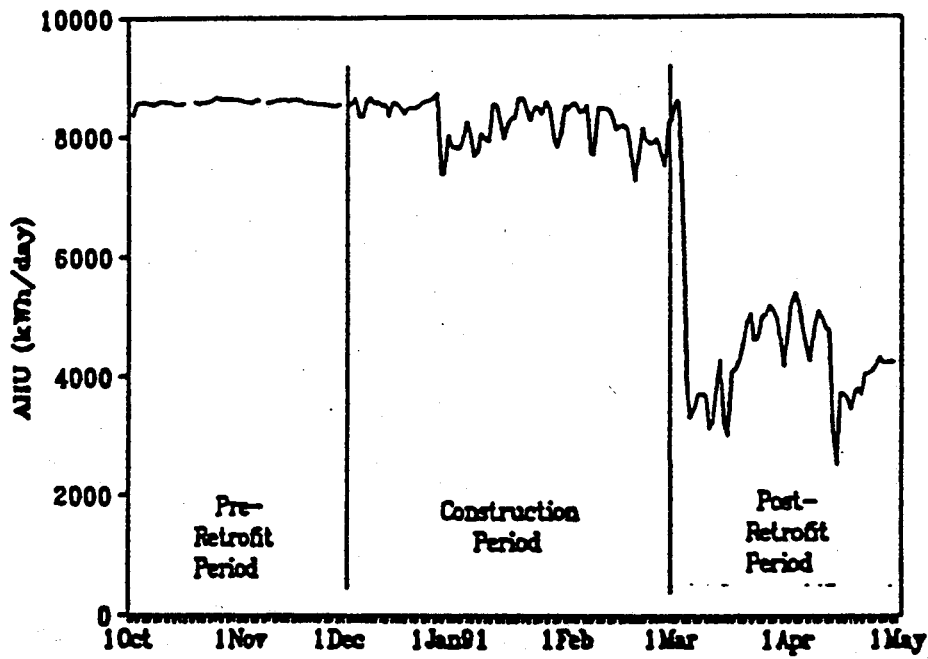


Figure 4.2: Pre-Retrofit Chilled-Water Use with Model and Savings.

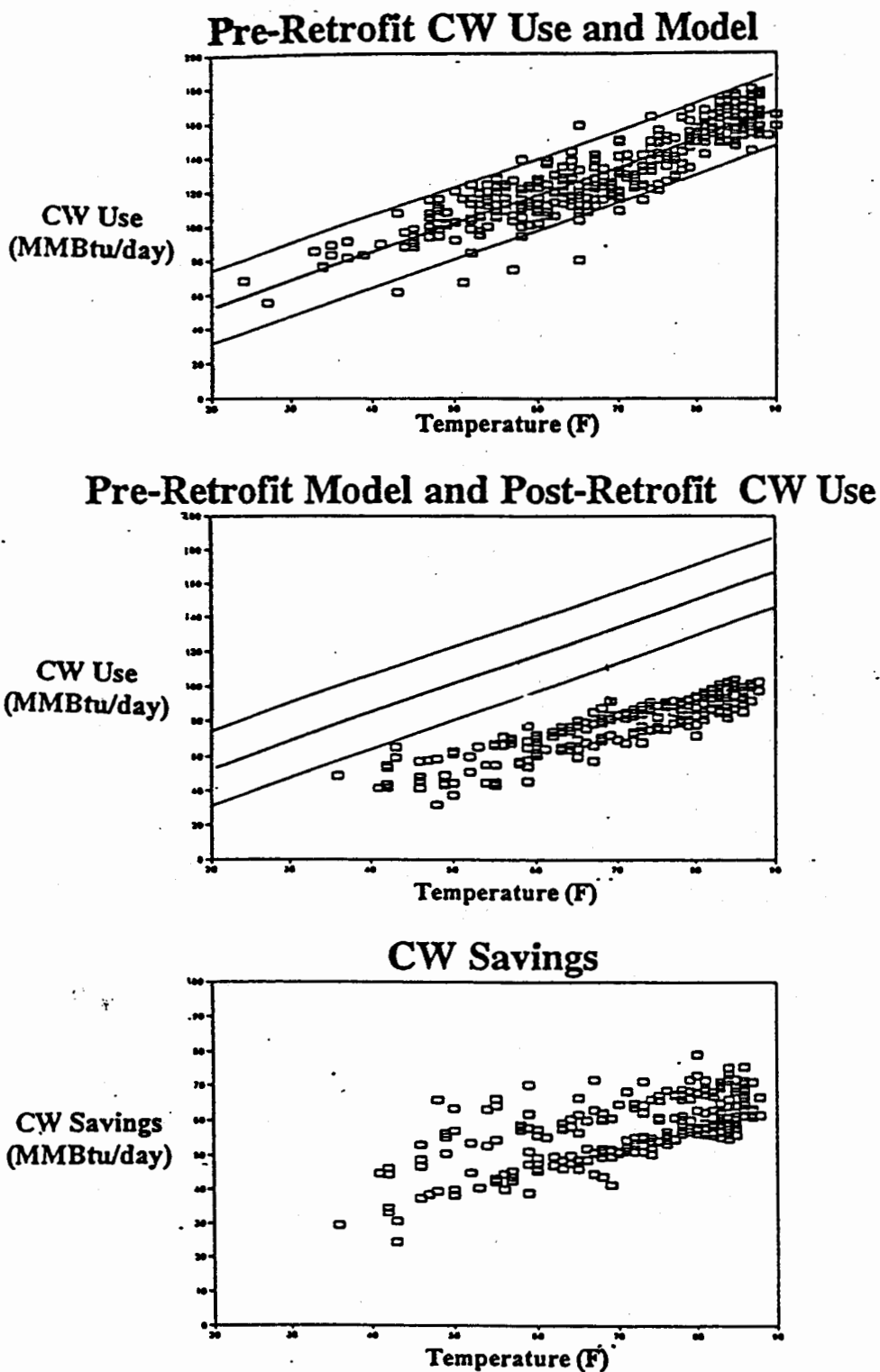


Figure 4.3: One, Two and Four Parameter Baseline Models for Savings Measurements.

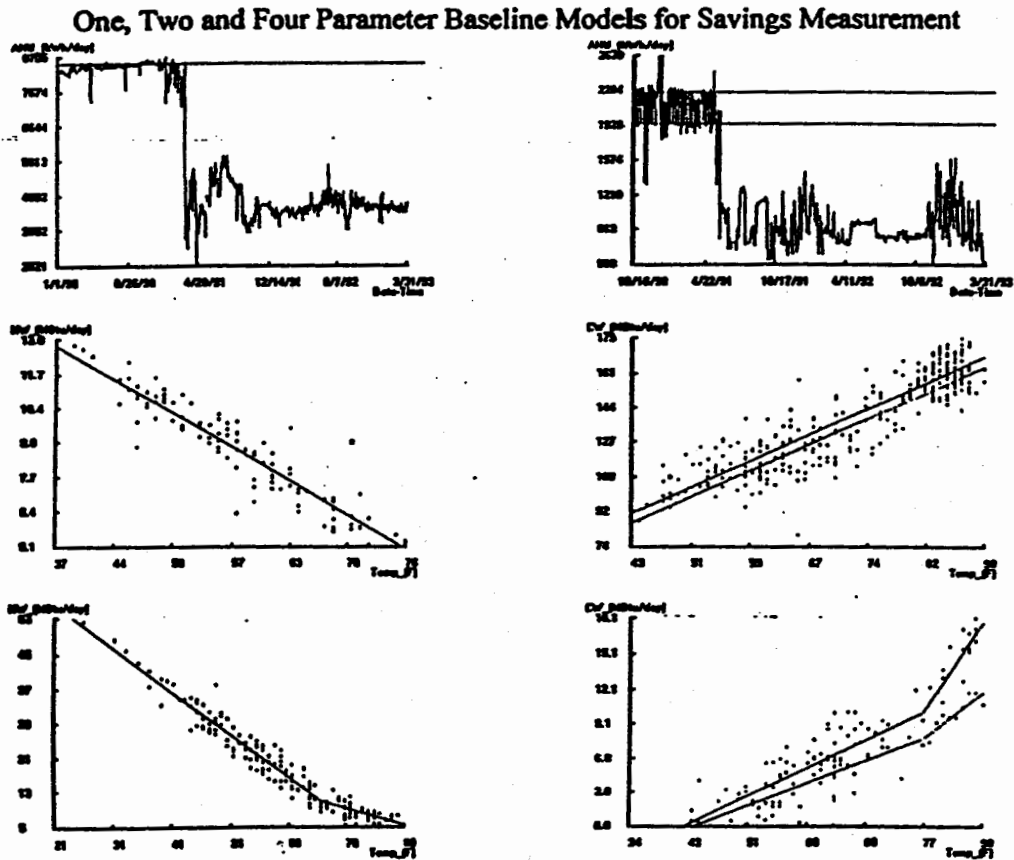


Figure 4.4: Examples of Four-parameter Change-point Models for Hot Water and Chilled Water Energy Use.

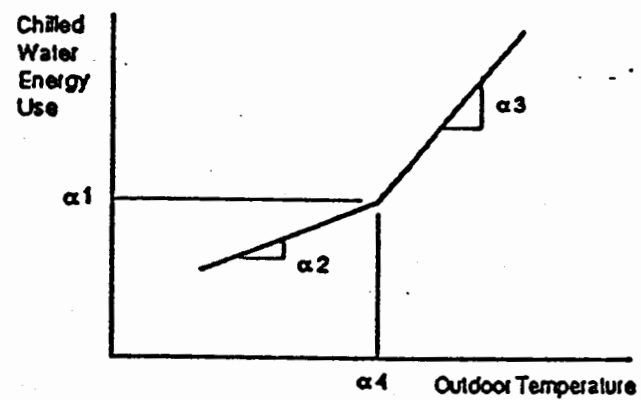
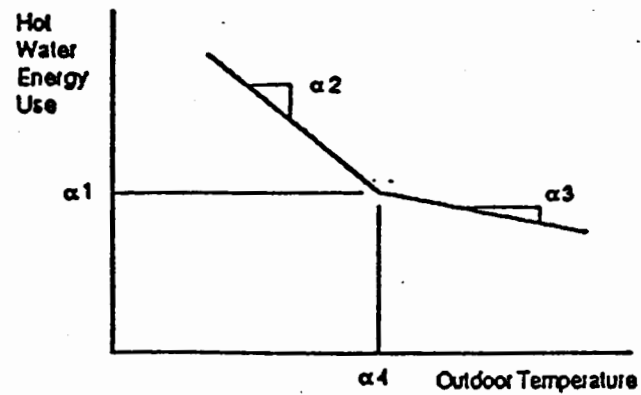


Figure 4.5: Flow Chart Summarizing Model Fitting Procedure.

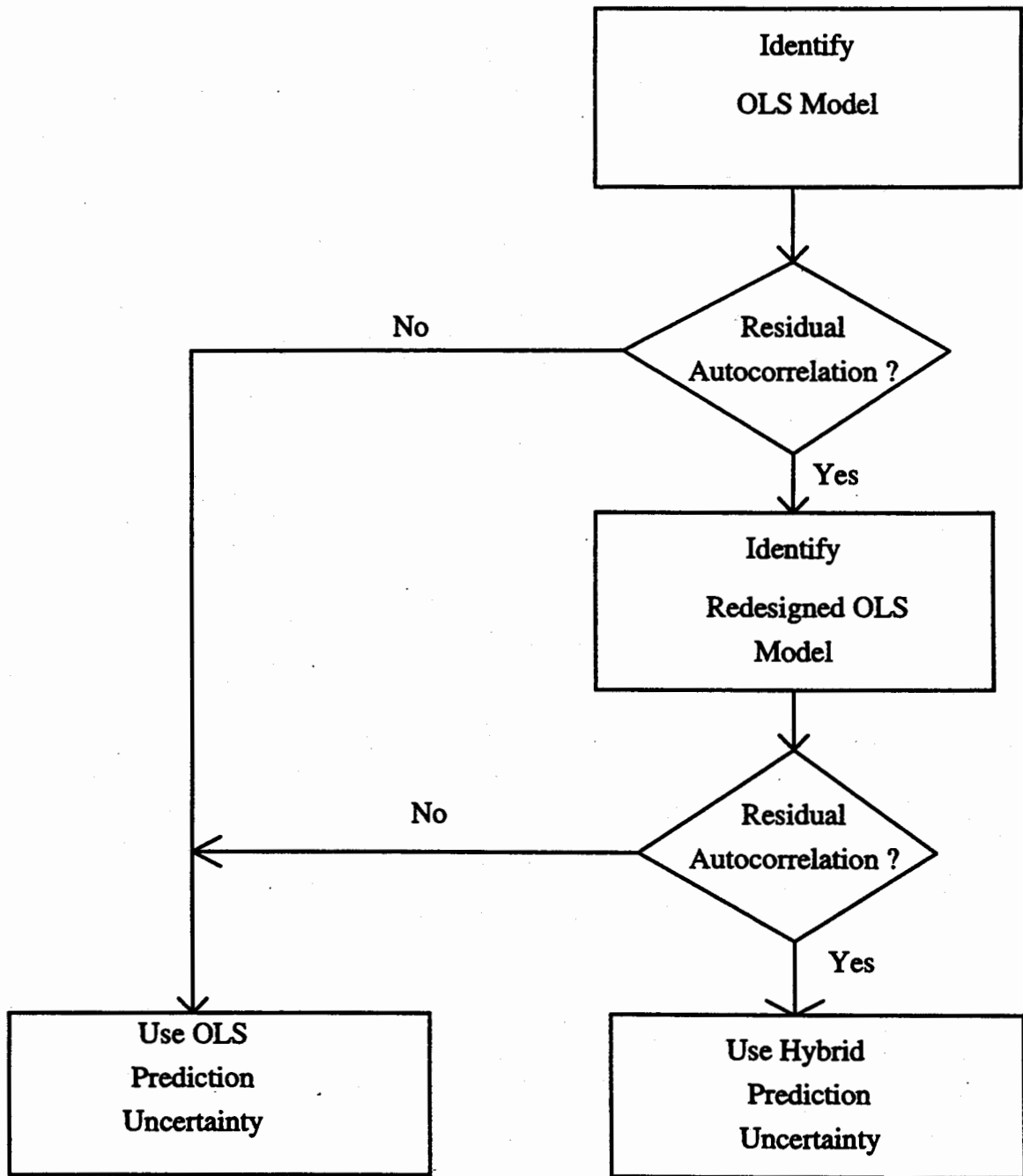
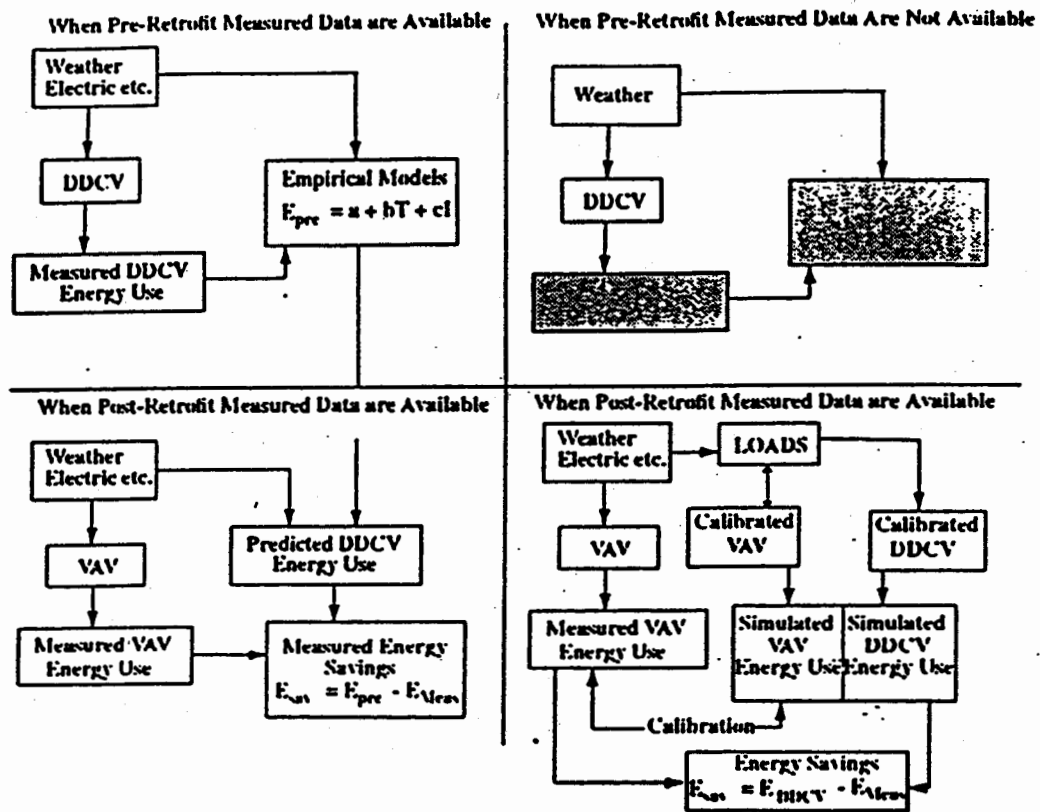


Figure 4.6: Schematic of Simplified Systems Model Approach.



DDCV = dual-duct constant volume air handler
 VAV = variable air volume air handler

Figure 4.7: Schematic of the HVAC and Building Zone Interaction Assumed in the Simplified Systems Model Approach. Zone E denotes the exterior zone of the two-zone building while zone I is the interior zone.

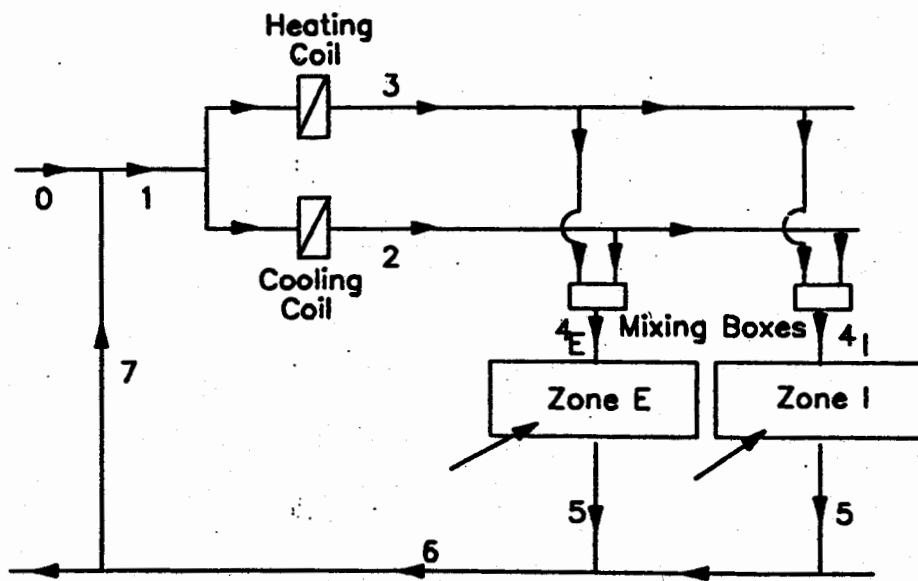
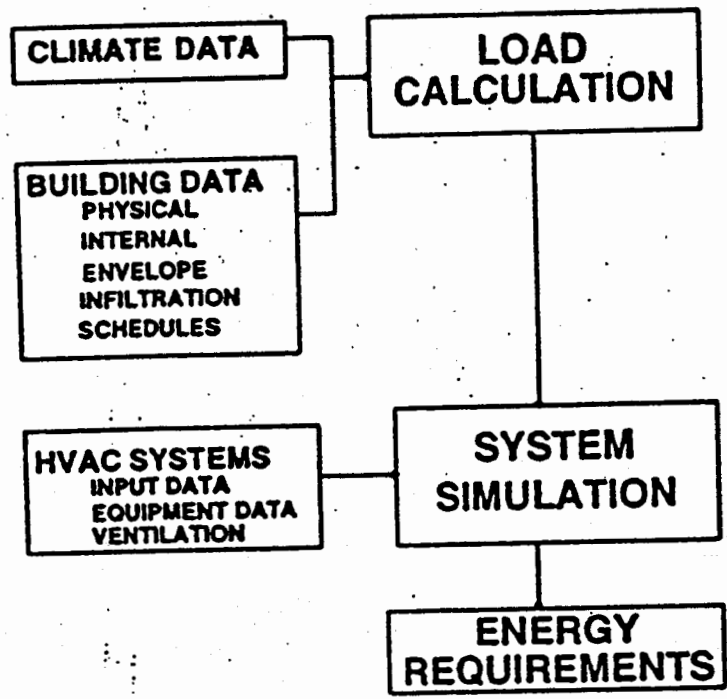


Figure 4.8: Schematic of the Simulation Procedure.



5.0 RESULTS FROM THE FIRST TWO YEARS OF MONITORING

5.1 Verifying Energy and Audit Dollar Savings of Retrofits

The objective of this section is to describe the savings verification methods used in the LoanSTAR program, to present the retrofit savings currently realized in LoanSTAR, and to compare audited to measured savings.

5.1.1 Energy Savings

The cumulative savings in dollars from the 24 LoanSTAR sites reporting savings, as of March 1993, is shown pictorially in Figure 5.1 for each energy type. Additional statistics are given in the table attached to Figure 5.1. The following points are noteworthy:

(a) Until March 1993, measured savings were close to \$ 4.5 million, of which 34.4% were in electricity savings, 43.8% were in cooling energy, and the rest in heating energy.

(b) The audit estimated savings and the measured savings of electricity and heating energy are very close--within 5%, with measured savings being surprisingly higher. In fact, measured cooling energy savings are much higher still, close to 100% more than the estimated value. This unexpected positive difference is difficult to explain satisfactorily, but it is undeniable that part of the cause was the incessant vigilance exhibited by the LoanSTAR analysts in pointing out operation and maintenance (O&M) problems to concerned building operators as soon as the problems appeared.

Table 5.1 depicts how the measured and audited energy savings for electricity, chilled water, and hot water compare on an individual basis for each of the buildings where savings are currently reported. We note that though audit and measured savings are close for the entire set of 24 buildings, there are large variations on an individual basis, as can be attested to by the ratio of measured to audit savings columns. More detailed investigation is required in order to ascertain why such differences have occurred.

5.1.2 Demand Savings

The audit estimates did not include demand savings benefits while evaluating cost effectiveness of a certain retrofit. We found that the reduction was substantial, close to 2 MW for the 24 LoanSTAR buildings where savings reported as of March 1993. Figure 2.6 presented in Section 2 depicts how this demand reduction was distributed between HVAC, lights and thermal storage retrofits. We note that 60% of the demand savings came from airside retrofits to the HVAC systems, 37% from lights, and 3% from thermal storage.

Figure 5.2 depicts electric demand reductions in 12 of the retrofitted LoanSTAR sites. The demand numbers refer to maximum hourly use during the year (because LoanSTAR

data are monitored hourly), which is not exactly consistent with the way utilities charge customers. Figure 5.3 shows the extent to which energy use normalized by building floor area, described by the annual energy use index (AEUI) and measured in kWh/yr/sf, has been reduced as a result of the retrofits. The two sites having the smallest savings, BUS and UTH, have had a change in operating mode in the post-retrofit period whereby the building is shut down at night. When the HVAC system comes on in the morning, it experiences a momentary spike in energy demand not present in the pre-retrofit period, which negates to some extent the demand benefits due to the retrofit.

Figure 5.2 expresses the same demand reduction as a fraction of post-retrofit air-handler demand to pre-retrofit demand. Other than four sites, namely BUS, UTH, NUR and WAG, the average demand reduction is about 30%. BUS and UTH have had a change in operation mode as described earlier, while problems with the heating coils were identified in NUR and WAG. Thus, we can conclude that if the building and the HVAC system are operated properly, one could expect demand savings of about 30% due to the air-side retrofits.

5.2 Reducing Energy Costs by Identifying O&M Problems

During the past 1½ years, the LoanSTAR operations and maintenance (O&M) group has conducted studies at six agencies participating in the LoanSTAR program to determine the effects of operations and maintenance on energy costs. The six agencies represent a total of 65 buildings with usages that include office buildings, schools, libraries, hospitals, and multi-purpose university buildings. Using the LoanSTAR Monitoring and Analysis Program (MAP) as a starting point, a methodology was developed to determine potential O&M savings at these sites. This methodology has been applied to six sites in the LoanSTAR program, which include the Texas State Capitol Complex, the University of Texas at Austin, the University of Texas at Arlington, the Fort Worth Independent School District, the Zachry Engineering Building at Texas A&M University, and the University of Texas Medical Branch at Galveston. A total of over \$1.75 million in potential O&M savings has been documented and reported to the above agencies. It should be noted that all sites, with the exception of the Texas State Capitol Complex, have had retrofits fully implemented.

The metering and monitoring aspects of the LoanSTAR program played a key role in helping the O&M staff recognize potential savings opportunities at each site. The primary form of formal feedback to facility engineers and building operators is the Monthly Energy Consumption Report (MECR). In addition, weekly inspection plots (IPNs) are generated in-house for data quality control but also allow the O&M engineers to document the positive results of changes in building operations patterns on a very short term basis, thus providing immediate feedback to the building operators.

Based on both the MECR and the IPN reports, the O&M staff has been able to discern a number of things that lead to potential savings: First, what is the minimum baseline load in the building and can it be lowered without compromising occupant comfort or productivity? Second, how does the actual consumption plot compare with a normalized

or “ideal” consumption curve? Third, does the plot indicate higher nighttime usage on weekends when compared to weekdays? Finally, have there been any abrupt increases in building energy consumption since the last report? Our case studies found examples of each of the above conditions, which were then reported to the building operators.

Another key indicator of potential O&M opportunities, as reported in the MECR, is the comparison of pre-retrofit audit predicted savings with post-retrofit measured savings. We have experienced instances of post-retrofit savings not meeting predicted savings. In one case study we found potential O&M savings far in excess of those originally predicted due to a lighting retrofit. Once a building or site was identified as having O&M savings potential, a formal procedure was followed. Figure 5.4 displays a flow chart for the O&M Identification Procedure.

Based on the data provided by the weekly polling and presented in the IPN, a field engineer would telephone the site contact and point out the possibility of O&M savings. In some instances the site contact would initiate the call to the O&M field engineer. The O&M Follow-up Procedure, after a problem is identified, includes:

- Research site from IPN, MECR, AECR, site notebook and audit report
- Telephone site contact and advise of O&M potential
- Mail or fax supporting data
- Site visit
 - Interview operator
 - Conduct daytime walk-through
 - Conduct nighttime walk-through
 - Perform short term test
- Analyze data
- Write report
- Present report
- Follow-up report

Operational and maintenance recommendations (O&Ms) are actions taken by building operators, as part of their regular duties to reduce energy costs. Typically, they are relatively inexpensive (low cost or no cost) to implement and can save hundreds, even thousands of dollars worth of energy after implementation. During the course of our case studies at the six aforementioned sites, numerous O&Ms were identified and are reported in Table 5.3.

Table 5.3 breaks down the identified O&M opportunities into four separate categories: they are lighting, equipment operation, occupant habits and administration. These findings were documented and reported back to the building operators, who have taken steps to implement the O&M opportunities. In all cases they have been provided

with graphical feedback to affirm the results of their actions, which includes data documenting their energy cost savings.

Table 5.4 is presented as a summary of the sites studied to date. The number of buildings at each site and the total square footage of the buildings are provided in the table. Potential O&M savings are also provided for each site. In some instances, annual utility costs were not available due to the fact that individual building metering does not apply because of central campus/complex metering. However, annual energy costs from LoanSTAR measured data are included in the table. Finally, the percentage of annual O&M savings compared with annual energy costs is presented.

As was mentioned previously, all the sites have had retrofits completed, with the exception of the State Capitol Complex. The potential O&M savings range from a low of \$20,000 per year to a high of \$550,000 per year. In terms of percentage of annual energy costs, the range of O&M savings is from 5.0% to 25.9% of annual energy costs, with an average of 15.2% for all the sites.

Clearly, the no cost or low cost O&M opportunities that exist at each site can have a significant impact on energy cost reduction.

Table 5.1: Comparison of Audit and Measured Savings on an Individual Building Basis for the 24 Buildings Currently Reporting Savings as of March 1993.

Site I.D.	Months of Post Retro-fits	Electricity		Cooling Energy		Heating Energy		Total	
		Measured Savings (\$ x 10 ³)	Ratio of Measured to Audit savings	Measured Savings (\$ x 10 ³)	Ratio of Measured to Audit savings	Measured Savings (\$ x 10 ³)	Ratio of Measured to Audit savings	Total Measured Savings (\$ x 10 ³)	Ratio of Measured to Audit savings
1	29	87	0.77	149	0.58	124	1.09	360	0.74
100	23	236	1.1	197	4.1	27	0.47	460	1.44
101	30	137	1.03	114	1.52	58	0.75	309	1.08
102	30	434	2.58	775	2.88	500	1.21	1709	2.02
118	27	24	0.8	42	2.1	14	0.93	80	1.23
119	22	34	0.62	17	0.85	10	1	61	0.72
105	23	18	0.49	22	1.16	10	0.91	50	0.75
106	22	108	2	99	2.61	-53	-	154	1.15
107	23	50	0.6	77	2.2	11	0.61	138	1.01
108	24	54	0.73	56	1.3	-10	-	100	0.7
114	21	71	0.8	156	5.2	81	4.5	308	2.25
115	23	-	-	7	0.78	4	0.8	11	0.79
116	22	50	1.56	24	0.45	32	0.72	106	0.82
117	26	24	0.83	60	4	47	7.83	131	2.67
111	22	12	0.19	16	0.4	0	0	28	0.25
112	20	8	0.15	25	0.7	11	0.37	44	0.38
113	22	37	0.46	49	1.23	18	0.51	104	0.67
124	23	111	0.78	0	0	0	0	111	0.78
130	8	19	0.48	40	20	5	-	64	1.52
126	15	-22	0.49	0	N/A	45	0.64	23	0.92
127	15	-3	0.11	0	N/A	20	0.51	17	0.81
128	17	10	0.63	0	N/A	0	N/A	10	0.63
129	17	8	0.89	0	N/A	0	N/A	8	0.89
145	10	8	0.73	0	N/A	0	N/A	8	0.89
ALL	-	1515	1.01	1925	1.84	9504	0.92	4394	1.23

Table 5.2: Energy Conservation Identified in Buildings Monitored Under LoanSTAR Program as of May 1993.

Purchased Utility Category	Site Energy	Site Energy** (million Btu/yr)	Source Energy * (million Btu/yr)	Fractional Site Energy Savings (%)	Fractional Source Energy Savings (%)
Electricity	113,282,528 (kWh/yr)	386,520	1,314,077	26.6	52.9
Natural Gas	305,274 (MCF/yr)	314,432	314,432	21.7	12.7
Steam/Hot Water	318,237 (million Btu/yr)	318,237	424,316	21.9	17.1
Chilled Water	35,986,682 (ton-hr/yr)	431,840	431,840	29.8	17.4
Totals		1,451,029	2,484,666	100	100

**Btu savings calculated on the basis of site Btus (i.e. 3,412 Btu/kWh, 1,030,000 Btu/MCF and 12,000 Btu/ton-hr)

*Btu savings calculated on the basis of source Btus (i.e. 11,600 Btu/kWh, 1,030,000 Btu/MCF, boiler efficiency of 75% and 12,000 Btu/ton-hr)

Table 5.3: O&M Opportunities identified at six sites.

O&M Opportunities Identified at Six Sites

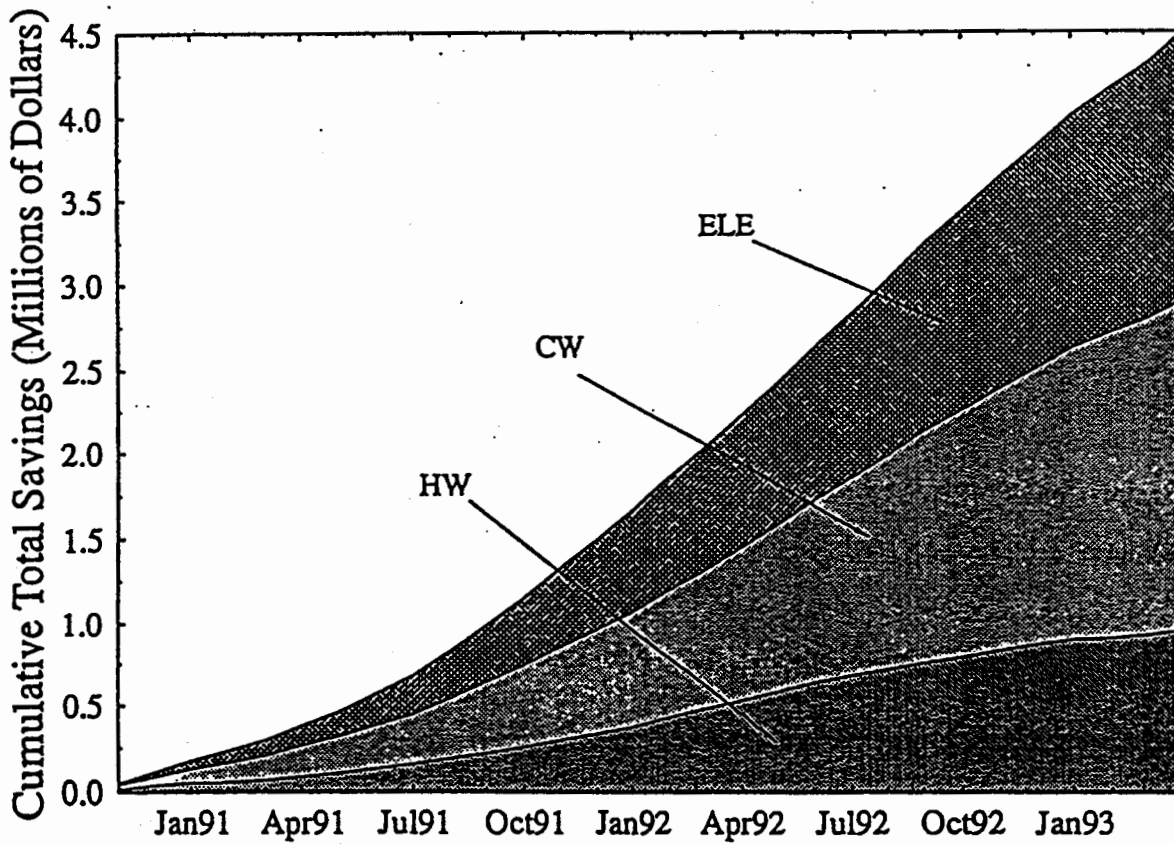
O&M Opportunity Identified	Location Where Applicable
Lighting	
Lighting Control	All sites except U.T. Austin
Delamp or reduce lighting levels when in excess of IES standards	Capitol Complex, U.T. Arlington and UTMB Galveston
Convert incandescent to compact fluorescent	All sites
Equipment Operation	
Change zone HVAC set points	Capitol Complex and UTMB Galveston
Raise AHU cold deck temperature	Capitol Complex and UTMB Galveston
Lower AHU hot deck temperature	Capitol Complex and UTMB Galveston
Turn off AHUs at night	Capitol Complex, Ft Worth ISD and U.T. Arlington
Turn off HW pump in summer	ZEC and WBT at the Capitol Complex
Repair leaky pipes, valves, and/or ductwork	SFA at the Capitol Complex
Turn off steam valve during summer	PCL at U.T. Austin
Disable economizer cycle	NUR at U.T. Austin
Occupant Habits	
Turn off PCs and office machines	All Capitol Complex Buildings
Turn off lights	All sites except U.T. Austin
Administrative	
Verify EMS operation, reprogram if necessary	Ft Worth ISD, GAR,RAS at U.T. Austin
Optimize custodial operations in the evenings	All Capitol Complex and Ft Worth ISD

Table 5.4: Summary of Potential O&M Savings at Six LoanSTAR Sites.**Summary of Potential O&M Savings at Six LoanSTAR Sites**

Site	No. of Buildings	Total Sq. footage	Annual energy costs \$/yr	Potential O&M savings \$/yr	O&M savings % of Annual energy costs
Capitol Complex	8	2,243,746	4,261,188	486,300	11.4
U.T. Austin	4	694,579	978,776	143,900	14.7
U.T. Arlington	3	496,350	452,376	80,000	17.7
Ft Worth ISD	44	2,410,740	2,123,773	550,000	25.9
Zachry Eng. Bldg.	1	324,400	403,336	20,000	5.0
UTMB Galveston	5	758,751	3,596,348	512,420	14.2
TOTAL/AVE	65	6,928,566	11,815,797	1,792,620	15.2

Figure 5.1: Cumulative Savings from LoanSTAR Retrofits: March 1993.

Cumulative Savings From LoanSTAR Retrofits: March 1993



	Electricity	Chilled Water	Hot Water / Steam	Total
Measured Savings	\$1,514,000	\$1,925,000	\$956,000	\$4,395,000
% of Pre-Retrofit Use	16.4	34.3	41.4	25.8
% of Total Measured Savings	34.4	43.8	21.8	100
Audit Estimated Savings	\$1,483,000	\$1,049,000	\$1,039,000	\$3,571,000

Figure 5.2: AHU Electric Demand Reduction.

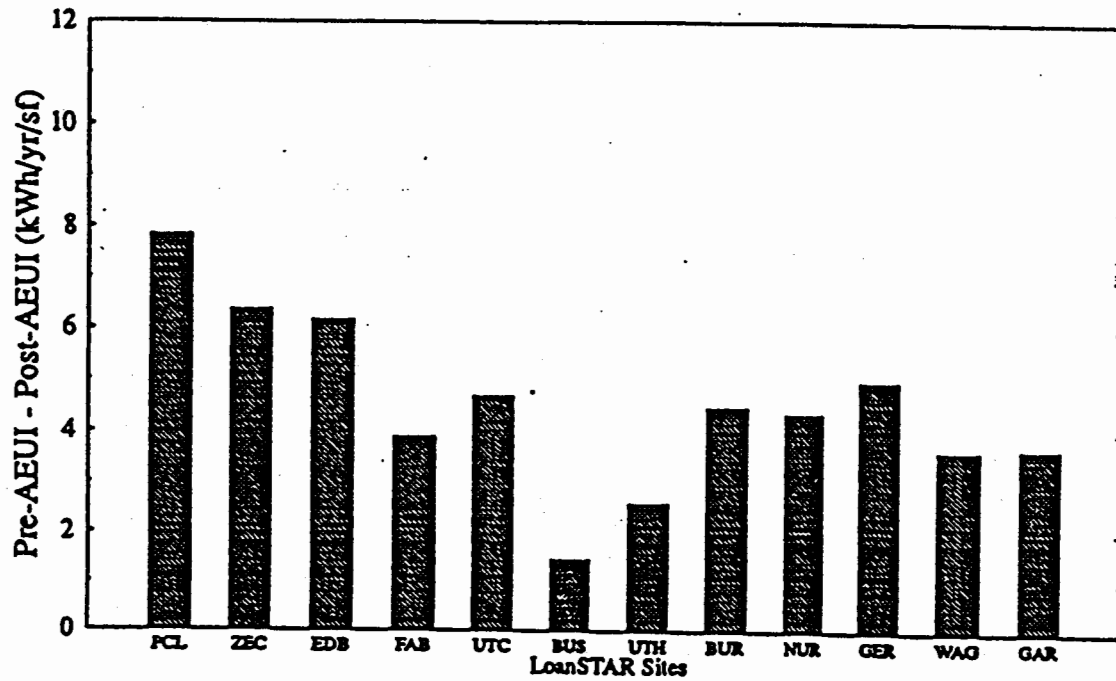


Figure 5.3: Electricity Energy Savings from HVAC Retrofits.

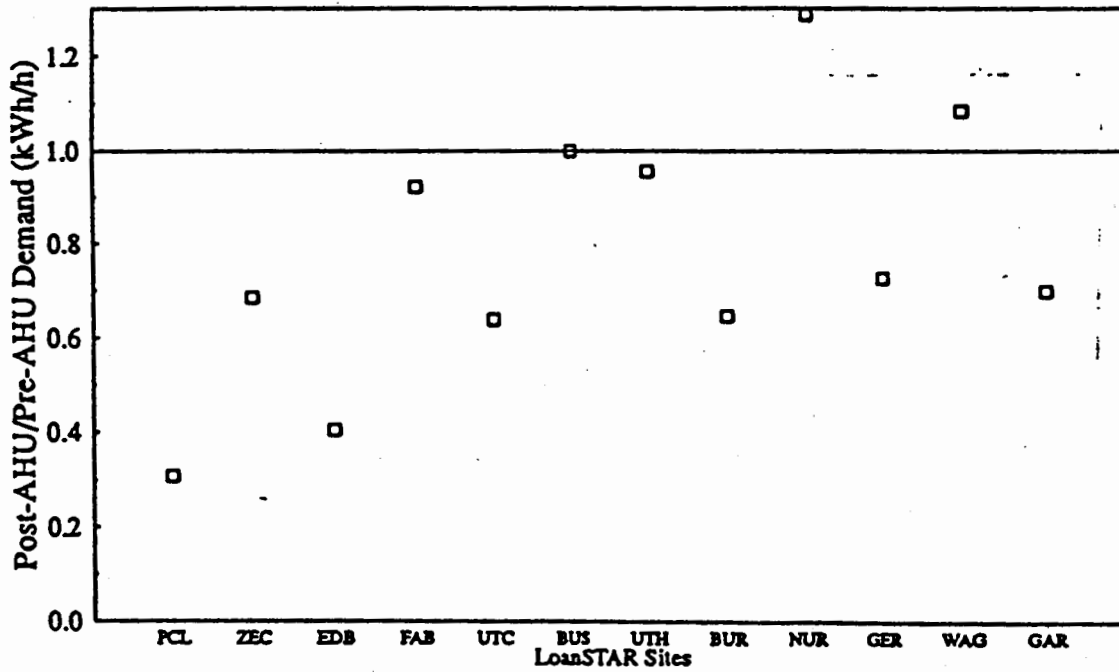
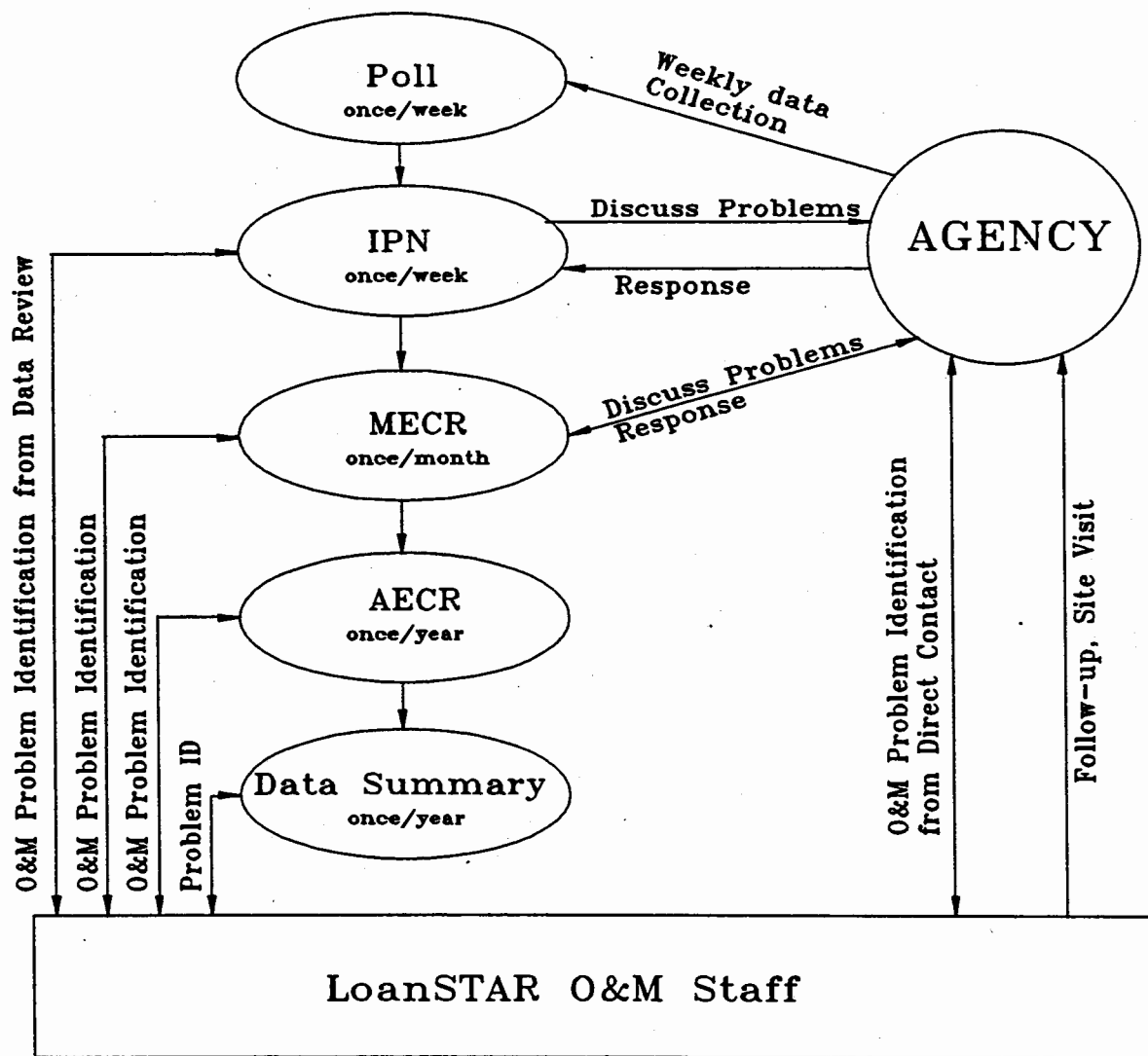


Figure 5.4: O&M Identification Procedure Flow Chart. This figure illustrates the procedure used in O&M identification.

O&M IDENTIFICATION PROCEDURE



6.0 RECOMMENDATIONS FROM THE FIRST TWO YEARS OF MONITORING

6.1 Recommendations from Task 1

The LoanSTAR program audit procedure was originally developed from the Institutional Conservation Program (ICP) procedure and format, which generally required an individual report for every building. Therefore, early LoanSTAR reports had individual sections for each building, which could easily be fit into the ICP format, if necessary.

As the program matured, detailed guidelines were written requiring more building and background information, much of which was intended to benefit the subsequent monitoring and analysis of the retrofits. Consultants were at first required to specify metering requirements to monitor retrofits, but this information was not used for a variety of reasons. Actual metering requirements are now determined entirely by the metering and analysis group at Texas A&M.

As efforts were made to simplify the audit process, the format was changed to an energy conservation reduction measure (ECRM) basis. The goal was to save both on audit cost and on time required to produce and review a report. Instead of repeating an ECRM write-up and calculation for each building, all building data could be compiled and calculated in just one ECRM. This saved effort and often substantially reduced the volume of the report by eliminating repetition. Much of the summary and background information was consolidated to single page table formats and the metering estimate requirements were eliminated.

An effort has been made to simplify the routine procedure even further. Energy saving measures, which are simple to calculate and widely implemented progressed to a fill-in-the-blank type form, referred to as Simplified Calculations (State Energy Conservation Office, 1990). Reference tables with common equipment data (e.g., electric motor efficiencies) and building data (e.g., U-factors) were provided with the forms in order to save consulting time and provide a standard reference base for calculations. The simplified forms have now been computerized into spread sheet programs known as SimpCalc (Apollo Data and Governor's Energy office, 1991) to further speed the process.

Other changes include categorizing ECRMs by degrees of complication. Category I ECRMs (shown in Table 6.1) are those measures whose energy savings are straightforward and paybacks are historically consistent. ECRMs in this category are based on estimated equipment quantities, with the annual cost savings to be determined by dividing the implementation cost by standard paybacks such as those in Table 6.1. Actual equipment numbers are determined for loan purposes by counts of installed or removed equipment made during or after the retrofit.

Category II ECRMs use the SimpCalc program or other approved simplified calculations. This program includes retrofits such as lighting conversions and controls, building ceiling/attic insulation, and window shading devices. Category III ECRMs require detailed calculations. This category includes complicated projects, which vary widely in either energy savings or implementation costs. These may include variable air volume (VAV) or variable frequency drive (VFD) conversions, chilling system conversions, energy management systems (EMSs), and rate schedule changes.

Accounting for dependencies is accomplished within in each ECRM (i.e., measure interactions). No independent calculations are required as was formerly the case (Governor's Energy Office, 1990). Several consultants informally estimated that this reduces reporting efforts by 10 to 30%.

A review of early program data showed that 19 of 43 reports had no (or negligible) dependencies, while 21 reports revealed dependencies that affected the calculations of cost savings by more than about three percent. In three reports, savings decreased by more than 10%.

O&Ms have been entirely eliminated from reporting requirements because the program's funding was designated for retrofits and O&Ms require little or no funding anyway.

Category I-type projects are also known as "direct install" projects. Basically, direct install projects are done with no calculation of energy or cost savings, and Texas A&M is evaluating LoanSTAR data to see if this approach can be extended to more complex projects than those described here for this Category.

6.2 Recommendations from Task 2

Administratively, many lessons have been learned about how to conduct and manage a large monitoring project. The focus of this section, lessons learned, is related specifically to the instrumentation. The presentation of the material is divided into three categories: 1) Equipment, 2) Installation, and 3) Maintenance.

6.2.1 Administrative Guidelines for Task 2

There are some administrative guidelines that should be passed on:

1. Installation guidelines should be written for each piece of instrumentation. A prototype monitoring system was installed approximately four months before the project started to allow for evaluation of difficulties of installation, costs, and hardware evaluation. Having a prototype was extremely useful. The feasibility of monitoring a large commercial building at a reasonable cost was demonstrated. Because of the success of the prototype installation and the need to quickly install monitoring hardware in the early phases of the project, it was decided to rely on the contractors' installation guidelines. Unfortunately, the procedures used by the different contractors resulted in non-uniformity in application of instrumentation.

The only solution was to make sure there was a uniform set of procedures for every installation regardless of contractor.

2. The installation subcontractor must have an engineer on-site during the metering installation. During our first contract year, several data acquisition system contractors were selected through a request for proposal (RFP) process. Only one of the contractors provided an engineer to supervise the installation of their metering projects. The others felt that an initial site visit by the project engineer to get their installing subcontractors (electrical, mechanical, etc.) started and a single follow-up visit to finish the assigned project was adequate. It was quickly determined that the supervision of the installation of this type of instrumentation has to be continuous during the project's duration. Numerous installation errors were made on the sites where no engineer was present. In some cases, these errors were not discovered until every sensor was manually checked and recalibrated. Equally disturbing was that when an electrical or mechanical subcontractor encountered a problem, work was often suspended until the project contractor could be reached, the problem described, and a solution developed. This process at times involved a delay of weeks on the project and incurred extraordinary travel costs.
3. Contractors should be assigned a "test" site to judge their capabilities. Even though contractors selected through the RFP process looked very good on paper, it was decided to assign each contractor a single test site so that an evaluation could be made on the quality of each one's actual installation. It became evident during this process which contractors were capable and which were not. At one of the installations, it became necessary to terminate the contract with the contractor even prior to the completion of the site.

6.2.2 Equipment Recommendations

In order to have a meaningful analysis of energy use data on buildings, it is critical that the instrumentation be reliable and provide accurate data on what is being measured. Unfortunately, instrumentation can provide a stream of numbers that may not reflect what is actually being measured. Equipment problems encountered in the first two years of this project have included instrumentation used in thermal metering, electrical measurement, and psychrometric measurements.

6.2.2.1 Thermal Metering

Thermal metering is required for most large commercial building applications where the building is purchasing chilled water, hot water, or steam. In addition, thermal metering may be applied where the user wants to track the efficiency of a chiller or boiler. For the majority of the sites on this project, it has been necessary to install the required transducers (typically thermistors and insertion flow meters) into the piping while the systems are operating. This requirement has made the thermal metering effort difficult and introduces room for more installation errors. These data points typically feed into a

thermal energy (“Btu”) meter, which processes the temperatures and flow rates to calculate the energy use. Some problems with thermal metering have included:

1. A thermal energy meter may pick up 60 Hz noise from its electrically noisy surroundings. In many building energy applications, a thermal energy meter and the instrumentation associated with it are located in an equipment room, which is an electrically “noisy” environment because of large pump and fan motors. If a turbine flow meter is connected to the thermal energy meter, the thermal energy meter will be expecting a signal from the flow meter, which many have a frequency component. We have seen instances where, with improper shielding, the only signal the thermal energy meter gets from the flow meter is a 60 Hz noise signal. The analyst may not even realize she or he has a problem because the total thermal energy may show a change from hour-to-hour because of fluctuations in the entering and leaving temperatures of the water. However, the actual thermal energy may be quite different than what is being measured. This problem is being further investigated at the Texas A&M Energy Systems Laboratory calibration facility (O’Neal, et al., 1990).

2. Two different brands of thermal energy meters most likely will not agree with each other. On one site, one brand of thermal energy meter that was installed according to the manufacturer’s recommendations was replaced by a second brand of thermal energy meter installed according to its manufacturer’s recommendation. The net result was that the “measured” thermal energy increased by an unexplained factor of two. Currently, both of these brands of thermal meters are being studied in our calibration facility to see if either of them is accurate.

3. A thermal energy meter that is not field scaleable can and will be set improperly at the factory. The initial brands of thermal energy meters utilized had to be set for a specific application at the factory. Information was provided to the factory on the type of flow meter, anticipated temperature difference, pipe size, maximum estimated energy, etc. The factory would then “burn in” a ROM for that particular application or install other hardware for that specific application. Often the estimate provided by the facilities personnel at a given site for the energy rate of the chilled or hot water line was off by factor of two to ten. Likewise, these personnel had only estimates of the pipe sizes and these were often wrong. There were also several meters delivered from the factory that had been incorrectly programmed. The net result was that the meters provided were not appropriate for the particular application. It was not unusual for the manufacturer of the thermal energy meter to tell us that it was going to take an additional four to six weeks to reprogram the meter. Hence, the LoanSTAR program now routinely installs field scaleable Btu meters.

6.2.2.2 Electrical Metering

For many building energy applications, electrical measurements are in many cases the only measurements made. The decision is often based on funds available for the metering installation and on the retrofits being installed in the building. Typically, these

measurements include whole-building feeds, motor control feed centers, individual motor loads, and lighting loads. Experiences with electrical measurements have included:

1. The marked polarity of current transformers (CTs) may be the opposite of its actual polarity. The polarity of CTs should be checked before installation. On a single phase application, a CT with a reverse polarity may be a nuisance (you'll get a negative power). However, on a three phase application, one CT with reverse polarity will cause major errors in the measured total power of the equipment that are difficult to detect when all three phases are added together.

In a recent application, we had one CT with reversed polarity on a 40 HP three phase variable speed motor. In another instance, a CT with reversed polarity was found on a 30 kW three phase variable speed motor. The CTs had been installed according to the manufacturer's instructions (i.e., with the arrow pointing toward the line). The indicated power of the motor was 1.5 kW, which did not make sense because of the size of the motor and the fact that it was running at 82% of its maximum speed. A close check of one of the CTs used to monitor the equipment revealed that the polarity was marked incorrectly. Switching the leads to the CT produced the correct total power of 20 kW.

2. The output of a current transformer may be far different from its rating. Much of the data acquisition equipment used in the monitoring studies utilizes a current transformer that produces a 333 mV output at its rated full load. Voltages of 3 and 10 Volts from some CTs that were clearly marked 333 mV output have been observed. Inputting 10 V instead of 333 mV into the data logging equipment has produced some very strange readings from the power channels in the data logger. One symptom was that the power signals for a fan load slowly decayed over time. The net result was that the bad CT not only affected the channel to which it was connected, but all power readings from that particular logger including readings from other channels. These problems have mandated the development of procedures to pre-check the polarity and output of CTs before being installed.

6.2.2.3 Other Instrumentation Problems

In some building applications, it is important to do measurements of the energy transfer into or out of the air stream. These data can be used to better simulate the air-side of the system. Lessons from experience in this area learned thus far include:

1. Some relative humidity instrumentation will be temperature dependent. While relative humidity instrumentation is not supposed to have any dependency on temperature, our experience has shown that specific brands of RH equipment do show a dependency on temperature. If the RH sensor puts out a 0 to 5 V signal, and is linear, one would expect it to generate a signal of 2.5 V for 50% RH whether the temperature is 10 C or 30 C. Some RH sensors have indicated that moisture was being added to the air across a heating coil (when, in fact, only sensible heat was being added). While a small error is acceptable, errors that far exceed the stated

measurement uncertainty of the transducer (typically $\pm 3\%$) are common. Closer inspection of the instrumentation has shown that, as the air temperature increases, deviation from the actual RH increases.

2. Relative humidity instrumentation may fail to perform adequately after only a few months of operation. Many of the RH sensors use a polymer element. If the humidity instrumentation becomes saturated (100% RH) for any length of time, this type of element does not seem to perform reliably afterwards. Particular applications where this will occur include placement of a RH sensor on the downstream side of a chilled water coil and in weather stations at locations where there are considerable periods (usually at night) when the air is saturated. Measuring relative humidity continues to be a problem. One solution has been to purchase enough RH sensors that each sensor in the field can be exchanged approximately once every six months (or more often if needed) with a sensor that has been recalibrated.

3. The data logger manufacturer may not volunteer information about an undocumented calibration procedure for their data logger unless asked. In one application, it was noted that none of the analog temperature (1000 Ohm Resistance Temperature Device (RTD)) channels were producing plausible readings; for instance, the entering chilled water temperature reading was -7 C. All instrumentation was checked closely for any possibility of stray voltage being fed into one of the channels. Finally, out of frustration, a call was made to the data logger manufacturer. The applications engineer diagnosed the problem as an analog board that had not been properly calibrated. He provided a step-by-step calibration procedure that was nowhere documented in the technical specification or user manual for the data logger. Not having the board calibrated earlier caused the program to lose four weeks worth of usable data from that data logger. Analog board calibrations are now checked regularly at each logger equipped with the analog option.

6.2.3 Equipment Installation

While the above section dealt more with problems with the instrumentation out of the box, many problems associated with instrumentation focus on their application (or misapplication). The problems encountered with the installation of instrumentation are listed below.

6.2.3.1 Thermal Metering

Problems with the installation of thermal metering include the temperature and flow inputs to the thermal energy meter as well as the thermal energy meter itself.

1. The flow velocity may be outside of the useful range of the flow meter. With some buildings, there is already flow instrumentation in place, such as a venturi, orifice, or turbine meter. It can be very cost-effective to utilize this instrumentation. However, for buildings designed before the early 1970s, when dual-duct and reheat systems were predominantly installed in buildings, the flow instrumentation was probably designed for much higher flow rates (and correspondingly higher chilled or

hot water usage) than is actually occurring in the building. Venturi flow meters operating in flows that were one-third of their minimum rating have been observed. In addition, if no flow meter is in the piping, then a flow meter must be installed. The linear range for several of the insertion turbine meters ranges from 0.6 to 9 m/s. Chilled water design flow velocities range from 1.2 to 2.4 m/s. Thus, one would expect the flow velocities to be within this range. However, due to poor design or, perhaps, oversizing in anticipation of future building additions, there have been a number of installations with oversized pipes where the velocities were between 0.15 to 0.6 m/s. At these lower velocities, insertion turbine flow meters no longer produce a signal at all or produce a signal that is inconsistent with the calibration curve over 0.6 m/s. One solution has been to develop calibration curves for flow meters in these applications that are only valid at the lower range of the meter. In general, there appear to be no reasonably priced insertion flow meters that can read below 0.15 m/s. In buildings where this condition occurs a special metering leg will need to be installed that reduces the pipe diameter. This reduced pipe diameter will push the flow velocity back into the range where the meter is useful.

2. Asbestos insulation may be on the piping where the thermal metering instrumentation will be installed. Unfortunately, asbestos is one of the hazards encountered in thermal metering in buildings. If the building was constructed before 1970, one can generally count on asbestos being used in some of the hot water and steam piping insulation. Asbestos abatement can drive the cost of metering so high that it can endanger the installation. "Is there asbestos on the chilled or hot water piping?" should be one of the first questions an engineer asks of the facilities or building manager before even going to the trouble of developing an instrumentation plan. If the answer is "Yes," the next question should be: "Who is going to pay for the abatement of the asbestos?"

3. The leads from the RTD sensors may follow the longest path and may not be compensated. In many of our installations, the entering and leaving hot or chilled water temperatures are measured. The data logger used for this project can accept a two wire 1000 ohm RTD for direct measurement of temperature. If the lead length to one RTD is 5 m, while to another it is 25 m, then it is possible to have several degrees of temperature difference indicated due to the differences in lead length. Ideally, a three wire RTD should be used, which will allow compensation for the differences in lead length. Otherwise, leads of equal lengths must be used.

4. The diameter of the pipe in which the flow meter is installed may be different from that indicated by the facility manager or shown on the building schematics. With many insertion flow meters, the pipe size is a critical piece of information for both installing the flow meter at the right depth in the flow and setting up the thermal meter correctly. If the pipe diameter is incorrect, then the pipe thickness is also incorrect, which means the depth of the flow meter is also incorrect. While building operators or building schematics (which may not reflect the as-built condition) are useful, the only diameter for the pipe that should be trusted is the one that is measured

(preferably twice). At one site, the information provided on five different pipes (out of five) was incorrect.

5. If a temperature probe can be reached by a person from the floor, the probe may be used as a chin-up bar, step ladder, or some other aide. On the first major installation on this project, a number of RTD probes were mounted in a near horizontal position within easy reach of maintenance personnel. Within six months, most of these RTDs were at 45 degree angles to the pipe because individuals had used them in ways for which they were not designed.

6. If a temperature probe is no longer functioning, it may be because it no longer exists. On some early installations, the compression fitting used for insertion of RTDs into a pipe allowed the RTD probes to vibrate within the pipe. The vibrations eventually produced a failure of the probe where it protruded from the compression fitting into the flow stream. Eventually, the probes broke off and travelled downstream until they became lodged or were picked up in a stainer. While thermowalls would be one solution to a temperature probe, the cost from "hot tapping" a thermowall is much higher than that for a probe.

6.2.3.2 Electrical Metering

There have been fewer problems with the installation of electrical metering equipment. In many cases, the problems could have been avoided if the installing electrician had been properly supervised.

1. If multiple transformer feeds are available in the building, then the potential transducer (PT) may be connected to the wrong reference voltage. The data logger used for this project has the ability to accept two different PT references, which are used for CT reference and the proper internal calculation of active power. A common field error is referencing CTs to the wrong PT or referencing all CTs in a building to a single PT when there are several transformers (requiring several PTs) in the building. The most extreme case involved a large 12-story office building that had four different transformers. Only one PT was installed and used as a reference for all the CTs in the building. Several costly fixes have been necessary to correct the problem and several months' worth of pre-retrofit data have been lost.

2. If current transformers are connected to a secondary line, they may not be scaled correctly. On large electrical loads (i.e. main building feed, centrifugal chiller feed) there often are existing current transformers available. These existing CTs are used by building operations personnel to monitor the electrical loads at these devices. For example, a large centrifugal chiller might have CTs with 1000 to 5 ratios on each of the 3 feeds to the chiller motor. The ratio indicates that the CT will output 5 amps if the motor is loaded at 1000 amps. The monitoring technique consists of installing a second 5 amp CT on the existing CT secondary wire. The CT ratio of the primary and the secondary CT is then necessary to calculate what the final CT ratio actually is. This is the ratio used to properly scale (through the data logger software) the signal

received at the data logger. In some installations, the primary CT ratio was not determined and the ratio was guessed. Only after the existing CT ratio is properly determined and field verified can the signal be trusted.

3. The standard conventions of three-phase power installation in electrical cabinets may not be followed. Electricians are supposed to use a standard set of rules for installing A, B, and C phases of three-phase equipment. These three phases should go (as one faces the electrical connection) left-to-right (A, B, C) or up-to-down (A, B, C) or front-to-back (A, B, C), depending on the style of the cabinet. One subcontractor installed all the three phase current transformers with the above assumptions without checking to see that the electricians who installed the original equipment in the cabinets were consistent. Another subcontractor had to be brought in to this site and to sort out the problems and resolve the current transformer referencing confusion.

6.2.3.3 Other Instrumentation

1. Data acquisition boards on the data logger can substitute as expensive fuses. With the particular data logger used, it has been found that when a 4 to 20 milliamp transducer is installed into a channel that was expecting a 0 to 5 Volt dc input, the analog board on the logger becomes an expensive fuse that protects the rest of the data logger from any damage. The only problem is that the analog board must be replaced after each mistake.

2. The data logger may be programmed incorrectly when you first start collecting data. The data loggers used vary from 4 to 45 channels connected. While care is taken to program the data loggers correctly when the site is first brought on-line, the loggers on every site have had to be carefully checked channel by channel to ensure that what is given in the documentation is in fact what was programmed into the logger.

6.2.4 Equipment Maintenance

Once the instrumentation is in place, it will have to be maintained. The maintenance may be more difficult to handle than the original installation. If an instrument fails, it requires a trip to the site to diagnose the problem and at least one more subsequent trip to the site to fix the problem. The cost of maintenance will probably exceed the initial expectations of personnel on the project. The types of failures seen in the field will depend on the type of instrumentation used. The rule of thumb is to expect every piece of instrumentation to fail at some point in the program. In the two years, the types of maintenance problems and failures seen thus far include:

1. Modem failure. While the number of modem failures in the past two years has been fewer than five, the failure of one modem can potentially disrupt the data collection for two to three buildings when the buildings are tied to the same data logger. One particularly annoying failure of the modem can occur after a short power outage. The modem will not properly reset, and when calls are placed to the data logger, the modem does not answer. Thus, the logger cannot be reached remotely via the phone. The modem and the logger have to be physically turned off and then back on to

properly reset the modem. Because there are buildings hundreds of kilometers from each other on this project, doing this more than once can be very time consuming and costly. Two methods have been developed to reduce the cost of this type of failure. The first method involves the insertion of a timed power interrupted circuit. The second method involves training personnel at the remote site to reset the loggers.

2. Dewpoint sensor getting dirty. After the temperature dependence and saturation problems were identified with some RH instrumentation, chilled mirror dewpoint sensors rated for outdoor use were specified for several weather stations at high humidity locations. While more accurate and reliable, these sensors require at least bi-monthly maintenance to clean the mirror and they need to be completely recalibrated every six months. Furthermore, it was found that calibrating a chilled mirror is far more difficult than calibrating an RH sensor.

3. Equipment disconnected or damaged. When energy conservation retrofits were installed under the LoanSTAR program (Nutter, et al., 1990), some of the energy metering equipment was damaged by the retrofit contractor. This damage is not evident until the data logger has been polled. The cause of the problems cannot be diagnosed without a visit to the site. At one site, it was found that an electrical subcontractor had disconnected the wiring for both power and CT inputs to the data logger. At another site, an asbestos abatement contractor ripped the wire out from a steam pressure transducer and caused a short to the data logger. The problem caused the loss of several weeks of building energy data. Measures are being taken to ensure that the building operations people as well as the designers for the energy retrofits are made aware that there is metering equipment installed in their buildings. Contractors are also held liable for damage to the data loggers and sensors (i.e. property of the state of Texas.)

4. Aspirating fan failure on weather station. The weather stations are equipped with aspirating fans, which ensure that an adequate fresh air sample crosses the relative humidity (or dewpoint) sensor and the dry-bulb temperature sensor. When measured air temperatures approached 50°C at one site, it became obvious that there was a problem. During a site visit, it was found that the aspirating fan had become "stuck" and after being given a helping twirl, it started again. Subsequent data showed marked improvement and the fan has continued to operate normally.

5. Current transformer failure. There have been several instances of the shunt resistor failing in the CT. This allows the CT to output a voltage far higher than the 0.333 VAC rated load. In one case, the CT was outputting 10 VAC, which caused the logger to record false power readings for the affected channel as well as other channels.

6. Flow meters can wear out. In sites where flow velocities are in excess of 5 to 10 ft/second the small wheel in the flow meter spins at a very high rate. Over time, this can wear out the shaft. In the worst case the shaft will break in two. In other cases, the wheel wobbles on the shaft which causes inaccurate readings.

7. Data loggers can lose their identity and become something else. In spite of the fact that the primary data loggers used in the program are extremely reliable a few simply lost their programming for no apparent reason and had to be replaced. Luckily, with some coaxing, the manufacturer overnighted a replacement which saved us travel costs.

6.3 Recommendations from Task 3

The recommendations presented here relate to calibration of new equipment, installations of equipment to achieve stated accuracy and re-calibration of equipment to ensure continued accuracy. Accuracy of data depends upon the calibration and stated accuracy of the equipment, proper installation of all equipment, and the maintenance or re-calibration of the equipment.

6.3.1 Equipment

Different types of monitoring equipment have different calibration needs. These needs depend upon the harshness of the environment, the sensitivity of the equipment to the environment, the existence of moving parts, and the ability of electronics to maintain stable settings. Additionally, frequency of calibration, ease of calibration, and the need to install new parts as part of the calibration process vary for any given piece of equipment. It is reasonable to anticipate that new equipment should arrive fully calibrated with the accuracy as stated in manufacturers specification sheets. At the least, there is a need to field verify the calibration of equipment. However, some equipment does not operate at the stated accuracy and cannot be calibrated other than through software manipulation of data. At the worst, some types of new equipment require calibration in every case.

Recognizing a calibration problem is not always simple once the equipment is installed in the field. Equipment failure, Data Acquisition System (DAS) software problems, data retrieval problems, and data reduction software problems complicate the issue. An effective isolation technique is to view real time data and compare it to time series records (TSRs) data and anticipated load levels. Shared signals from facility energy management and controls system (EMCS) are dependent upon facility calibration schedules if they are calibrated at all. These shared signals are usually difficult to calibrate.

6.3.1.1 Electrical Metering

Electrical metering equipment consisted of current transformers (CTs), potential transducers (PTs), Watt Hour Transducers (WHTs), and the DAS. Additionally, utilities or facilities provided pulse initiators on their meters for whole-building or campus metering in about half of the sites. For the LoanSTAR project, these items were factory calibrated and were accurate. A double check of given scale factors is recommended. Field verification of loads was always completed using hand-held RMS, volt, amp, and watt meters. Early in the project, the CTs, PTs, WHTs, and DASs were checked for accuracy in the Calibration Facility to ensure the specified accuracy of the selected equipment. These types of equipment had to be as accurate as specified because there are

no physical calibration adjustments available. If errors had existed, software corrections would have been necessary when possible.

6.3.1.2 Thermal Metering

Thermal metering equipment consisted of liquid flow meters, temperature sensors and flow/Btu totalizers. These equipment items were factory calibrated and have no physical calibration capability. The various items selected for use in the LoanSTAR program were tested in the calibration facility. The temperature sensors and Btu/flow totalizers were as accurate as specified. Spot checks on those items of new equipment are completed on an ongoing basis. The insertion type paddle wheel flow meters are not as accurate as specified by the manufacturers in flows less than 3 ft/second depending on the manufacturer. The calibration facility tests every new insertion flow meter prior to installation, so that corrections may be made to data. In-line type turbine flow meters, target meters and shedding vortex meters were tested and found to be accurate.

6.3.1.3 Other Equipment

Other equipment requiring calibration attention or review included Analog Data Acquisition Systems, weather stations, and gas pulse initiating meters. The gas meters were calibrated by the utility and in effect are identical to the meters used for their billing purposes. The Analog DASs have a calibration capability and are checked and adjusted if necessary upon completion of installation. The modular weather stations complete with solar radiation, wind speed, dry-bulb temperature, and relative humidity (RH), or dew point temperature sensors, were calibrated by the supplier. Replacement sensors and newly constructed weather stations are tested and calibrated at the calibration facility. The solar and temperature sensors with associated transmitters calibrate easily and are normally accurate. The wind and RH sensors are difficult to calibrate and are typically not within the manufacturer's stated accuracy.

6.3.2 Installation

Proper handling and installation of equipment is a necessity in order to ensure the calibration and proper function of the equipment.

6.3.2.1 Thermal Metering

In order to achieve maximum accuracy there are several considerations. Study of the physical piping is usually necessary to be sure which pipes are right for supply and return. This may seem simple, but in a maze of piping, it is easy to neglect to notice a supply or return line, which feeds from or into the line being metered. This can reduce the metered load and could be difficult or impossible to detect. Placement of the flow meter in a straight section of piping without obstructions for 10 pipe diameters on the up stream side and five pipe diameters on the downstream side is normally recommended. Although this is rarely possible, the installer should study the piping to find the best possible alternative. Extra care should be taken to insert the meters to the specified insertion depth. Field verifications of flow rate and temperatures is necessary to be certain that the flow/Btu totalizers are functioning properly.

6.3.2.2 Electrical Metering

The main consideration for installation of electrical metering equipment to achieve accurate readings is phasing. The CT, PT and DAS programs must all be in phase agreement for accurate power measurements. Also, in the confined areas of electrical panels, it is easy to place the CT on the wrong phase or the wrong load. Care must be taken to trace each wire prior to installing the CTs. Field verification of every CT and PT output and DAS power calculations is desired using hand-held amp, volt and watt meters. In some cases watt verifications may be impossible, but volt and amp readings can be adequate for a calculated watt verification.

6.3.2.3 Other Equipment

The physical placement of weather stations and DASs is important for maintaining accuracy of calibration and accuracy of data. The DAS should be located in an environment that is not too harsh, such as one that is or could become wet, too hot, or too dusty. The weather station must be placed where it is free from interference from ambient conditions. The main considerations are shading of the solar sensor and building exhaust, which would affect RH and temperature data. Extra care should be taken with sensors as they are very sensitive. Field verification of RH and temperature using a hand-held instrument is recommended.

6.3.3 Maintenance

Maintaining calibration of equipment throughout the life of a monitoring project is essential. Naturally, when equipment fails it is anticipated that replacement items will be calibrated. It is simple to recognize failed equipment, but a different matter to recognize equipment that has lost its calibration. Weekly review of data records is needed to spot equipment problems. When a potential problem is spotted, it is suggested that current data be compared to old data and that real time data be reviewed and compared to the most current time series record. Additionally, a discussion with facilities operators will help recognize operational changes of equipment being monitored.

Rather than wait for equipment to lose its calibration, it is more desirable to change it out just prior to the need for re-calibration. In order to accomplish that, a maintenance schedule for calibration must be established. Naturally, this will depend upon the quality of the equipment used, as well as the quality of the installation.

6.3.3.1 Thermal Metering

In-line flow meters have proven to be accurate and dependable if they are measuring flow velocities between 3 and 10 ft/second. The life of the calibration has not been determined. Failure of these items has been limited to excessive temperature and most often, mistreatment by facilities personnel. Flow rates have been fairly stable where this type of meter has been used, making it relatively easy to recognize equipment problems.

Insertion type paddle wheel flow meters are removed for calibration after 12 to 18 months of service. It appears that calibrations have been maintained over the period in most cases. The main problem has been paddle wheel shaft wear, which eventually leads to failure. The meters with excessive wear were repaired and recalibrated. A post-removal

re-calibration was completed in every case except one, where the paddle wheel shaft was broken. Upon completion of a flow meter change out, a field verification of flow and temperatures must be completed and compared to flow/Btu totalizers data.

6.3.3.2 Electrical

There has been no need of a maintenance schedule for electrical metering equipment. The life of the factory calibration has not been determined. A very limited number of current transformers have failed. Failure was easily noted in the weekly data review. Replacement and field verification of new equipment was completed.

6.3.3.3 Other Equipment

Analog Input Data Acquisition Systems should be checked for calibration annually. The Analog DAS used in this project has a calibration check channel, which can be stored into time series records or viewed in real time each week when data are down-loaded. Drift is normally less than 1 % of scale and adjustments made were completed during visits to the facility for other purposes.

Weather stations require the most calibration maintenance. It is recommended that all sensors be recalibrated every 6 to 12 months. Depending upon the quality of the instruments, replacement of the wind sensor and RH sensor may be necessary every 1 to 2 years. The LoanSTAR project maintains seven weather stations with an eighth station now used as a complete calibration change out. After nearly three years of service, it became necessary to rebuild the entire weather station with a new wind sensor, RH sensor, and temperature sensor. A recalibrated solar sensor was used and a new aspiration fan was installed. Each removed sensor undergoes a post-removal calibration check and is then recalibrated if possible. During the 3 years of service there have been many individual sensor failures. Weather stations require the most in calibration needs and first in maintenance needs when compared to all other equipment used.

6.4 Recommendations From Task 4

In this section recommendations are presented based on experiences from Task 4—the Communications Test Bench and Computer Support group. In a large project such as the LoanSTAR program, the first step in the data management involves acquiring the data by polling the remote loggers over existing phone lines, followed by some sort of quality control and cross checking, and finally visual inspection of the incoming data, including cross-checking of weather data against NWS weather data, etc. The sections that follow discuss the recommendations for each of these issues. A list of the public domain software used in the LoanSTAR program is included at the end of this section.

As of June 1993, each week the LoanSTAR program was retrieving and analyzing over 3 MBytes of data (1,000 + channels) from 82 loggers, which covers 200+ buildings, and 50 weather stations from the NWS. This includes hourly and 15-minute data from remote Synergistic and Campbell loggers via phone lines and data from weather stations accessed through the NWS Aviation Weather Observations. Special purpose software was developed for the polling, including the POLLC180 program, to call the loggers

automatically and download exactly 168 hourly records or 672 15-minute records from each logger beginning and ending on midnight on Monday each week.

For any project involving this many data channels, the following recommendations are made:

6.4.1 Acquiring the data

1. First, make sure to check the manufacturer's polling software to be sure how the loggers are called, how records are retrieved, and how data are captured on the disk. In general these programs allow the user to connect to the Data Acquisition system either through a modem or RS232 and perform rudimentary functions on the system from remote locations. The programs also allow data to be downloaded into predetermined formats, such as columnar ASCII, spreadsheet formats, or complicated proprietary formats that might include headers and footers for each page of information, which need to be removed prior to integration into a continuous data base.
2. DASs must be polled periodically to remove data before the local memory is overwritten with new data. The maximum time between pollings depends on the amount of data collected and the frequency with which data are stored in memory.
3. A PC-based flat file type of data structure is appropriate for a limited number of sites, say 10 to 20. Beyond that number, at 52 files per site per year and one directory per site, the data handling limits of the PC can soon become a problem. Each hour of data should have a site number attached (i.e. - each row of data) in case file names become corrupted and one needs to double check the individual records.
4. Raw files should be captured and archived without any tampering. In this way data can be restored to the data base in case of a disk crash. Any adjustments, and/or editing required for a given channel can then be recreated exactly.
5. A flawless permanent record should be made of any "adjustments" made to the data.
6. The processing of data should be as automated as soon as possible to avoid human error. Access to the data, especially the ability to write permanently to the data base, should be tightly controlled and monitored. Multiple generations of tape backups are required.
7. The use of modular routines, or filters, and a standard format is the most efficient means of handling data from different sites. Modular routines are very helpful for processing data, such as the ones that form the foundation of the LoanSTAR data processing. The use of a standard format ensures that one routine will work across multiple sites. A decimal date stamp is important for calculating the day of the week and is helpful in plotting.

8. Most of the polling in the LoanSTAR program is performed at 1200 baud. At 1200 baud a significant amount of time is spent "on the phone" each week pulling data down from the loggers. Certain "quiet" sites can use 2400 baud, which cuts the connect time; however, 1200 baud will probably be required in most large mechanical rooms where 60 hz electrical noise is significant. Budgets should be prepared for significant long distance phone bills. For example, the polling of 82 loggers in the LoanSTAR program requires almost 13 hours on the phone each week. Obviously, with the advent of fiber optics, digital-FM communications, the internet and satellite-based communications, this should improve substantially.

9. In general, experience with the LoanSTAR program has indicated that 9 out of 10 (i.e., 90%) sites will be error-free each week during the polling process. With due diligence, this can be cut to 19 out of 20 (i.e., 95%) sites. This reinforces the need for rapid response to problems and easy access to loggers and sensors, etc. For a given logger, 5+ weeks of data could be lost each year yet still maintain 90% data quality (assuming all the retrieved data were perfect).

6.4.2 Data quality control

1. Control of logger parameter sets and channel tables is as important as the data itself since the data are 100% dependent on any processing that takes place at the logger or on the way toward the data base. Therefore a complete history of channel tables and logger parameter sets, as well as backup copies, is mandatory.

2. All data should pass through static high-low filters, such as those provided by the public domain ARCHIVE program (Feurman and Kempton 1987).

3. Data should be checked for continuous records. Loggers often lose power and certain loggers do not record data until power is restored, leaving a gap in the data records. These gaps must be sought out and tagged with a missing label such as "-99" or filled by the appropriate means.

4. Each week a logger should be checked for power outages, and have its clock inspected to ensure that the time is synchronized. Sumchecks and analog ANCHECKS (this is a special feature that one manufacturer provides to check the integrity of their analog to digital conversions) should be applied where appropriate. Some thought should be given ahead of time how to handle daylight savings. All of these features are incorporated into the public domain LoanSTAR software, such as the POLL180 and ARCHIVE programs.

5. Weather data are also critical if weather-dependent analysis is being performed on a building. Cross-checking weather station data with the NWS data are helpful and can be useful for quickly spotting "dead" aspiration fans or sensor drift. With some diligence, dry-bulb temperature, humidity, and solar can be cross-checked with the NWS. Only the wind speed is problematic since the NWS records peak wind gusts

each hour, which typically do not correlate with the average hourly wind readings that a data logger records.

6.4.3 Hardware issues

1. DOS-based PC's are probably useful up to the 50-site level with no more than one year's worth of data. Beyond that a networked, UNIX-based system or mainframe computer becomes a necessity. This is driven mostly by efficient access to the data. Also, having more than one PC means that a user will need to go from one computer to the next to retrieve data. This can be a problem when one wants to access channel five from site 40 on the first PC and merge it with channel 1 from site 10 on another PC. Networked PCs do provide some advantage but are still limited in their data storage capability and processing speed, especially when a large relational data base is used.

2. In the LoanSTAR program we found the following to be barely adequate for 50+ users: One UNIX-based server, 64 MB RAM, 3.5 GB disk space; one PC NetWare server, 386-33 MHz, 16 MB, 1.5 GB disk, one floating license server, 386SX-20, 4 MB RAM, 40 MB disk; 64 PC workstations, 3 UNIX workstations, 3 X-terminals, one high speed printer and 26 desk top printers.

3. Staffing needs are critical. LoanSTAR has a programming manager, a data base administrator, a hardware manager, and a small group of staff, students, and faculty.

4. If inspection plots are to be plotted for more than a few hundred channels there is a need for a high speed laser printer, preferably one that is very durable and can be fixed fast when it breaks.

6.5 Recommendations from Task 5

In this section, we list and briefly discuss recommendations relating to our experience from Task 5--Analysis and Reporting. Specifically, we shall address issues involving 1) agency contact and site description, 2) pre-screening of data, 3) modeling and analysis, 4) savings calculation, and 5) reporting of savings.

6.5.1 Agency Contact and Site Description

1. There is a definite need for an agency contact to provide a two-way communication channel for determining status of retrofits, verification of monitored data, setting up meetings and scheduling visits, following up on monthly reports and O&M identification and verification. It is recommended that one person from the monitoring group and one person from the site being monitored be selected to carry out all communication. We have found this system to be the least intrusive while maintaining good communication.

2. It is also recommended that a Site Description Notebook (SDN) be maintained for each building. The SDN should include the following specifics: photographs of the site, site summary form, site description form, data channel list, monitoring diagrams,

ECRM list, O&M opportunities, estimated savings from the audit report, modeling characteristics, Monthly Energy Consumption Reports (MECRs), Annual Energy Consumption Reports (AECRs), Data Summary Notebooks (DSNs), Weekly Inspection Plots (IPNs) and all communication to and from the site.

6.5.2 Pre-screening of Data

1. Weekly Inspection Plots (IPN) in the form of time series plots of hourly data for all monitored channels have been found to be useful in providing the analyst a means of detecting data abnormalities in either the building operation or in the monitoring. These abnormalities can then be either rectified or the bad data eliminated before further data manipulation and analysis is done. This data quality control and diagnosis of operating changes and problems is crucial for proper retrofit savings analysis.
2. Data exploration software (we are currently using Voyager software) is routinely used to examine system performance and analyze consumption data at an hourly level. A program such as this is a very useful tool to have.
3. A software program that automatically deletes missing hourly data and aggregates hourly data into daily data eliminates hours of tedious manual data manipulation.
4. A program that merges the monitored energy data with concurrent climatic data, either from specially installed weather stations or from National Weather Stations, is also a useful tool that reduces analyst time.

6.5.3 Modeling and Analysis

1. Normally, six months or more of hourly or daily pre-retrofit data are required to develop accurate regression models. It was found (Kissock et al., 1992) that regression models based on fewer than three months of data may seriously misrepresent annual energy use. However, if the mean outdoor dry-bulb temperature during the period of data availability is close to the annual mean temperature, three months of data may be adequate to yield accurate regression models. If fewer than three months of data are available, the simplified calibrated systems modeling approach (Katipamula and Claridge, 1993) is recommended.
2. Though there are numerous computer packages available to view data and perform statistical analysis, we have found none that is user-friendly, relatively cheap and enables data viewing and statistical analysis to be performed interactively. In an attempt to resolve this problem an in-house program called EModel (Kissock et al., 1993) has been developed for the analysis of building energy use data. It integrates the previously laborious tasks of processing, graphing and modeling in a user-friendly Microsoft Windows environment. Its built-in features allow for quick determination of baseline energy use models. Copies of EModel can be obtained by contacting the authors at the Energy Systems Laboratory.

3. Regression models based on daily time scales with outdoor dry-bulb temperature as the only regressor variable are most frequently used in the LoanSTAR program to model weather dependent energy use. Models may involve two parameters, three parameters or four parameters. On the other hand, weather independent energy use is modeled using mean or one-parameter models. In any case, we have found that the accuracy of our savings estimates is increased if proper day-typing is done. This involves separating days into groups with more or less similar building operating schedules. The common data groups for buildings on a university campus or in school districts are: weekdays, weekends, holidays, Christmas-New Year's Day holidays and semester breaks. The extent to which the models improve when other regressor variables are added is an issue currently being investigated. Finally, for those buildings where neither hourly or daily pre-retrofit nor post-retrofit data are available, utility bill analysis is the only recourse. Analysis methodologies for such cases have been studied, and though preliminary recommendations are available (Yue, 1993), these are rather specific to the building, the type of retrofits performed, and the type of post-retrofit monitoring installed.

There are specific instances where hourly models are more appropriate, for example, in buildings where HVAC systems are scheduled on/off according to a predetermined time-of-day. As of May 1993, we have 17 sites with daily regression models, 3 sites with hourly regression models, 3 sites with zero level models, and 2 sites with calibrated simplified systems models. An example of a site that needs an hourly model would be one where HVAC systems are turned on/off according to a EMCS schedule that varies with semester and non-semester use.

4. Increased automation in the modeling phase would be valuable for monitoring programs. Our current approach to modeling, which involves a more or less well defined methodology, is not automated, partly because several judgment decisions are required at several points. Though the analyst cannot be entirely eliminated, her or his involvement can be reduced by resorting to methodologies that are amenable to automation.

6.5.4 Savings Calculation

Once the models have been developed, it is recommended that a special program be written for routine (i.e., monthly) calculations of energy savings. As of May 1993, LoanSTAR uses an in-house program called ESAVE, which contains all the dates (retrofit dates, day grouping information, etc.) and model data (regression coefficients, etc.) specific to each individual building. The user has merely to supply the program with climatic data and energy use of each day of the month for the program to calculate savings for all buildings. This procedure is currently being further automated by imbedding the model data specific to each building into the Informix Database, which contains all the monitored hourly data as well.

6.5.5 Savings Reporting and Follow-up

1. Monthly Energy Consumption Reports (MECRs) are mailed each month to the site contact of each building. These MECRs are about 6 pages per building and provide hard copy tabular and graphical feedback on monthly, daily and hourly performance of building systems. Plots such as time series plots (both 2-D and 3-D) and scatter plots are used. We have found this type of reporting to be useful to building operators and administrators, facility and design engineers, and project managers.

2. Another form of reporting, which is strongly recommended, is an Annual Energy Consumption Report (AECR) for each building. This is similar to the MECR but performance over the entire year is summarized. In the LoanSTAR program the AECR (and the accompanying monthly analysis) is the only report for sites where the retrofit cost is too small to justify installing a logger.

3. We also recommend telephoning each of the site contacts a few days after the MECRs have been received to discuss the problems highlighted in the MECR by the LoanSTAR staff. This follow-up call is a means of maintaining continued involvement and fostering good will. All comments about a site need to be entered into the permanent database for that site.

4. Finally, we recommend that a minimum of information be sent routinely to the site contact; sending too much information can overwhelm them and is often distracting. For example, it is not wise to send weekly Inspection Plots (IPNs) or a detailed description of the particular models used to determine savings to sites where it has not been requested. Our current practice is to send Weekly Plots and Voyager data files only to those sites, which have specifically requested them.

Table 6.1: Category I ECRMs.

ECRM	Payback (years)	Minimum Annual Operation (Hours)
Delamping	1	N/A
Repair Steam Traps	2	N/A
Incandescent to 18-W Screw-in or Fluorescent PL (cost less than \$20/unit)	2	6500 (replacing 60-W inc.) 3400 (replacing 75-W inc.)
Incandescent to H.P. Sodium	4	N/A
Incandescent Exit Lamps to 9-W (or less) Fluorescent (install cost less than \$35 per unit)	3	N/A
Energy-Efficient Fluorescent Lamps	2	4400
Photocells on Exterior Lights	3	N/A
Time Clock Shutdown of Equipment	3	N/A

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AVAILABLE SOFTWARE

These packages are available for distribution now. Others will be added as they are ready.
 Send inquiries to the attention of Mr. Robert Sparks, ph. 409-847-8779.

1. 023-124 v 1.1 Adjusts time stamps in columnar data to convert from the 0-23 representation of hours to 1-24 representation. D Bronson, R. Sparks, J. Haberl	14. MK3DSurf v.9 10/92 Creates a 3D surface animation from time series data using Golden Software's SURFER and Lantern Corporation's MOVIE. R. Belur, J. Haberl, R. Sparks
2. 3DMac v 1.0 10/91 A Lotus 1-2-3 macro that facilitates graphing 3D surfaces using Intex Solutions' 3D-Graphics. Matson, J. Haberl	15. MKVoy-DOS v.9 7/92 Prepares time series data for compilation into Lantern Corporation's Voyager. Kissock, J. Haberl
3. 3DMacXL v 2.0 9/92 A Microsoft Excel v4.0 macro for producing 3D surface plots. R. Belur, R. Sparks, J. Haberl	16. Min_Conv v 1.3 4/92 Converts an n-minute data stream to an m-minute data stream where n divides m. (e.g. 15 min. to hourly or hourly to daily) R. Sparks, R. Belur, J. Haberl
4. Air v 1.3 1/92 Performs psychrometric calculations on columnar data. R. Sparks, S. Katipamula, J. Spadaro, J. Haberl	17. Min_Shift v 1.1 4/92 Moves timestamps in a file by an arbitrary number of minutes (useful for correcting for DST) R. Sparks, R. Belur, J. Haberl
5. Multiwindow Animate v 1.1 3/93 A flexible MS Windows compatible program for producing X-Y animation of columnar data. R. Sparks, G Bailey, J. Haberl	18. Missing v 1.4 2/93 Replaces missing records (rows) in columnar data. R.. Sparks, K. Weber, J. Haberl
6. Archive A&M v 1.1 1/92 Princeton Archive with A&M patches.	19. PollC180 v 1.1 WFA* Unattended polling of Synergistics C180. R. Sparks, K. Weber, J. Haberl
7. ColRow3D v 4.0 10/91 Converts columnar data to a matrix suitable for input to Intex Solution's 3D-Graphics add-in for Lotus 123. J. Matson, R. Sparks, J. Spadaro, J. Haberl	20. PowerFactor v 1.0 WFA* Calculates power factors from kW & kVA on an arbitrary number of phases. R. Cox, R. Sparks, R. Belur, N Ahmed, J. Haberl
8. Datcon v 1.6 6/93 Converts dates and times between Gregorian, Julian and Decimal formats. R. Sparks, N. Ahmad, J. Haberl	21. PRMWatch v 1.0 10/91 Graphs the output of the Esterline Angus Power Reporter Module in real time. R. Sparks, J. Haberl
9. EModel v 1.2 WFA* An MS-Windows program for browsing, manipulating, and modeling columnar data (with special features for time series data). It is copyrighted by TEES and Kelly Kissock for distribution in the public domain. K. Kissock	22. Psychrometric plotting with Grapher v1.0 1/92 A .plt template of a psychrometric chart for use with Golden Software's Grapher. M. Palani, J. Haberl
10. KWC v 1.0 10/91 A PC-based interface to the Acurex Autocalc, which includes program editing and real time graphics. R. Sparks, J. Haberl	23. TimeMerge v 1.5 3/92 Combines two timestamped data streams, merging on the timestamp fields. R. Sparks, J. Haberl
11. LoanSTAR Monitoring Workbook 7/92 This workbook is intended to be a stand-alone survival guide to acquiring energy use and environmental data in buildings. It includes monitoring procedures and data analysis routines developed for the Texas LoanSTAR program and is copyrighted for distribution in the public domain. R. Lopez, R. Sparks, J. Haberl	24. Xair v.1 WFA* X windows utility psychrometric calculator. K. Weber, S. Katipamula, J. Haberl
12. MkMov v .91 10/92 Produces contour animation from time series data using Golden Software's SURFER and Lantern Corporation's MOVIE. R. Belur, J. Haberl, R. Sparks	25. Solrpath v.1.0 2/93 A graphical preprocessing program that plots Olgyay's sunpath diagram and shading protractor for any location. Requires Golden Software's Grapher. K. McWatters, J. Haberl
13. MkMov3D v.9 7/92 Creates a 3D animation from time series data using Lotus 123, Intex Solution's 3D Graphics and Lantern Corporation's MOVIE. R. Belur, T. Bou Saada, D. Bronson, J. Haberl, R. Sparks	*WFA = Write for Availability

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10.0 APPENDIX

10.1 Compendium of Analysis Papers

This section provides a compendium of the associated LoanSTAR documentation that has been published in ACEEE, ASME, ASHRAE, and other publications. These papers can be found in the proceedings and journals indicated. Copies of the papers can also be obtained by contracting the authors at the Energy Systems Laboratory.

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10.2 Helpful Hints about Polling and Retrieving Data

10.2.1 Processing/Plotting Synergistics Data

The following are some helpful hints about what to do with the data once they have been collected from a logger. A collection of routines used to process and plot data collected from Synergistics loggers used by the Texas LoanSTAR Program over the last three years on a weekly basis is described here. Instructions and sample code are available on disk for developing inspection and summary plots, and 3-D plots using a combination of public domain data processing tool kits and inexpensive commercially available plotting software. The routines discussed are available in the workbook by Haberl et al. (1992).

This section describes a collection of routines that are used to process and plot data collected from data loggers. These routines have been used by the Texas LoanSTAR Program over the last three years on a weekly basis to create a set of *inspection plots*, which can be used as a primary quality control measure. One of the major goals of LoanSTAR has been to provide a fully functional system for presenting measured building energy data at a minimum of both cost and effort. To these ends, the system utilizes a collection of inexpensive commercially available products and public domain packages, as well as a set of public domain software filters written in-house to knit the streams together.

Controlling batch files are used to call the routines in sequence; once a production mode is established for creating the plots for a particular building, only a few keystrokes are required to actually create the graphic report. As each building being measured possesses some unique properties, an inherent amount of tailoring of these routines is required. Most of the effort required to run and maintain this system is in the initial setup.

Software available with the Monitoring Workbook (Haberl et al. 1992) contains a sample set of data for a typical university building, an associated weather file, and the routines used to process the data. This processing includes:

- 1) Automated quality control checks of all data channels against static lower and upper bounds.
- 2) Insertion of missing records with bad data markers (-99).
- 3) Creation of time series graphs of all channels, grouped twelve graphs per page.
- 4) Creation of summary plots.

The processing stream makes these assumptions:

- 1) Data are being collected on an hourly basis.
- 2) Each data file to be processed contains *exactly one week* worth of hourly records.
- 3) Each site (data logger) has an associated three-digit code. The example used herein is site 101 – The University Teaching Center at the University of Texas in Austin.

- 4) The raw data recorded from the Synergistics logger has been stored into a file using real numbers and no headers from the Synergistics software (10192168.RAW).
 - 5) The file name used to record the raw data follows the strict format of XXXYYDDD.RAW, where XXX is the three-digit site code, YY is the year, and DDD is the number of the day during which the data were collected. Collectively, YYDDD is known as the *Julian date*. As an example, the raw data file available on the distribution diskette is 10192168.RAW (Table 10.1). This is data for site 101. Because it was collected on 92168 (the 168th day of 1992 or June 15, 1992), this file contains data for the period beginning 92161 (June 8, 1992 at midnight) and ending 92167 (June 15, 1992 at 11:00 p.m.).
 - 6) To print summary plots, a weekly weather file containing hourly data for the region is present (20292168.WEA).
 - 7) The commercially available graphing program GRAPHER (Golden 1990) is used to create the plots.
 - 8) The public domain programs ARCHIVE and COLS (Feuermann and Kempton 1987), and GAWK(FSF 1989) (available on a distribution diskette) are used for quality control and data manipulation.
 - 9) The subdirectory \TEMP has been created prior to running the routines.
- Additional information about the routines is contained in the LoanSTAR Monitoring Workbook.

The following sections discuss the methodology of these routines as well as possible modifications for plotting other metered data.

10.2.1.1 Preparing Data from Time Series Channels from Raw Synergistics Data with R2A.BAT

Given this set of filters and programs, a rudimentary quality control range check can be performed and a full set of time series plots can be created with a simple command line operation. To perform the quality control and produce plots the following simple commands are issued:

```
R2A 101 92168 90001 <CR>
```

This command calls the controlling batch file R2A.BAT to begin the process as shown in Figure 10.1. The parameters passed to R2A.BAT include the three-digit logger code (101), a Julian polling date (92168), and a channel table descriptor (90001). R2A.BAT uses the logger code and Julian date to understand which file to process.

R2A includes an ARCHIVE channel table, which is a data dictionary that attaches static high/low bounds, English language descriptions, and scaling factors to each data column. In a long term monitoring project, this channel table might change significantly during the course of the project; therefore, new channel tables can be written or changes added to the same channel table. The channel table descriptor tells R2A.BAT which channel table is current for the data being processed.

The output of this scheme includes the flat file 10192168.ACS, which is incorporated into the LoanSTAR database, and two pages of Postscript output, 101ONE.OUT and 101TWO.OUT. These pages contain time series plots of all the channels being monitored at site 101. Examples of these pages are given as Figures 10.2 and 10.3.

Briefly, these steps are performed by R2A.BAT:

1) The GAWK script RAW2DAT.AWK is called to preprocess the raw data 10192168.RAW for quality control checks. The quality control is performed by the public domain program ARCHIVE (Feuermann & Kempton, 1989), which is unable to understand some of the characters that the Synergistics software leaves in the 10192168.RAW file. An example of Synergistics data is given as Table 10.1. The output of RAW2DAT is given as Table 10.2. Notice date/time columns have been adjusted, and certain characters have been stripped out of the file (e.g., “/,” “:,” etc.).

2) The output of RAW2DAT and the site's ARCHIVE channel table are fed into ARCHIVE for static high/low range checking. The ARCHIVE channel table 10190001.CHT for site 101 is given as Table 10.3. Example output from ARCHIVE is given as Table 10.7. ARCHIVE will report any offending data readings in a log file and will replace such readings in the data with a “bad data” marker (Table 10.4). For the LoanSTAR program, this marker is -99. ARCHIVE automatically appends the DOS file extension .ACH to the filename. For the example dates as provided, this step will have created the file 10192168.ACH.

An ARCHIVE channel table is created for each site that contains the instructions that ARCHIVE uses to process the data from each site. In Table 10.3, the ARCHIVE channel table 10190001.CHT that processes the data from site 101 is shown. The first four lines of the channel table are labels for the columns below. The “-----” column alignment guide indicates to the user how many characters to include in each parameter, and uses a blank as a separating delimiter. The line beginning with “#” contains special characters that tell ARCHIVE what kind of data it is processing, and what to use as a missing variable (the default is -99).

- The first eight characters are the date to which the parameters are to be applied. Excluding the last line, this is “04/23/92” for site 101, which is the most recent date for this parameter set.
- The next variable is the time, in this case “00:00”. This is instructing ARCHIVE to begin processing on April 23, 1992 at midnight.
- Next are the line number and column number of the input channel. These are followed by the ARCHIVE output column number. A “0” value is essentially a comment line and does not appear in the .ACH file.

- Following the ARCHIVE column position indicator is an eight character descriptor of the channel. This is followed by another twelve character descriptor of the ARCHIVE units and a six character code word for the ARCHIVE output format.
- The next two variables contain the conversion code word and conversion constants. The conversion code word is an integer from 1 to 31 and instructs ARCHIVE whether or not to perform conversions on the incoming data. Conversion code "0" will place a missing variable into this column, code "1" is an identity code that allows the value to pass through ARCHIVE untouched, code "2" is a linear transformation that requires two constants (i.e., slope and intercept), and so forth.
- The last three columns contain the error code, error constants, and channel description. The error checking code, 1 = on, 0 = off, initiates the high/low limit checking, which makes use of the high/low limit values that immediately follow.

In the 10190001.CHT channel table in Table 10.3, there are 24 lines of input. The first line

```
04/23/92 00:00 1 0 0 Begin UTC Beginning Date
```

is basically a comment line that does not appear in the output. The next line

```
04/23/92 00:00 1 1 1 Bldg. # XX I3 2 0 101 0 0 *Good starting 92.19*
```

places the site number "101" in the first column of the ARCHIVE output. This is done by using a linear transformation of slope = 0 and intercept = 101.

The next six lines

```
04/23/92 2
B ... B ...
04/23/92 6
```

create the second through seventh columns in the output file. The second, third, and fourth columns in 10192168.ACH are the month, day and year that are simply passed through ARCHIVE without change.

- The fifth column is the Julian date (92161), that is calculated by ARCHIVE using the first, second, and third input columns.
- The sixth column is the decimal date (4543.000) that is calculated by ARCHIVE. The decimal date is a combined date and time stamp that is an offset number of days and hours from January 1, 1980. It is similar to the @DATE(YR,MO,DAY) function that is used in many spreadsheets.

- The seventh column is the hour of the day using military notation (i.e., 0 to 23 hours).
- Columns eight through eighteen in 10192168.ACH all contain monitored data from the UTC building.

As can be seen in Table 10.7, many additional columns have been appended to the data. These columns are:

Site number Because these files are stored as ASCII text, it is very easy for records from other sites to be mistakenly inserted into a data set. This simple site number at the beginning of each line is a first step to ensure that the data recorded in this file really belong here.

Month, Day, Year This is recorded in the file so that people can understand the dates.

Julian date This has been discussed previously.

Decimal date Although this looks bizarre at first, the decimal date is a very handy way for a computer to understand time and graph data points as a time series. The integer part of the decimal date is merely an offset number of days from January 1, 1980. The decimal part is the hour of the reading divided by 24. This date format guarantees different timestamps for all data points including leap years. A time series graph based on hourly indices is difficult to handle and plot because of the cyclic nature of the clock (20, 21, 22, 23, 0, 1, 2, 3, etc.).

Time This is recorded in military units to differentiate between a.m. and p.m.

3) The .ACH file is fed to the program MISSING. This program scans the timestamps and inserts records and appropriate bad data markers for any missing records. When a Synergetics logger loses power in the field, it stops recording TSRs, and begins recording TSRs when the power is restored. However, a hole will exist in the data for those periods when the power was off. This hole is filled to aid in file merging and in graph readability. The output of MISSING uses the file extension .ACS. This is the ASCII flat file from which most of the work at LoanSTAR gets done. When there are no missing data there is no difference between an .ACH and .ACS file except the extension.

4) The final task of R2A is to call the graphing routines found in the batch file 101GRAPH.BAT. This program is sufficiently complicated and merits discussion on its own.

10.2.1.2 Using GRAPHER to Create an Individual Graph

GRAPHER is one of many commercially available general purpose graphics software programs. GRAPHER is very useful for rapidly plotting data because of its flexibility, overlay, and programmable batch mode operation. GRAPHER is actually composed of several subprograms, as shown in Figure 10.4. The most important of these (once

configured) are the VIEW and PLOT programs. VIEW allows one to quickly preview a graph that has been created. PLOT translates GRAPHER's .PLT file into device-specific plot instructions.

In general, to produce a plot with GRAPHER, one needs data (.DAT) and plotting instructions (.GRF). GRAPHER also allows for additional customization with axis (.AXS), grid (.GRD), dividing line (.DIV) and text (.TXT) files.

Figure 10.5 shows the result of processing the T1017.GRF GRAPHER instruction file.¹² Table 10.5 contains a summary of the graphics instructions provided in the T1017.GRF file. Table 10.6 is the T1017.GRF file that GRAPHER produces. From Table 10.5, one can see that input file T101.DAT is being used and that a linear X-Y plot is being produced using the sixth column (F) for the X variable and the fourteenth column (N) for the Y variable. GRAPHER produces a time series graph because the X variable is actually the decimal date. A solid line without symbols is being used to plot the data. Each graph that is to be plotted requires a .GRF file. The use of GRAPHER to produce weekly inspection plots is reasonably efficient because the same .GRF file (modified slightly) can be used with each week's data.

10.2.1.3 Creating Graphs Using 101GRAPH.BAT

101GRAPH.BAT is another controlling batch file. Its function is to automatically produce a set of time series plots (Figures 10.2 and 10.3), one per channel being reported by the logger. A flowchart for 101GRAPH.BAT is given as Figure 10.6.

Briefly, these steps are performed by 101GRAPH.BAT:

- 1) Copy a temporary version of the 10192168.ACS file into the \TEMP directory and rename the file to T101.DAT. This is required because GRAPHER only takes files with the .DAT extension as input.
- 2) Call the GAWK script 101DATE.AWK to determine the beginning dates. This script automatically writes the batch file 101CHGRF.BAT.
- 3) Call 101CHGRF.BAT. This uses the GAWK script 101CHGRF.AWK and the dates found in 101DATE.AWK to change the .GRF files for each plot. These files need to be changed to start the time line (the X axis) at the correct spot for each week. As each GRAPHER file is modified, it is written into \TEMP.
- 4) For each .GRF file in \TEMP, call GRAPHER. The output is an intermediate GRAPHER .PLT format.

¹² This .GRF file and sample input data are provided with the distribution diskette that comes with the LoanSTAR Workbook by Haberl et al. (1992).

5) Format each page. To print twelve graphs per page, the .PLT files need to be shrunk and pasted together. This is accomplished with a simple set of scale/translate files and the DOS copy command. The scale/translate files work as follows:

- A.PLT: Shrink. Move to the lower left corner (only one shrink command is needed).
- B.PLT: Move up one row.
- C.PLT: Move to the right one column and down two rows (back to the bottom of the page).

Therefore, a full page of twelve plots (i.e., #1, #2, ...#12) is created by appending all of these together:

A.PLT + #1 + B.PLT + #2 + B.PLT + #3 + C.PLT + #4 + B.PLT + #5 + B.PLT + #6 + C.PLT + #7 + B.PLT + #8 + B.PLT + #9 + C.PLT + #10 + B.PLT + #11 + B.PLT + #12.

6) For each page of twelve graphs, use the GRAPHER PLOT program to create a Postscript .OUT file.

7) Clean out all the temporary files.

10.2.2 Modification of Routines

In order to modify the example routines to produce plots of channels from another logger, the following steps must be taken:

- 1) Assign a three digit code to the logger. For the purposes of these instructions, we'll use the generic designation XXX.
- 2) Using the Synergistic PARSET program, make a printout of the logger's parameter set for this site. This is accomplished with the EDIT PRINT command after a logger has been selected. The last page produced by this report is a list of the channels that the PARSET software is using, as well as the left-to-right ordering of the columns in which they will appear in each TSR.
- 3) Using the last page of the parameter set report, modify the example ARCHIVE channel table (Table 10.3) to reflect the new site. This can be accomplished with any ASCII editor. These modifications include:
 - the site number (line 2 after the header);
 - the start date (first column of all lines after the header);
 - the name of each channel;
 - the error constants for each channel;
 - the description of each channel;
 - scaling of any channel that has not been previously scaled by PARSET.

Save this file as XXX90001.CHT.

4) Modify 101DATE.AWK to utilize site XXX instead of 101. Save this file as XXXDATE.AWK.

5) Modify 101CHGRF.AWK to utilize site XXX instead of 101. Save this file as XXXCHGRF.AWK.

6) 101CHGRF.BAT does not need to be changed. This routine will be written automatically at runtime.

7) For each channel in the parameter set, a template GRAPHER .GRF file needs to be written. The easiest way to do this is to modify the T1011.GRF through T10116.GRF files. This can be accomplished by either using GRAPHER interactively or by hand-editing the .GRF files. The following items must be changed:

- Data file name from T101 to TXXX (in line 3).
- The site/date designation from "Site 101 Beginning" to "Site XXX Beginning" (line 16).
- The actual description of the channel being plotted (line 24).

8) Modify and rename 101GRAPH.BAT to utilize site XXX. This includes changing the user diagnostics that appear on the screen both at the beginning of the script and the termination, but it mainly consists of tailoring the middle section to knit together the page sections that print all the graphs cleanly. As has been stated previously, the given scaling and translation factors in A.PLT, B.PLT, and C.PLT can yield up to twelve graphs per page. Additional pages that might be required can be pasted into the routines by copying the lines, which create page XXXONE.PLT and using a different destination filename.

10.2.3 Creation of Summary Pages From Raw Synergistics Data and Area Weather Data

Because each building usually has a unique parameter set, summary plot pages have been created to produce a generalized scheme for quickly inspecting data collected from multiple buildings. A summary plot page contains whole-building information presented in a standard orientation.

The motivation for creating such a page is twofold: first, in many buildings, whole-building readings are often recorded on multiple channels (e.g. A, B, and C phases); second, unless a very rigid channel selection is followed each time, it is very difficult to get the same graph appearing in the same location on the standard time series pages over several buildings. This makes it difficult to review data from multiple sites because a fair amount of time is spent finding relevant channels in different places for each site. Summary plot pages decrease the time required during plot inspection to find the information that might be crucial to them. It was found early on in the LoanSTAR Program that pages such as these are tremendously helpful for visual quality control.

An example summary plot page is shown in Figure 10.7. The first row of the summary plot page always contains a time series plot of whole-building electric for the site, as well as weather time series data (outdoor dry-bulb temperature, relative humidity, and solar radiation) for the region. In the LoanSTAR program, one or more loggers may share the same weather station. In the case where a logger does not have its own weather station, weather data from a nearby site must be merged in from an outside file.

The second row contains time series graphs of building chilled water consumption, hot water consumption or steam condensate, submetered electrical points, and lighting where applicable. The third and final row contains scatter plots of the same data points in the second row plotted against outdoor dry-bulb temperature for the region.

To create a summary plot page for the example dates as provided, the following command would be typed:

```
UTSUMM 101 92168 <CR>
```

This invokes the controlling batch file UTSUMM.BAT, and tells it to print a summary of site 101, using the Julian date of 92168 as its target. The output is the file 101SUMM.OUT, which contains the summary page in Postscript form. The flowchart of UTSUMM.BAT is given in Figure 10.8.

The methodology behind the creation of summary pages is almost identical to that of the standard time series plots, preceded by two steps:

- 1) A step to create summary pseudo-channels. This is needed in buildings with multiple electric or chilled water feeds to create a temporary channel, which totals all the subfeeds. This is accomplished for site 101 with a call to the GAWK script 101SUMM.AWK.

For example 10192168.ACS is passed to 101SUMM.AWK and produces TS101.DAT in the current directory. Within 101SUMM.AWK channels #8, 9, 10, 11, 12, 13, 19, 20, 21, and 22 are added together to form a Motor Control Center Channel (MCC), excluding any values that are missing (-99). The TS101.DAT output file then contains values for the Motor Control Center (MCC), whole-building electricity (ELEC), whole-building steam use (HW), and whole-building chilled-water use (CW). The whole-building steam is multiplied by 9.075 to allow for units of Btus.

The output file TS101.DAT is then merged together with local weather data with the command:

```
COLS ^TS%1.DAT ^202%2.WEA A1:5 B8:11 > \TEMP\TS%1.DAT <CR>
```

This calls COLS with the input files TS101.DAT and 20292168.DAT. Columns 1 through 5 from TS101.DAT and 8 through 11 from 20292168.DAT are merged together to form TS101.DAT in the subdirectory \TEMP, which is immediately followed by a deletion of TS101.DAT in the current directory because it is no longer needed.

2) A step to merge in regional weather data for the same week. Assuming both the building data and the weather data have been filtered through the MISSING program, this step can be accomplished with a simple call to COLS. COLS is one of the helpful tool kits that comes with ARCHIVE.

The remaining steps that are performed in UTSUMM.BAT are as follows:

3) Call the GAWK script 101DATE.AWK to determine the beginning dates. In a similar fashion to 101GRAPH.BAT, this creates the batch file 101CHGRF.BAT.

4) Call 101CHGRF.BAT, which uses 101CHGRF.AWK to change the TS*.GRF files for each plot. Modified graphs are then written to \TEMP.

5) Change directory to \TEMP. Then for each .GRF file in \TEMP, call GRAPHER.

6) Format the summary page using a combination of shrink and paste commands as shown.

7) Plot the Postscript file and clean-up.

10.2.3.1 Modification of Summary Plot Routines

Prior to modification of summary plot routines, it is assumed that the process for creating the standard time series plot pages is in order and functional. To modify the example routines to produce summary plots of channels from an arbitrary logger, the following steps would need to be taken:

1) Modify each template GRAPHER file, TS1011.GRF through TS10112.GRF, to reflect site XXX. This is identical to changing the original files when creating the standard pages.

2) Modify UTSUMM.BAT to do the following:

- a) Report the correct site number in the user diagnostics upon entrance and exit.
- b) Merge the weather data from the correct region/file.

3) Create a GAWK summary script similar to 101SUMM.AWK. The contents of this script will be completely site specific.

10.2.4 Creating a 3-D Graph Using Lotus 123 and Intex Solutions 3D Graph

Three dimensional (3-D) graphs have been shown to be useful in displaying schedule-related whole-building and end-use energy profiles. However, it is not always easy to create useful 3-D plots on a PC because certain software packages require that data be placed in a special format prior to processing. One such combination of processing schemes is shown in Figure 10.9. Columnar data are plotted with the Intex Solutions 3-D plot package that can be attached to Lotus 123 on a PC.

To facilitate the creation of 3-D plots, a special routine was created to convert COLUMnar data into ROW format to produce a 3-D plot -- COLROW3D (1991). With this routine two columns of ASCII data are fed to COLROW3D where they are reformatted into a row-wise matrix to allow for importing into 123 for plotting with the 3-D graphics add-on package.¹³ To facilitate this easily in a batch mode previously compiled 3-D plot instructions can be used in a 123 macro file. Output from 123 consists of .PIC files that can be plotted or passed on to additional programs for further processing. This next section describes how to use the software to produce 3-D surface plots with the Lotus 123 add-on package that is available from Intex Solutions. The reader is referred to the Lotus 123 manual or the Intex Solutions 3D graphics manual for further information about plotting the 3-D graphs.

10.2.5 Using the COLROW3D Columnar to Row Data Processing Routine

COLROW3D is a columnar data manipulation program that processes hourly energy consumption data to produce a "new" file containing a spread sheet-compatible data matrix. COLROW3D compresses each day's worth of data into one row in the matrix. For example, a leap year's worth of hourly data (8784 lines) will be compressed down to just 367 lines!

The output file generated by COLROW3D can be used in conjunction with Lotus 123 and Intex Solution's 3D-Graphics add-on package to produce a 3-D picture of energy consumption versus day of year and time of day. COLROW3D also creates a .LOG file containing information about the run and any erroneous data found. The COLROW3D program is written in ANSI Standard C.

Keywords:

<i>Source:</i>	COLROW3D's input filename.
<i>Dest or Destination:</i>	COLROW3D's output filename.
<i>LOG:</i>	COLROW3D's log file.
<i>Method or Option:</i>	Code used to process input data.
<i>3D extension:</i>	Output filename extension.
<i>3D Graph:</i>	Three dimensional graph.
<i>Decimal date:</i>	Data string used to express date and time of data together.
<i>kWh/h:</i>	Hourly energy consumption data.

¹³ This matrix file can also be passed to Microsoft Excel, which results in a similar looking 3-D graph. The ESL has a similar routine for Excel called 3DMACXL.

Requirements:

For COLROW3D: IBM PC compatible computer with at least 128K memory
MS-DOS 2.11 or greater

Input file(s):

The original energy consumption file contains two columns of data: Date (day of year and time of day expressed as a single decimal date string), and consumption (expressed in units between -999.9 and +9999.9). The data should be separated by a space from the decimal date and can be of real or integer type. The input file may contain up to 366 days of hourly data with each day containing 24 hours. All dates must be in chronological order.

COLROW3D requires one input file. Table 10.8 is a sample input file. The input file contains two columns of data separated by at least one space. The first column is the date and time of the data expressed in decimal format, while the second column is the energy consumption data. When preparing the input file, keep in mind the following "Rules":

- *The input file may only contain numeric data of the integer and real type.* No characters other than the numerals 0 through 9, decimal points, minus signs, and spaces are allowed.
- *Each line row or record should contain only two data fields.* If more than two values are included, data beyond the second value are ignored. If only one datum is given on a line, the program will assume a missing value for the second field. A value of 0 is used as the missing code.
- *The maximum data that will be read are 366 days worth of hourly data.* Each day may contain from 1 to 24 hours of data--one record per hour. Only hourly data should be used as input to COLROW3D. Data in sub-hourly format must be converted to hourly format prior to processing.
- *The first column of data in the input file is the decimal date stamp.* The decimal date is a contrived method of representing the date and time using a single data string. Before you run COLROW3D, you must first convert your date and time to the decimal date format. The Princeton ARCHIVE program by Feuermann and Kempton (1987) is recommended for this purpose. A copy of ARCHIVE is included with the LoanSTAR workbook.

Arbitrarily, January 1, 1980 00:00:00 hours is considered to be day 0 and has the decimal date representation 0000.0000. The number on the left hand side of the decimal point represents the number of days since January 1, 1980. The number on the right hand side of the decimal point represents the hour as a fraction of the day. Hours range from 0

through 23 and are calculated using the formula Hour = Decimal portion multiplied by 24 and rounded to the nearest integer. Hour 24 becomes Hour 0 of the following day. Note: while the days of the year must be in chronological order, no such requirement is imposed on the hour of the day.

Valid dates are from January 1, 1980 (day 0) through December 31, 2009 (day 10957). Leap years and century leap years are taken into consideration. The program will need to be updated for decimal dates beyond the year 2009. Table 10.11 gives decimal dates for January 1 from 1980 through 2009. The following are examples of decimal date conversion:

Date	Time	Decimal date
January 21, 1988	11 p.m.	2942.9583
May 1, 1990	1 a.m.	3773.0417
December 31, 1991	5 p.m.	4382.7083

The second data column in the input file can be either consumption or environmental data. Acceptable values are between -999.9 and 9999.9. A value of 0 will be used for missing data. If the value lies outside the acceptable range, the program records an error message to the .LOG file, and sets the hourly consumption to 0 for missing data. Data are recorded to the output file by rounding off to the first decimal place.

Examples of Energy use data

2901.0417 100 record indicates that on December 11, 1987 at 1:00 am the building used 100 kW of energy.

4020.0000 99999 ERROR! data value is out of bounds. A message will be written to the .LOG file, and the consumption will be set to 0.

Output file(s):

The output data file contains the original energy use data, which have been rearranged in a matrix format for use with Lotus 123. This file must have a .3D extension. The .LOG file contains information written by COLROW3D while the program is executed. Information regarding date and time of run, and any errors encountered during processing are included. The date of the first and last string of processed data are shown.

Output File.

The output file is an N by 24 matrix containing only the valid input data. Here N stands for number of days between the first and last valid date stamp read from the input data file. For example, for one year's worth of data N is 366.

Both sample output files are shown in Table 10.9. The first row is a header that contains the hour of the day (ranging from 0 to 23); the first column is the day of the year (for example, day 121 is May 1st); and the remaining fields are hourly consumption data (in units of kWh/h). Missing data are represented by the value 0. The very first value in the first row shows the day of year for the last date read. This makes it convenient to use the output file in a spreadsheet because it can be used to compute the number of rows in the table.

.LOG File.

COLROW3D keeps a record of what happened during each run of the program. This information is written to disk in a .LOG file. The .LOG file has the same name as the input data file, but with a .LOG extension. Existing .LOG files with the same name will be overwritten. Any errors encountered during execution are written to the .LOG file. An example of a .LOG file is shown in Table 10.10.

The header specifies the name of the program and the date and time the run was made. The next line gives the name of the input file, the output file, the .LOG file, and the option selected. The following line gives the time the first record was read and the beginning date associated with that record.

The error table follows, and lists the location of the erroneous record, the data in the record, and the invalid datum. Because *COLROW3D* can deal with very large data files, a maximum of 50 date stamp errors and 20 data errors will be recorded in the .LOG file. This is to prevent a single bad datum from causing the entire data file to be written to the .LOG file. At the end of the error table is the time the last record was read and the ending date associated with that record.

The last part of the .LOG file consists of statistics about the input records. The .LOG file ends with a note, which states that the time portion of the date stamp is not checked for chronological order, and a message that the .LOG file is complete.

Execution:

COLROW3D Input Output Option <CR>

Input is the input file name (with complete path and extension specified.)

Output is the processed data file (with .3D extension).

Option is the integer 0 or 1. Choose 0 to create a file beginning with days = 1 and ending with day = 366, each day containing 24 hours of data. If the original file has fewer than 366 days of data, missing data are set to 0. Select a value of 1 to output fewer than one year's worth of data in contiguous order. Option 1 preserves the chronological order of input file. Figure 10.10 illustrates the difference in 3-D graphs between a "0" and "1" option. Table 10.9 shows the difference in the output files.

Example:

```
COLROW3D SAMPLE.DAT SAMPLE.3D 1 <CR>
```

Action: COLROW3D will read data from the input file called SAMPLE.DAT, output data to SAMPLE.3D, and create the .LOG file SAMPLE.LOG. Because the SAMPLE.DAT input file contains less than one year's worth of data, missing data are given the value of 0.

Example:

```
COLROW3D SAMPLE.DAT SAMPLE.3D 0 <CR>
```

Action: COLROW3D will read the file SAMPLE.DAT, output to the file SAMPLE.3D, and create the .LOG file SAMPLE.LOG. The output file is a 366 by 24 matrix with missing data set to 0.

Example:

```
COLROW3D ? <CR>
```

Action: COLROW3D displays the on-line help screen. For additional help, check the manual.

Notes:

1) An additional program is available from the Energy Systems Lab that automatically creates the Lotus .PIC graphing instructions called 3DMAC.WK1. Feel free to contact the Energy Systems Laboratory about availability.¹⁴ This program is useful for automatically creating 3-D spreadsheet graphics in the batch mode.

Table 10.12 above contains the 3DGRAPH plotting instructions that were used to produce the lower half of Figure 10.10 above. The plot instructions are also included in electronic form in the SAMPLEM1.3DP file that is included with the workbook diskette. After installing, configuring, and initiating the Intex 3DGRAPH Lotus add-

¹⁴ Ask for a copy of the ESL publications list which contains a list of the public domain software that is available.

on, the SAMPLE.3D data matrix can be loaded with a FILE IMPORT command (with the pointer in cell A1). The SAMPLEM1.3DP graphing instructions can then be loaded after the 3D Graph has been initiated with a GRAPH NAME USE command.

2) COLROW3D will accept only numeric data of the real and integer type separated by at least one space. This program cannot handle any other data types. Two primary kinds of errors can occur:

(i) Decimal date errors. An error with the date stamp will occur if the day is not in chronological order. The hours of the day do not need to be in order. Example, if the input file reads:

```
3840.0000 24.2
3840.0417 25.3
3880.0000 28.0
3840.1250 25.9
3840.0833 25.5
..... ..
```

The last two records will be skipped and reported as an error in the .LOG file because the decimal dates 3840.1250 and 3840.0833 are out of sequence with the record 3880.0000.

Another date error will occur if the decimal date value is less than 0 (January 1, 1980) or larger than 10957 (December 31, 2009). Refer to the COLROW3D manual for further details.

(ii) Energy use errors. A data out-of-bounds error will occur if the consumption value lies outside the acceptable range [-999.9, 9999.9]. If this should happen, the data record is skipped and an error message is written to the .LOG file. These limits are established by the maximum file import size in Lotus 123.

Table 10.1: Example Synergistics Raw Data Format 10192168.RAW.

6/ 9/92 0: 0: 0 391 "V " 9.837 3.795 1.186 1.225 14.253 4.483 2.428 1.751 1.504 1.443 160.000 20.000 1180.000 7780.000 22.000
6/ 9/92 1: 0: 0 392 "V " 9.905 3.746 1.213 1.256 13.551 4.461 2.417 1.540 1.541 1.515 144.000 0.000 1090.000 7230.000 22.000
6/ 9/92 2: 0: 0 393 "V " 10.088 3.739 1.235 1.282 13.112 4.430 2.406 1.295 1.541 1.563 102.000 19.000 940.000 6480.000 22.000
6/ 9/92 3: 0: 0 394 "V " 10.119 3.624 1.245 1.299 13.217 4.442 2.409 1.334 1.595 1.626 102.000 0.000 1000.000 6480.000 22.000
6/ 9/92 4: 0: 0 395 "V " 10.239 3.619 1.249 1.301 13.436 4.508 2.420 1.290 1.612 1.647 100.000 21.000 940.000 6400.000 24.000
6/ 9/92 5: 0: 0 396 "V " 10.302 3.619 1.253 1.313 13.562 4.536 2.419 1.241 1.620 1.662 102.000 21.000 930.000 6240.000 22.000
6/ 9/92 6: 0: 0 397 "V " 10.365 3.642 1.250 1.316 13.572 4.571 2.427 1.233 1.610 1.659 102.000 21.000 940.000 6170.000 22.000
6/ 9/92 7: 0: 0 398 "V " 10.365 3.821 1.223 1.298 13.499 4.803 2.475 1.259 1.571 1.628 114.000 0.000 920.000 6180.000 22.000
6/ 9/92 8: 0: 0 399 "V " 10.177 3.732 1.203 1.278 13.918 4.728 2.504 0.758 1.615 1.670 130.000 19.000 960.000 6700.000 24.000
6/ 9/92 9: 0: 0 400 "V " 10.574 3.605 1.240 1.315 16.911 4.596 2.515 0.439 1.680 1.713 196.000 41.000 1360.000 11170.000 24.000
6/ 9/92 10: 0: 0 401 "V " 12.212 4.130 0.979 0.985 21.306 5.262 2.629 0.438 1.400 1.393 214.000 41.000 1310.000 9270.000 30.000
6/ 9/92 11: 0: 0 402 "V " 12.474 4.756 1.089 1.132 25.240 4.596 2.720 0.436 1.304 1.236 210.000 0.000 1390.000 8850.000 32.000
6/ 9/92 12: 0: 0 403 "V " 12.610 4.660 1.168 1.210 22.164 4.539 2.596 0.436 1.343 1.267 212.000 21.000 1390.000 8910.000 30.000
6/ 9/92 13: 0: 0 404 "V " 13.353 3.857 1.236 1.287 20.782 4.508 2.510 0.436 1.474 1.406 214.000 20.000 1280.000 8440.000 30.000
6/ 9/92 14: 0: 0 405 "V " 11.145 3.741 0.995 0.986 21.285 5.233 2.513 0.434 1.582 1.503 208.000 21.000 1240.000 7920.000 28.000
6/ 9/92 15: 0: 0 406 "V " 10.145 3.857 0.934 0.905 21.641 5.648 2.502 0.433 1.614 1.534 206.000 20.000 1140.000 7600.000 30.000
6/ 9/92 16: 0: 0 407 "V " 9.852 3.840 1.145 1.158 19.663 4.499 2.504 0.430 1.582 1.508 202.000 0.000 1040.000 6910.000 28.000
6/ 9/92 17: 0: 0 408 "V " 9.727 3.727 1.002 0.971 15.163 5.243 2.521 0.995 1.614 1.530 198.000 21.000 870.000 5370.000 24.000
6/ 9/92 18: 0: 0 409 "V " 10.030 3.751 1.118 1.112 14.598 4.543 2.527 1.312 1.605 1.538 196.000 21.000 940.000 5250.000 24.000
6/ 9/92 19: 0: 0 410 "V " 10.224 4.127 1.076 1.059 15.341 4.511 2.709 1.380 1.523 1.490 200.000 0.000 930.000 5490.000 24.000
6/ 9/92 20: 0: 0 411 "V " 10.025 4.229 1.059 1.074 15.037 4.552 2.755 1.976 1.435 1.434 202.000 22.000 1130.000 7140.000 24.000
6/ 9/92 21: 0: 0 412 "V " 10.109 4.175 1.059 1.071 14.336 4.539 2.686 1.833 1.440 1.438 190.000 20.000 1050.000 6890.000 24.000
6/ 9/92 22: 0: 0 413 "V " 10.088 4.973 1.052 1.058 14.117 4.527 2.690 1.700 1.309 1.274 194.000 21.000 1160.000 7270.000 24.000
6/ 9/92 23: 0: 0 414 "V " 10.198 5.025 1.072 1.084 13.028 4.543 2.687 1.580 1.318 1.311 174.000 0.000 1140.000 7050.000 22.000

Table 10.2: Example Output 10192168.DAT From RAW2DAT Program.

6 9 92 0 0 9.837 3.795 1.186 1.225 14.253 4.483 2.428 1.751 1.504 1.443 160.000 20.000 1180.000 7780.000 22.000
6 9 92 1 0 9.905 3.746 1.213 1.256 13.551 4.461 2.417 1.540 1.541 1.515 144.000 0.000 1090.000 7230.000 22.000
6 9 92 2 0 10.088 3.739 1.235 1.282 13.112 4.430 2.406 1.295 1.541 1.563 102.000 19.000 940.000 6480.000 22.000
6 9 92 3 0 10.119 3.624 1.245 1.299 13.217 4.442 2.409 1.334 1.595 1.626 102.000 0.000 1000.000 6480.000 22.000
6 9 92 4 0 10.239 3.619 1.249 1.301 13.436 4.508 2.420 1.290 1.612 1.647 100.000 21.000 940.000 6400.000 24.000
6 9 92 5 0 10.302 3.619 1.253 1.313 13.562 4.536 2.419 1.241 1.620 1.662 102.000 21.000 930.000 6240.000 22.000
6 9 92 6 0 10.365 3.642 1.250 1.316 13.572 4.571 2.427 1.233 1.610 1.659 102.000 21.000 940.000 6170.000 22.000
6 9 92 7 0 10.365 3.821 1.223 1.298 13.499 4.803 2.475 1.259 1.571 1.628 114.000 0.000 920.000 6180.000 22.000
6 9 92 8 0 10.177 3.732 1.203 1.278 13.918 4.728 2.504 0.758 1.615 1.670 130.000 19.000 960.000 6700.000 24.000
6 9 92 9 0 10.574 3.605 1.240 1.315 16.911 4.596 2.515 0.439 1.680 1.713 196.000 41.000 1360.000 11170.000 24.000
6 9 92 10 0 12.212 4.130 0.979 0.985 21.306 5.262 2.629 0.438 1.400 1.393 214.000 41.000 1310.000 9270.000 30.000
6 9 92 11 0 12.474 4.756 1.089 1.132 25.240 4.596 2.720 0.436 1.304 1.236 210.000 0.000 1390.000 8850.000 32.000
6 9 92 12 0 12.610 4.660 1.168 1.210 22.164 4.539 2.596 0.436 1.343 1.267 212.000 21.000 1390.000 8910.000 30.000
6 9 92 13 0 13.353 3.857 1.236 1.287 20.782 4.508 2.510 0.436 1.474 1.406 214.000 20.000 1280.000 8440.000 30.000
6 9 92 14 0 11.145 3.741 0.995 0.986 21.285 5.233 2.513 0.434 1.582 1.503 208.000 21.000 1240.000 7920.000 28.000
6 9 92 15 0 10.145 3.857 0.934 0.905 21.641 5.648 2.502 0.433 1.614 1.534 206.000 20.000 1140.000 7600.000 30.000
6 9 92 16 0 9.852 3.840 1.145 1.158 19.663 4.499 2.504 0.430 1.582 1.508 202.000 0.000 1040.000 6910.000 28.000
6 9 92 17 0 9.727 3.727 1.002 0.971 15.163 5.243 2.521 0.995 1.614 1.530 198.000 21.000 870.000 5370.000 24.000
6 9 92 18 0 10.030 3.751 1.118 1.112 14.598 4.543 2.527 1.312 1.605 1.538 196.000 21.000 940.000 5250.000 24.000
6 9 92 19 0 10.224 4.127 1.076 1.059 15.341 4.511 2.709 1.380 1.523 1.490 200.000 0.000 930.000 5490.000 24.000
6 9 92 20 0 10.025 4.229 1.059 1.074 15.037 4.552 2.755 1.976 1.435 1.434 202.000 22.000 1130.000 7140.000 24.000
6 9 92 21 0 10.109 4.175 1.059 1.071 14.336 4.539 2.686 1.833 1.440 1.438 190.000 20.000 1050.000 6890.000 24.000
6 9 92 22 0 10.088 4.973 1.052 1.058 14.117 4.527 2.690 1.700 1.309 1.274 194.000 21.000 1160.000 7270.000 24.000
6 9 92 23 0 10.198 5.025 1.072 1.084 13.028 4.543 2.687 1.580 1.318 1.311 174.000 0.000 1140.000 7050.000 22.000

Table 10.3: Example Channel Table For the 10190001.CHT ARCHIVE Program.

Date	Time	Raw-	Data	Arch	Name of	Archive	Arch	Conv'n	Conv'n	Error	Error	Channel
MM/DD/YY	HH: mm	lin	coln	coln	Channel	Units	Format	Code	Constants	Code	Constants	Description
(YY DDD)		pos	pos	pos								
#-----	-----	-----	-----	-----								
04/23/92	00:00	1	0	0	Begin	UTC						
04/23/92	00:00	1	1	1	Bldg.#	xx	I3	2	0 101	0		Beginning Date
04/23/92	00:00	1	1	2	Mon-Raw	MM	I3	1		0		*Good starting
04/23/92	00:00	1	2	3	Mon-Raw	DD	I3	1		0		Month
04/23/92	00:00	1	3	4	Mon-Raw	YY	I3	1		0		Day
04/23/92	00:00	1	3	5	Greg-Jul	MMDDYY	I5	24	1 2	0		Year
04/23/92	00:00	1	4	7	Time	HH mm	I5	16	5	0		Time
04/23/92	00:00	1	3	6	Greg-Dec	DDD.frac	F10.4	28		0		Gregorian Date
04/23/92	00:00	1	6	8	S/RMCC1	F9.3	F9.3	1		1	-5 500	S/R MCC 1 (kWh)
04/23/92	00:00	1	7	9	S/RMCC1	F9.3	F9.3	1		1	-5 500	S/R AHUs 1s,2
04/23/92	00:00	1	8	19	HDF1-2N1	F9.3	F9.3	1		1	-5 500	Hot Deck Fans
04/23/92	00:00	1	9	20	HDF1-2N2	F9.3	F9.3	1		1	-5 500	Hot Deck Fans
04/23/92	00:00	1	10	10	S/RMCC2	F9.3	F9.3	1		1	-5 500	S/R MCC 2 (kWh)
04/23/92	00:00	1	11	11	S/RMC2/1	F9.3	F9.3	1		1	-5 500	S/R AHU 2n, R
04/23/92	00:00	1	12	12	S/RMC2/1	F9.3	F9.3	1		1	-5 500	S/R AHU 1n, R
04/23/92	00:00	1	13	13	ChWPump	F9.3	F9.3	1		1	0 500	ChW Pump (kWh)
04/23/92	00:00	1	14	21	HDF1-2S1	F9.3	F9.3	1		1	-5 500	Hot Deck Fans
04/23/92	00:00	1	15	22	HDF1-2S2	F9.3	F9.3	1		1	-5 500	Hot Deck Fans
04/23/92	00:00	1	16	14	kWh M A	F9.3	F9.3	1		1	0 500	Bldg kWh Meter
04/23/92	00:00	1	17	15	CondRet	F9.3	F9.3	1		1	0 99999	Cond Ret Meter
04/23/92	00:00	1	18	16	ChWBtuT	F9.3	F9.3	1		1	0 99999	ChW Btu (kBtu)
04/23/92	00:00	1	19	17	ChWGalt	F9.3	F9.3	1		1	0 99999	ChW Gal (gal)
04/23/92	00:00	1	20	18	kWh M B	F9.3	F9.3	1		1	0 500	Bldg kWh Meter
04/11/99	23:00	1	0	0	End	UTC						

Table 10.4: Example .LOG File From the ARCHIVE Program.

Log of Archive, version: 1.41 of 15 June 1987, processed on 24 June 1992

Files:

RAW DATA 10192168.dat
 CHANNEL TABLE 10190001.cht
 ARCHIVE 10192168.ach
 LOG 10192168.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*
 |numbers| indicates a line of data, *numbers* is a comment line.

First case on raw data: 92 161 00:00

 BeginDate: 92 114 00:00 First output case: 92 161 00:00

 EndDate: 99 101 23:00 Last output case: 92 167 23:00

STATISTICS:

168 lines read from beginning of raw data file.

168 lines processed between Begin and End dates.

(including 0 comments and 0 all-blank lines)

0 line errors detected.

0 data errors, and 0 missing data detected

TABLE 10.5: Summary of GRAPHER Instructions for Graph T1017.GRF.

**AXIS DATA COLUMNS CENTERED BEST
X Y FILENMS X Y LINE SYM. FIT**

TYPE: LINEAR LINEAR 1 T101 F N SOLID NO NO

TITLE: Site 101 Building Meter 2

START: 1.5,1.0 1.5,1.0 3

LENGTH: 6.0 6.0 4

START: 4543.0 0.0 5

END: 4550.0 0.0 6

TICS: YES YES 7

TIC LAB: YES YES 8

AXIS FILE: X-AXIS Y-AXIS

GRID FILE:

TEXT FILE:

DIV.FILE:

Table 10.6: T1017.GRF GRAPHER File.

1243
 1 2 0 0 0
 t101
 70 78 48 19"NO " 48
 "YES" "SOLID" 1.500e-001 1
 "NO" 41 1.000e-001 1 1
 48 9.900e+028 9.900e+028 0.000e+000 "DEFAULT" 1.000e-001 1
 "SOLID" 0 1.500e-001 9.9000000e+029 9.9000000e+029 200 2.000e+000 1
 9.9000000e+028 9.9000000e+029 9.9000000e+028 9.9000000e+029 1.500e-001
 X-AXIS
 1.5000000e+000 1.0000000e+000 6.0000000e+000 88
 3.9200000e+003 3.9270000e+003 9.9000000e+028 1 1
 0.0000000e+000 1.0000000e+000 1.5000000e-001 1 1
 7 0 1
 1 9.9000000e+028 0.0000000e+000 9.9000000e+028 2.5000000e-001
 "DEFAULT" "DEFAULT" "Site 101 Beginning"
 4.0000000e-002
 Y-AXIS
 1.5000000e+000 1.0000000e+000 6.0000000e+000 89
 0.0000000e+000 9.9000000e+028 9.9000000e+028 1 1
 2.7000000e+002 9.9000000e+028 1.5000000e-001 1 1
 10 1 1
 1 9.9000000e+028 0.0000000e+000 9.9000000e+028 2.5000000e-001
 "DEFAULT" "DEFAULT" "Bldg Meter A (kWh/h)"
 4.0000000e-002

TABLE 10.7: Example Output from the ARCHIVE Program, File 10192168.ACH.

101 6 9 92 92161 4543.0000 0 9.837 3.795 14.253 4.483 2.428 1.751 160.000 20.000 1180.000 7780.000 22.000
1.186 1.225 1.504 1.443
101 6 9 92 92161 4543.0417 100 9.905 3.746 13.551 4.461 2.417 1.540 144.000 0.000 1090.000 7230.000
22.000 1.213 1.256 1.541 1.515
101 6 9 92 92161 4543.0833 200 10.088 3.739 13.112 4.430 2.406 1.295 102.000 19.000 940.000 6480.000
22.000 1.235 1.282 1.541 1.563
101 6 9 92 92161 4543.1250 300 10.119 3.624 13.217 4.442 2.409 1.334 102.000 0.000 1000.000 6480.000
22.000 1.245 1.299 1.595 1.626
101 6 9 92 92161 4543.1667 400 10.239 3.619 13.436 4.508 2.420 1.290 100.000 21.000 940.000 6400.000
24.000 1.249 1.301 1.612 1.647
101 6 9 92 92161 4543.2083 500 10.302 3.619 13.562 4.536 2.419 1.241 102.000 21.000 930.000 6240.000
22.000 1.253 1.313 1.620 1.662
101 6 9 92 92161 4543.2500 600 10.365 3.642 13.572 4.571 2.427 1.233 102.000 21.000 940.000 6170.000
22.000 1.250 1.316 1.610 1.659
101 6 9 92 92161 4543.2917 700 10.365 3.821 13.499 4.803 2.475 1.259 114.000 0.000 920.000 6180.000
22.000 1.223 1.298 1.571 1.628
101 6 9 92 92161 4543.3333 800 10.177 3.732 13.918 4.728 2.504 0.758 130.000 19.000 960.000 6700.000
24.000 1.203 1.278 1.615 1.670
101 6 9 92 92161 4543.3750 900 10.574 3.605 16.911 4.596 2.515 0.439 196.000 41.000 1360.000 11170.000
24.000 1.240 1.315 1.680 1.713
101 6 9 92 92161 4543.4167 1000 12.212 4.130 21.306 5.262 2.629 0.438 214.000 41.000 1310.000 9270.000
30.000 0.979 0.985 1.400 1.393
101 6 9 92 92161 4543.4583 1100 12.474 4.756 25.240 4.596 2.720 0.436 210.000 0.000 1390.000 8850.000
32.000 1.089 1.132 1.304 1.236
101 6 9 92 92161 4543.5000 1200 12.610 4.660 22.164 4.539 2.596 0.436 212.000 21.000 1390.000 8910.000
30.000 1.168 1.210 1.343 1.267
101 6 9 92 92161 4543.5417 1300 13.353 3.857 20.782 4.508 2.510 0.436 214.000 20.000 1280.000 8440.000
30.000 1.236 1.287 1.474 1.406
101 6 9 92 92161 4543.5833 1400 11.145 3.741 21.285 5.233 2.513 0.434 208.000 21.000 1240.000 7920.000
28.000 0.995 0.986 1.582 1.503
101 6 9 92 92161 4543.6250 1500 10.145 3.857 21.641 5.648 2.502 0.433 206.000 20.000 1140.000 7600.000
30.000 0.934 0.905 1.614 1.534
101 6 9 92 92161 4543.6667 1600 9.852 3.840 19.663 4.499 2.504 0.430 202.000 0.000 1040.000 6910.000
28.000 1.145 1.158 1.582 1.508
101 6 9 92 92161 4543.7083 1700 9.727 3.727 15.163 5.243 2.521 0.995 198.000 21.000 870.000 5370.000
24.000 1.002 0.971 1.614 1.530
101 6 9 92 92161 4543.7500 1800 10.030 3.751 14.598 4.543 2.527 1.312 196.000 21.000 940.000 5250.000
24.000 1.118 1.112 1.605 1.538
101 6 9 92 92161 4543.7917 1900 10.224 4.127 15.341 4.511 2.709 1.380 200.000 0.000 930.000 5490.000
24.000 1.076 1.059 1.523 1.490
101 6 9 92 92161 4543.8333 2000 10.025 4.229 15.037 4.552 2.755 1.976 202.000 22.000 1130.000 7140.000
24.000 1.059 1.074 1.435 1.434
101 6 9 92 92161 4543.8750 2100 10.109 4.175 14.336 4.539 2.686 1.833 190.000 20.000 1050.000 6890.000
24.000 1.059 1.071 1.440 1.438
101 6 9 92 92161 4543.9167 2200 10.088 4.973 14.117 4.527 2.690 1.700 194.000 21.000 1160.000 7270.000
24.000 1.052 1.058 1.309 1.274
101 6 9 92 92161 4543.9583 2300 10.198 5.025 13.028 4.543 2.687 1.580 174.000 0.000 1140.000 7050.000
22.000 1.072 1.084 1.318 1.311

Table 10.8: Example Input Data File for COLROW3D.***An Example of An Input Data File***

```
4138.0000 928.74
4138.0417 915.18
4138.0833 903.13
4138.1250 876.25
4138.1667 864.20
4138.2083 857.17
4138.2500 861.44
4138.2917 883.79
4138.3333 982.74
4138.3750 1094.50
4138.4167 1178.63
4138.4583 1215.80
4138.5000 1218.32
4138.5417 1196.97
```

Table 10.9: Example Output Data File for COLROW3D.

```

Method "0"

366 0 1 2 3 4 20 21 22 23
1 929 915 903 876 864 ... 980 982 984 957
2 910 883 869 855 840 ... 969 974 988 968
.
.
.
366 918 887 863 850 837 ... 877 889 895 892

Method "1"

120 0 1 2 3 4 ... 20 21 22 23
359 831 828 822 816 809 ... 839 853 850 851
360 839 822 813 811 809 ... 835 846 853 844
.
.
.
366 877 873 864 874 879 ... 874 889 877 883
1 875 851 811 807 807 ... 859 863 867 864
2 351 839 831 827 818 ... 821 832 839 841
3 841 831 827 825 825 ... 857 866 855 852
.
.
.
120 894 883 881 878 872 ... 926 921 922 920

```

Table 10.10: An Example .LOG File for COLROW3D.

Sample .LOG file.

.LOG of COLROW3D run Fri Aug 16 01:59:30 1991
 Raw data file : njb0691.DAT
 COLROW3D matrix file : NJB0691.3D
 .LOG file : NJB0691..LOG
 Method used : 1
 First record read at 01:59:31 Begin Date : 4138.0000
 The following records were skipped
 Record Decimal Date kWh/h data Incorrect Value

9 4138.3335 99982.7422 kWh
 49 4139.9165 987.5110 date

Last record read at 01:59:55 End Date : 4198.9585
 Statistics :
 Total number of records read: 1464
 Total number of records processed: 1462
 Total number of records skipped: 2
 Total number of bad Decimal Dates: 1
 Total number of bad data values: 1

Notice : Time values within a day are NOT checked for
 chrono.LOGical order.
 *** Error report completed. ***

Table 10.11: Decimal Date Reference Table for COLROW3D. The following is a table of decimal dates for January 1 for the years from 1980 through 2009.

	Year	Dec.Date	# Days
January 1	1981	.....366	..... 365
January 1	1982	..... 731	..... 365
January 1	1983	.....1096	..... 365
January 1	1984	.....1461	..... 366
January 1	1985	.....1827	..... 365
January 1	1986	.....2192	..... 365
January 1	1987	.....2557	..... 365
January 1	1988	.....2922	..... 366
January 1	1989	.....3288	..... 365
January 1	1990	.....3653	..... 365
January 1	1991	.....4018	..... 365
January 1	1992	.....4383	..... 366
January 1	1993	.....4749	..... 365
January 1	1994	.....5114	..... 365
January 1	1995	.....5479	..... 365
January 1	1996	.....5844	..... 366
January 1	1997	.....6210	..... 365
January 1	1998	.....6575	..... 365
January 1	1999	.....6940	..... 365
January 1	2000	.....7305	..... 366
January 1	2001	.....7671	..... 365
January 1	2002	.....8036	..... 365
January 1	2003	.....8401	..... 365
January 1	2004	.....8766	..... 366
January 1	2005	.....9132	..... 365
January 1	2006	.....9497	..... 365
January 1	2007	.....9862	..... 365
January 1	2008	.....10227	..... 366
January 1	2009	.....10593	.....365

Table 10.12: Intex Solutions 3DGRAPH Plotting Instructions for 3D Surface Plot SAMPLEM1.3DP.

TYPE SURFACE HIDDEN
X B1..Y1
Y A2..A127
A B2..Y127
OPTIONS TITLE FIRST "EXAMPLE PLOT FOR COLROW3D"
 SECOND "INPUT=SAMPLE.DAT, OPTION=1"
 X AXIS "HOUR OF DAY"
 Y AXIS "DAY OF YEAR"
 Z AXIS "ELECTRICITY USE (KWH/H)"
OPTIONS SCALE Z-SCALE AUTOMATIC
 X-SKIP 2
 Y-SKIP 15
OPTIONS B&W
DISPLAY ROTATION 270
 VIEWPOINT MEDIUM
 AXIS YES

Figure 10.1: Flow Chart for R2A.BAT Plotting Procedure.

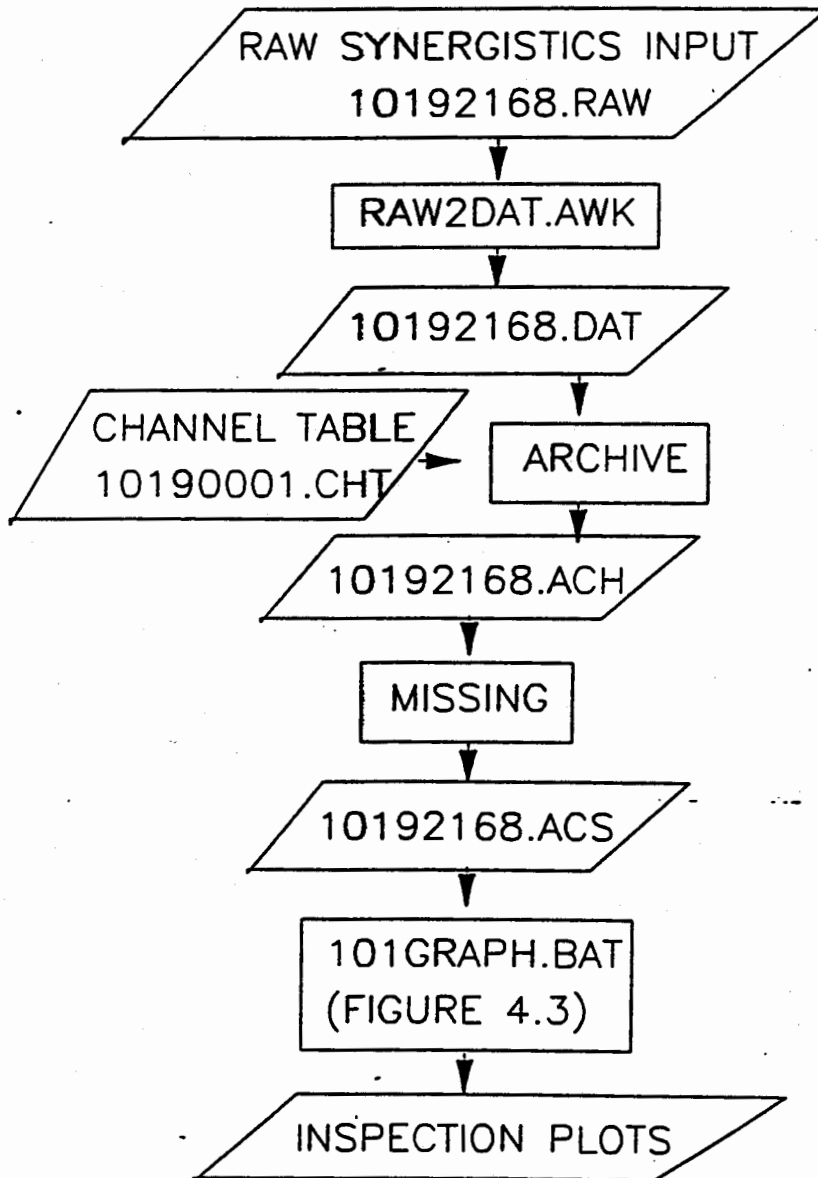


Figure 10.2: Example plot of the first 12 channels from Site 101.

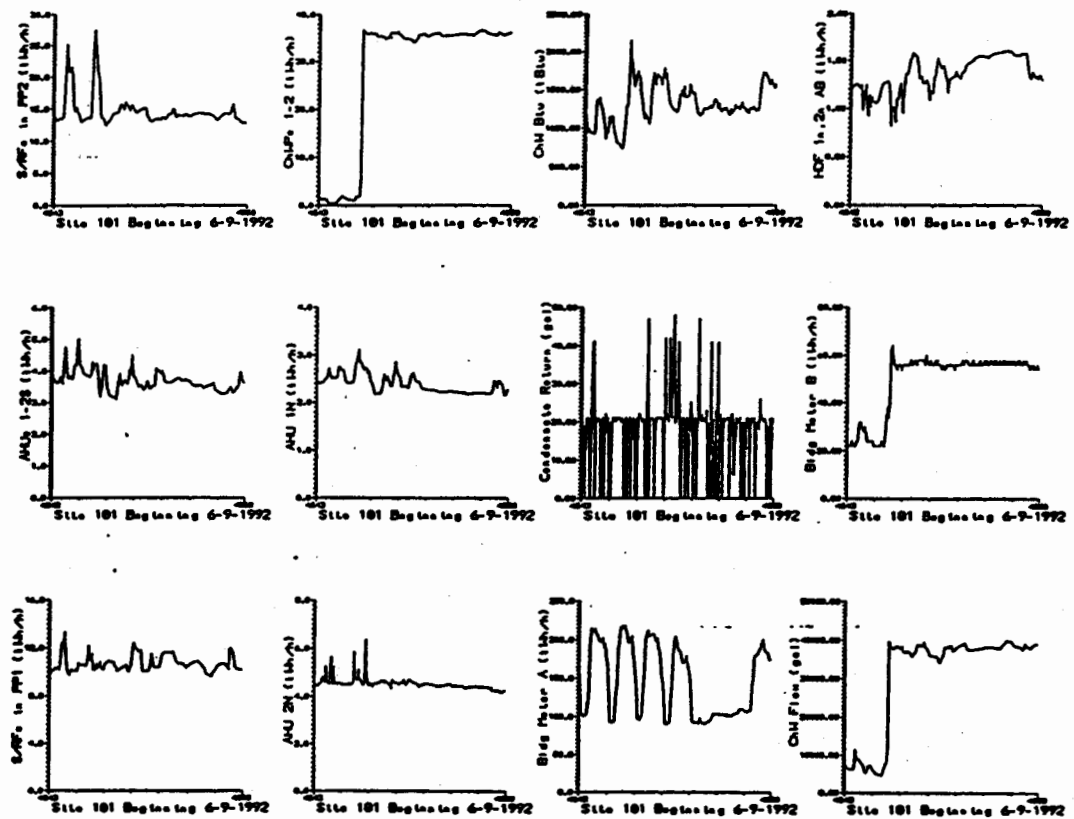


Figure 10.3: Example plot of the remaining channels from Site 101.

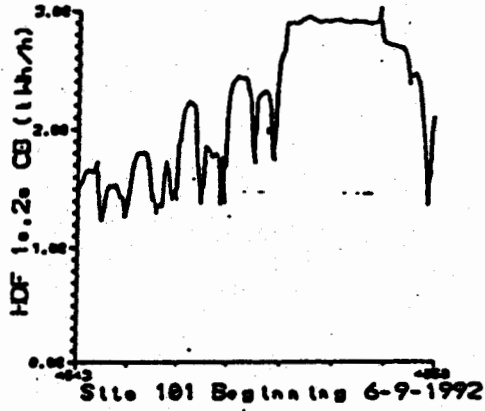
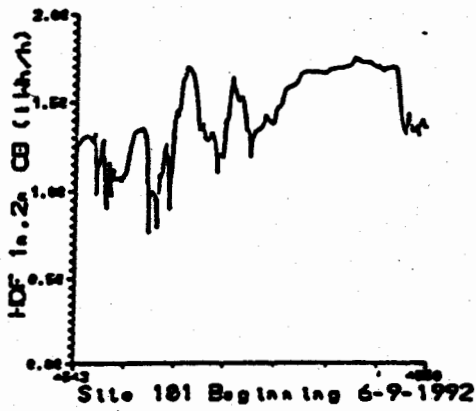
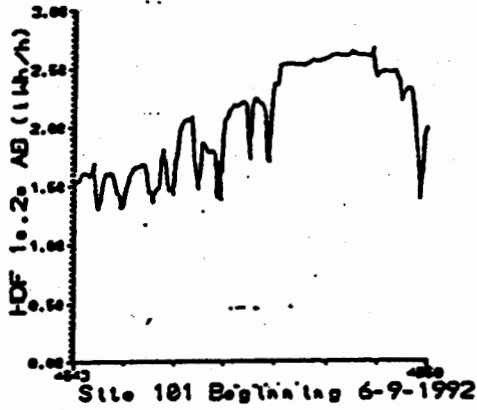


Figure 10.4: Flow Chart for the GRAPHER Program. This figure illustrates the basic command flow chart for the GRAPHER software

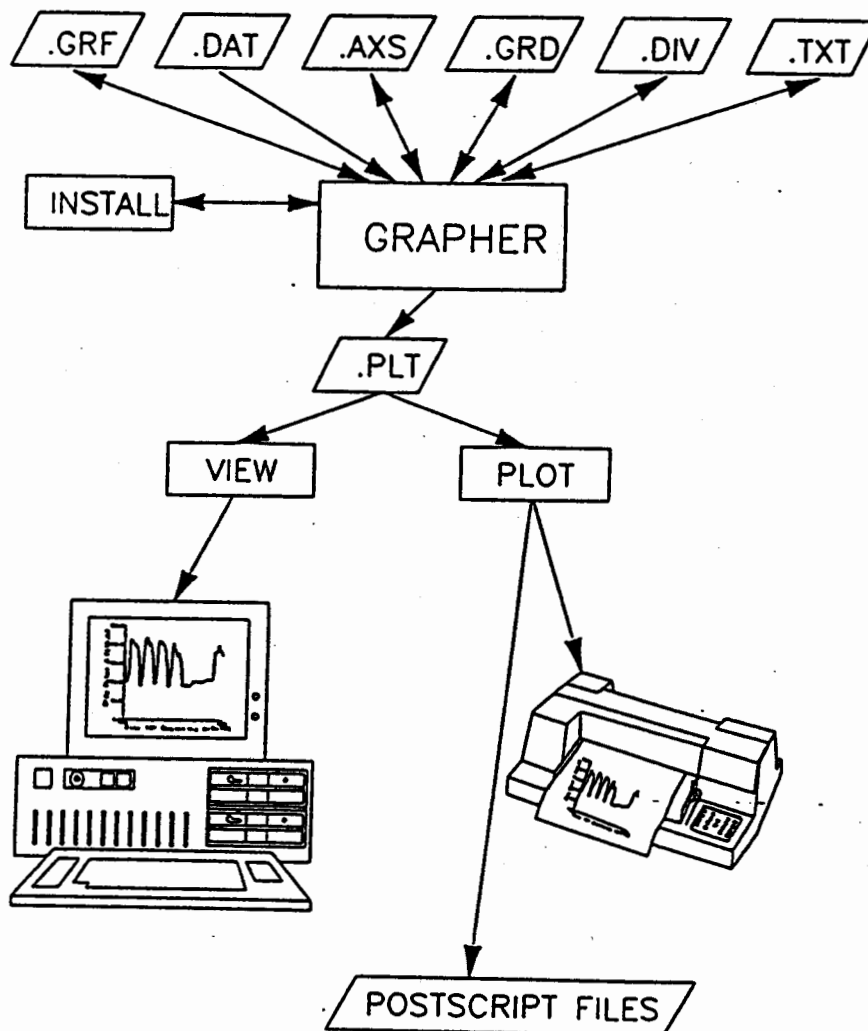


Figure 10.5: Graph created with T1017.GRF and T101.DAT Data File.

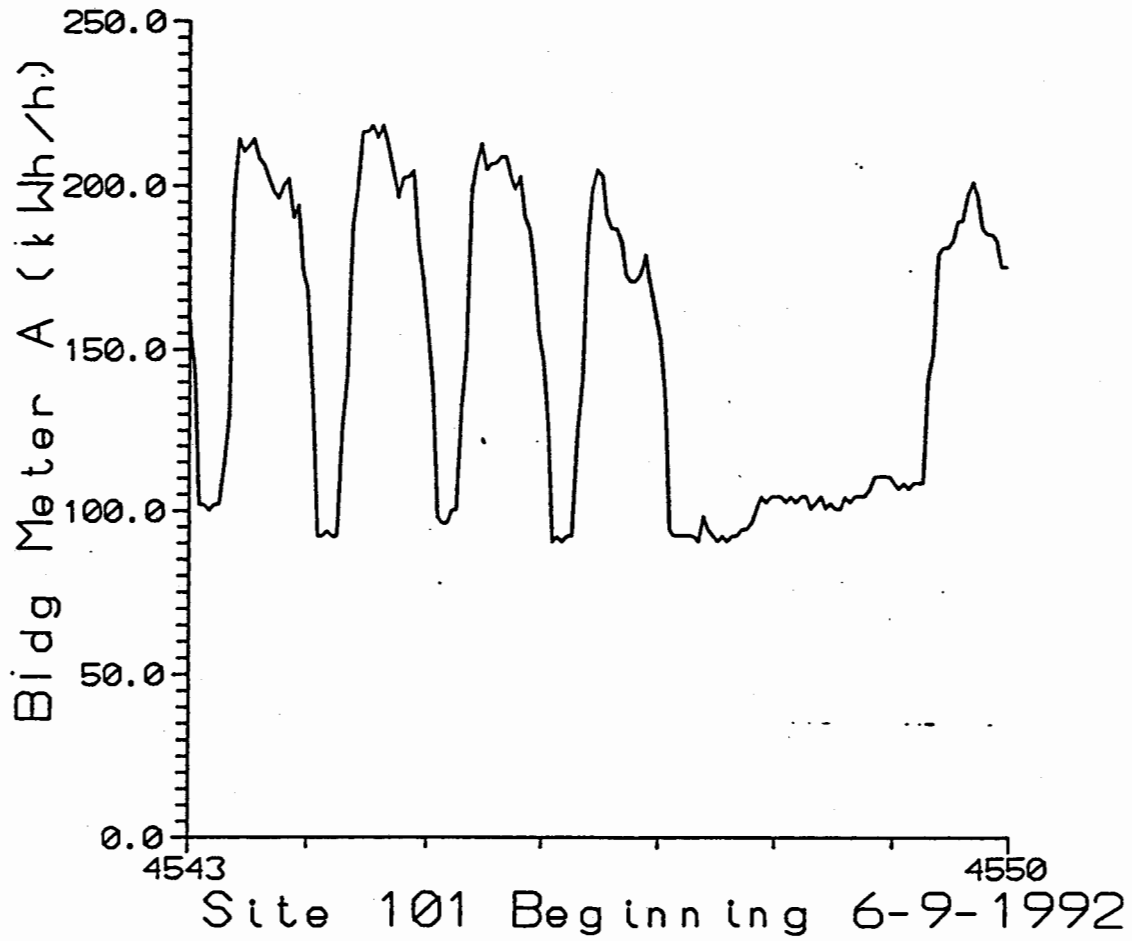


Figure 10.6: Flow chart for 101GRAPH.BAT.

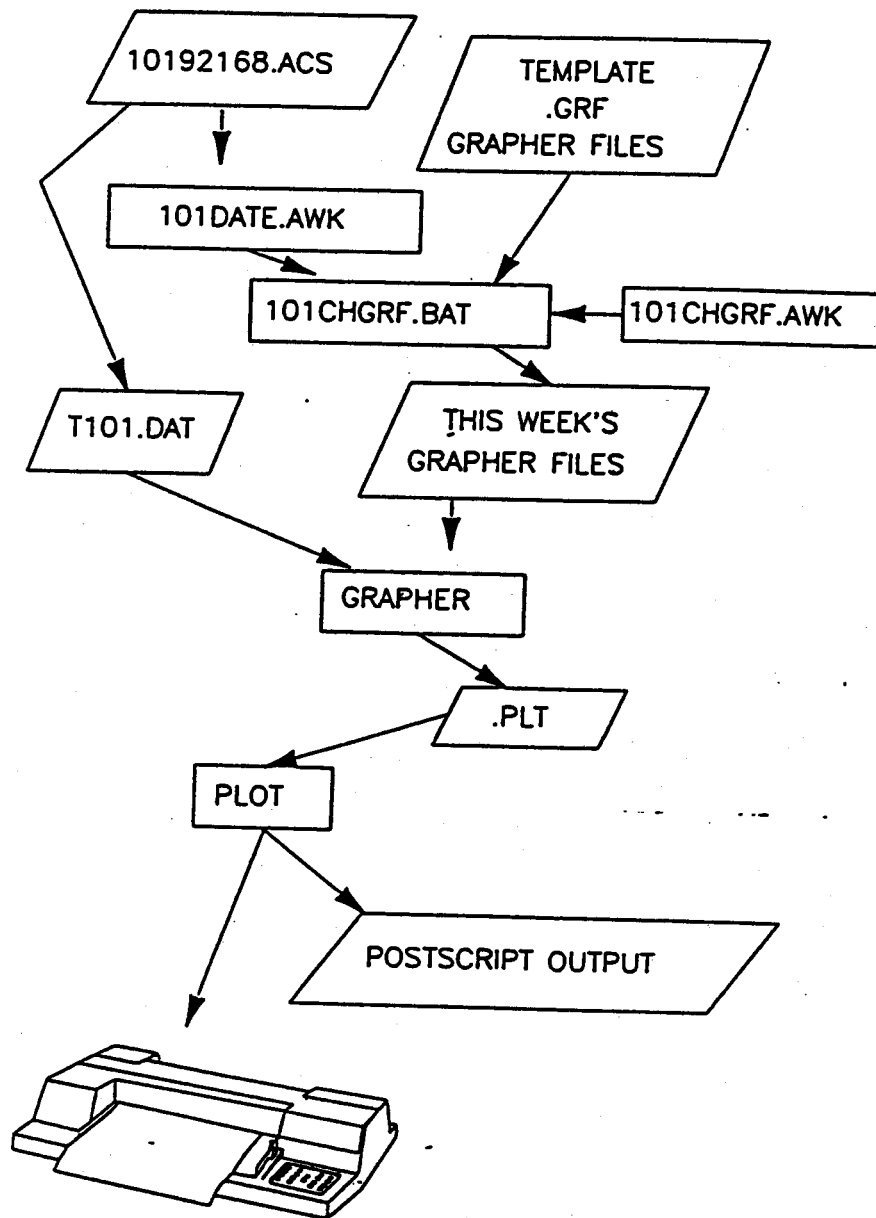


Figure 10.7: Example summary plot for Site 101.

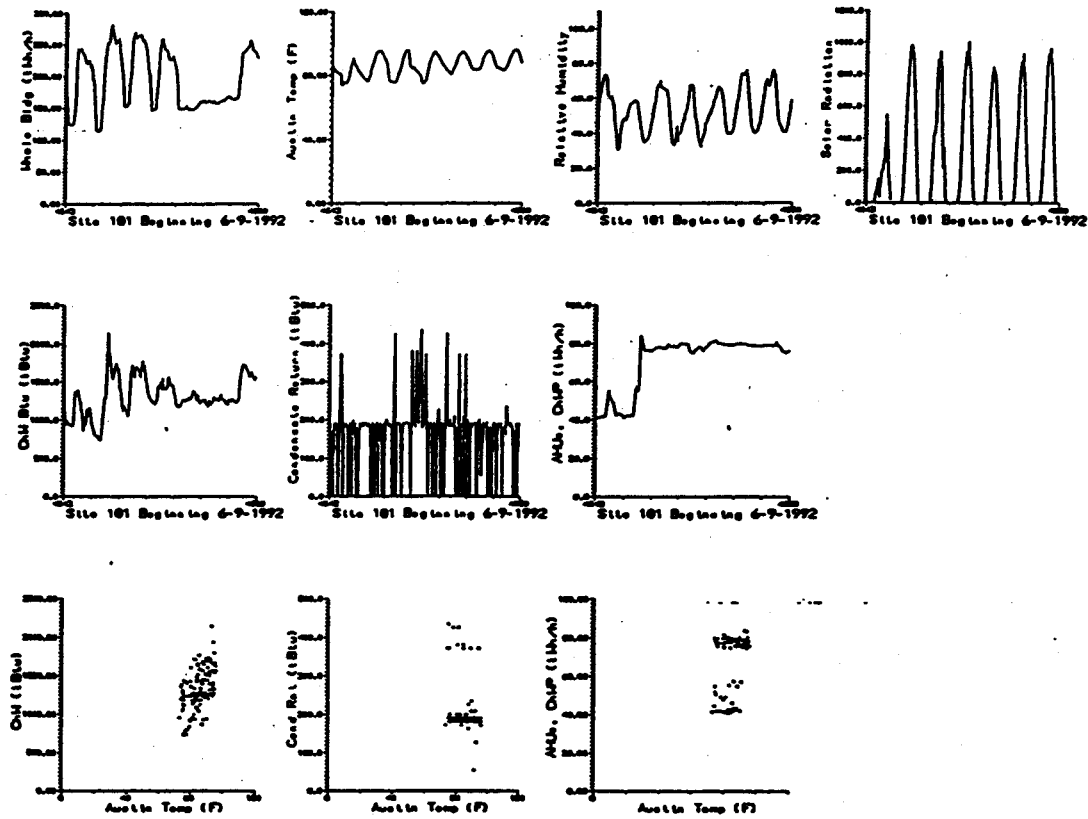


Figure 10.8: Flow chart for summary page UTSUMM.BAT.

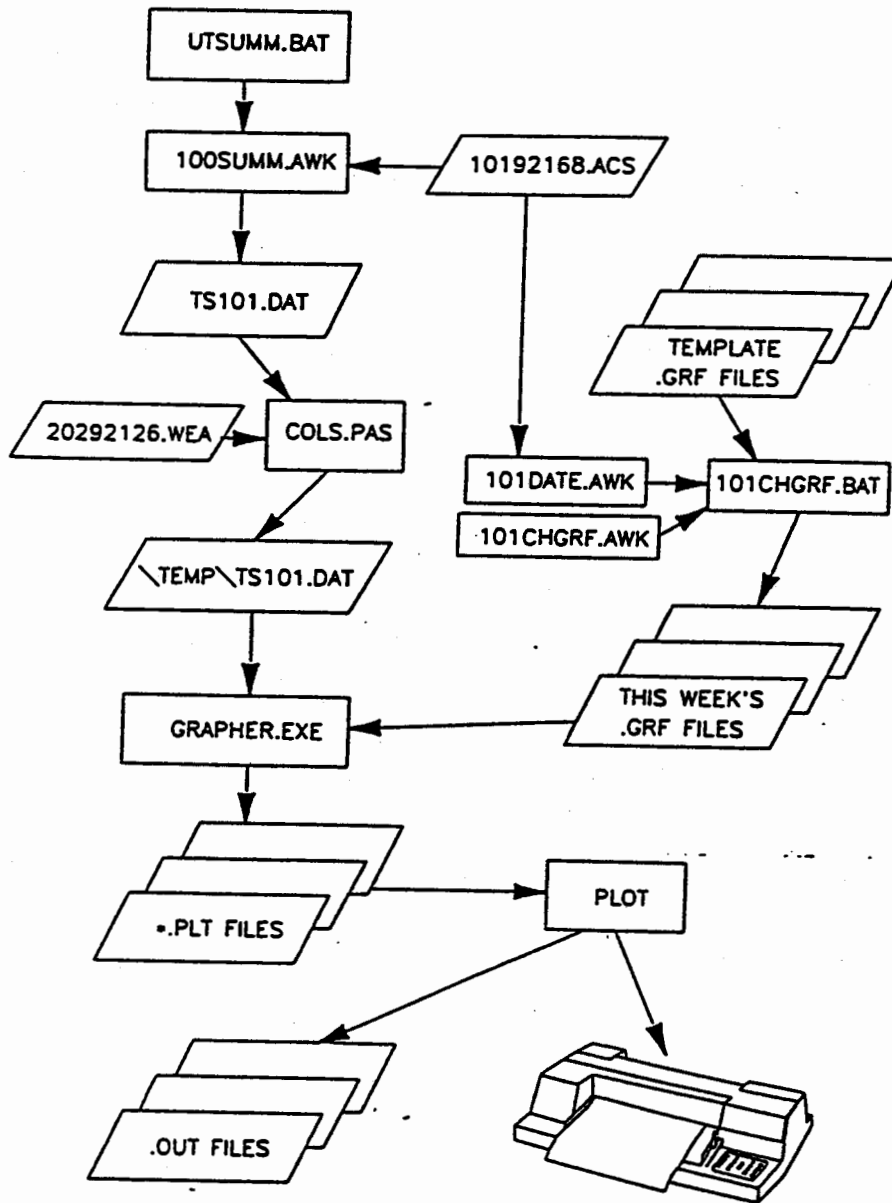


Figure 10.9: Basic flow chart for producing 3-D plots. This figure shows a basic flow chart for producing 3-D plots using several commercially available software packages and data processing routines from the LoanSTAR program.

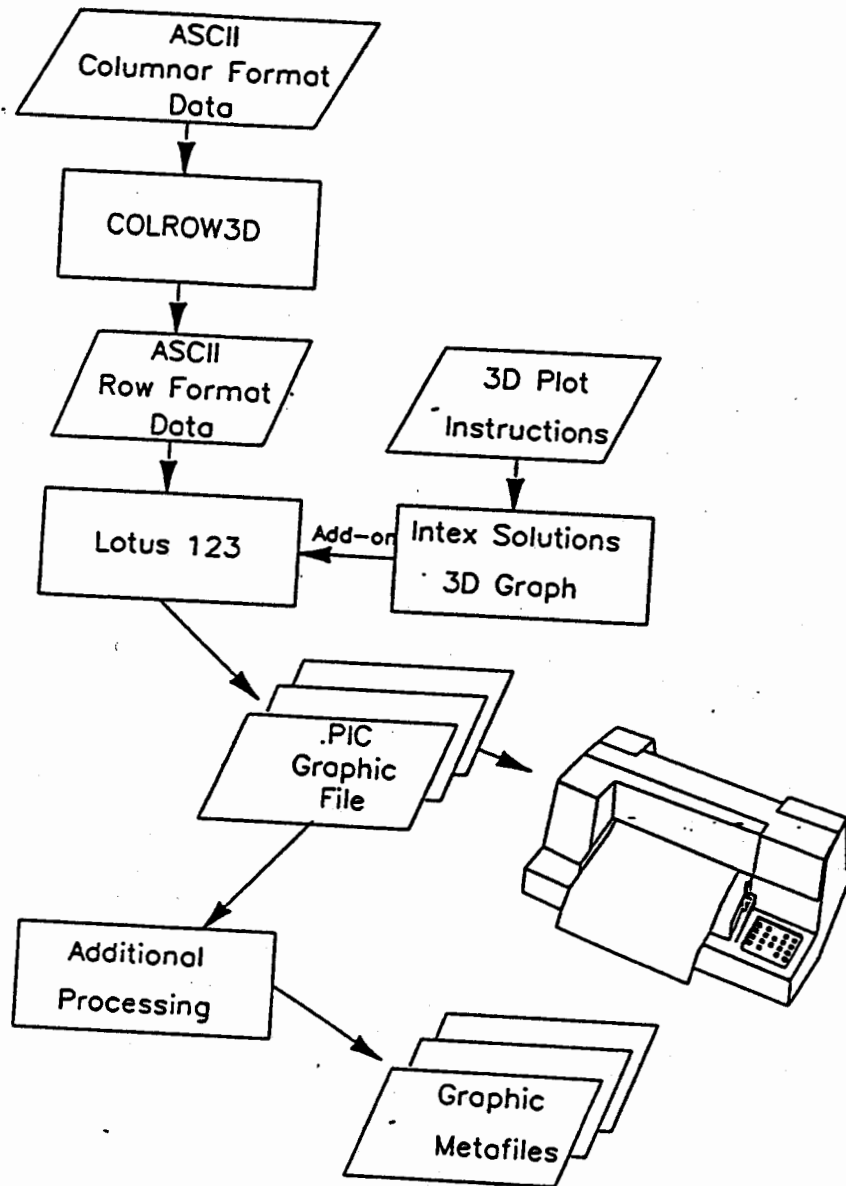
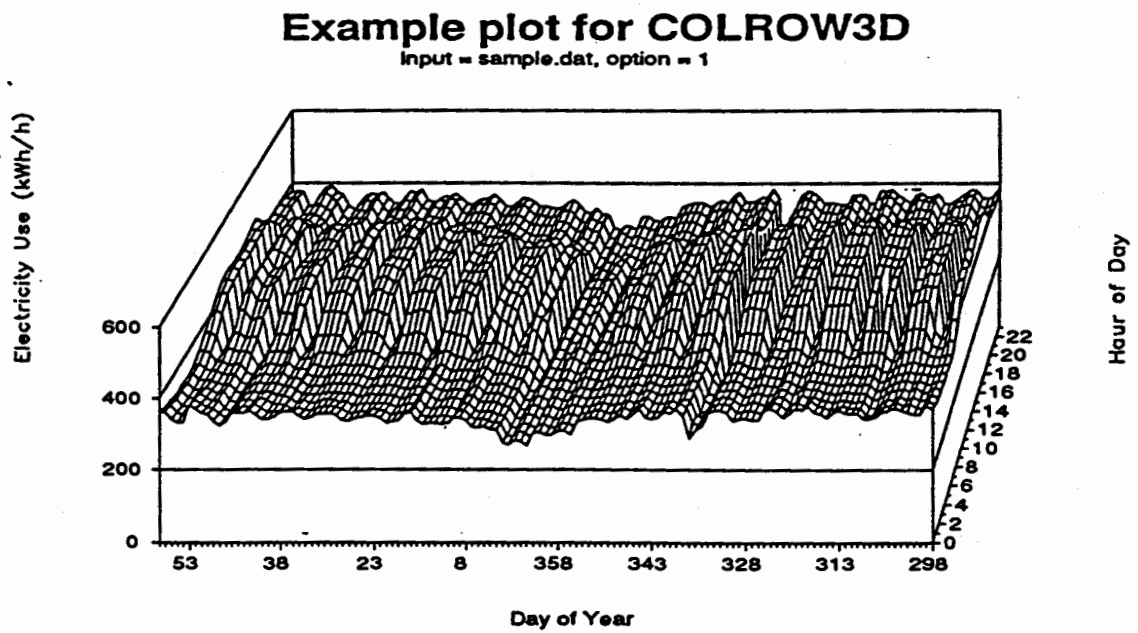
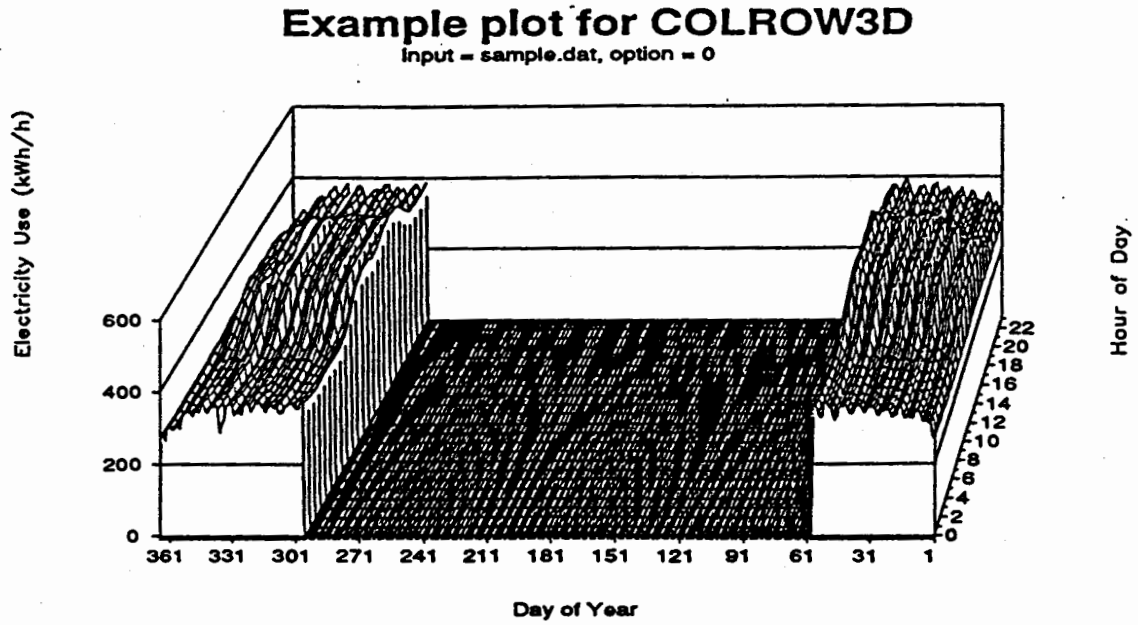


Figure 10.10: Example .PIC plots using the COLROW3D software packages.



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