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Texas Loan STAR Monitoring & Analysis Program
Improving the Performance of Retrofits by Providing Operator Feedback from Measured Data

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ABSTRACT

This paper describes how continuous monitoring and follow-up has improved the savings from energy conservation retrofits in the LoanSTAR program. It describes the importance of the feedback from the facility engineer or the building operator and how it can improve retrofit performance. Finally, the importance of Operation and Maintenance (O&M) is outlined. Results are presented which provide the status and cost savings for selected LoanSTAR buildings. Three O&M opportunities identified by the monitored data and follow-up are discussed in detail, including the process of outlining the problems, investigating the problems and the final outcomes.

INTRODUCTION

Energy use in commercial buildings amounts to about 13% of the total U.S. energy use (EIA, 1986). Energy saving retrofits have proven effective at reducing energy cost for building owners and at moderating the total U.S. energy consumption. One recent study of over 1,700 building energy retrofits reported a median annual savings of 18% of whole building energy usage with a median payback time of 3.1 years (Greely et al. 1990).

The Texas LoanSTAR program is an eight year, $98 million revolving loan program for energy conservation retrofits in Texas involving local government and school buildings funded by oil overcharge dollars. The program began in 1988. Public sector institutions participating in the program must repay the loans according to the estimated savings in four years or less.

As a part of this program, a state-wide Monitoring and Analysis Program (MAP) was established in 1989. The major objectives of the LoanSTAR MAP are to: 1) verify energy and dollar savings of the retrofits, 2) reduce energy cost by identifying operational & maintenance improvements, 3) improve retrofit selection in future rounds of the LoanSTAR program, and 4) initiate a data base of energy use in institutional and commercial buildings in Texas. Currently the program is monitoring 1,700+ channels of hourly data from over four dozen buildings and fifty-five weather stations, using public domain polling procedures that collect information from microcomputer-based field data recorders from several manufacturers.

The Use of Monitored Energy Data to Better Understand and Operate Buildings

Monitored data from commercial and residential buildings have been used in several ways to better understand the consumption behavior of specific buildings or types of buildings and to find ways to use energy more efficiently by developing models or indices of energy consumption. A study of multifamily residents in New Jersey in the late 1970's analyzed typical town-houses, by using performance indices (e.g. cubic feet of natural gas/°F-day). These indices were used to establish average levels of energy consumption and thereby determine their dependency on weather and building characteristics. These indices also enabled the study of remaining sources of variability (Socolow, 1978).

The continuous analysis of metered data has also been used to provide large commercial building operators and administrators with information regarding day to day energy consumption to help identify operational and maintenance problems (Haberl & Vajda, 1988). Diagnoses which are based on continuous analysis have also been developed into an expert system to automatically diagnose new potential problems (Haberl and Claridge, 1987). Such a system analyzed daily energy consumption by comparing it with historical energy consumption patterns. Causes of abnormal consumption were identified by comparison to previously observed patterns of abnormal consumption. Daily electricity prediction models for a supermarket have also been developed by Schrock & Claridge (1989) and extended by Ruch et al. (1991).

Using Monitored Data and Operator Feedback to Improve Retrofit Performance and Building Operation

Monitored data can be used in conjunction with operator feedback to identify measures that can be implemented to make the buildings operate more efficiently following a retrofit. In general, such a process should address the following questions:

- Is the retrofit working properly?
- Are the building systems working properly?

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• Can changes in operation or maintenance lower operating cost?

Determining the answers to these questions requires a thorough understanding of the data collected and the building systems which are consuming the energy. The cooperation and willing participation of the facility engineer and building operator is absolutely essential if operational savings are to be realized.

The use of consumption data to provide near-term feedback to owners and operators to increase operating efficiency has emerged in the last few years. The benefits of regular feedback have been shown in several case studies (Haberl and Claridge 1987; Haberl and Vajda 1988; Haberl and Komor 1990; Kempton and Komor 1990; Kinney and Romano 1990; Socolow, 1978; Katzev and Johnson 1987). Part of the communication process is transmittal of the data collected from the building to the operators in a format that they can easily understand. Traditional engineering reports and papers are not current enough to be useful, and the format and the language typically obscures key information for most operators. Hence, we have developed several forms of largely graphical reporting. These reports are supplemented by follow-up phone calls and personal visits with the facility engineers and operators.

In the LoanSTAR program three forms of formal feedback are provided to the facility engineers and building operators, including Monthly Energy Consumption Reports (MECR), data diskettes for use with data exploration software and sometimes weekly inspection plots.

The MECR is a six page report of consumption and savings, including four pages of graphs, which is provided to each building every month. The data exploration software and pre-compiled data diskettes are provided to facilities whose engineers or operators wish to examine the data in greater detail using a special browsing database program. Weekly inspection plots of data channels are used for internal data quality control and are sometimes provided to facility engineers and operators on an as-needed basis. A detailed description of all the reports is available in Claridge et al. (1992).

Anomalous behavior in the data is usually identified by the MAP staff and when such behavior is observed, comments about the behavior are included in the MECR, followed by a phone call to the site contact person to discuss the behavior observed (Figure 1). If a problem is be determined, steps are taken by the MAP staff and the facilities personnel to diagnose the problem, quantify the cost of the problem, identify and implement a solution. If it is determined that the retrofit measure(s) is (are) not working properly, the design engineer or contractor is contacted to help resolve the problem. If the building systems are not operating properly, the facilities staff will normally change procedures or make repairs as needed.

Each agency participating in the LoanSTAR program has an audit performed on its facility. These audits typically identify several measures of this type, normally called Operational and Maintenance (O&M) recommendations. A summary of O&Ms identified in 11 buildings are given in Table 1. The eight categories of O&Ms are detailed in the appendix

Results from Several Case Studied

As mentioned earlier, one of the major objectives of the MAP is to reduce energy costs by identifying operational and maintenance improvements through monitored data. We have identified O&M opportunities at several sites. Three specific cases discussed in this paper are 1) Reheat steam valve closure at the Perry Castaneda Library at U.T. Austin, 2) hot water pump shutoff in the Zachry Engineering Center at Texas A&M University and 3) identification of a heating problem in the Nursing Building at U.T. Austin. Each case will be discussed individually.

Perry Castaneda Library

The Perry Castaneda Library (PCL) is a six story structure built in 1977, with a gross area of approximately 484,000 square feet (Figure 2). The exterior walls consist of limestone panels and concrete block. The windows consist of 1/4 inch, single-pane tinted glass and cover approximately 12% of the exterior wall area. It is used as an open-stack library, with most of the floor area occupied by book shelves and study tables. The building was retrofit in November 1991 with variable air volume AHUs and variable speed pumping. Under the new system it is conditioned by four groups of air conditioning equipment consisting of eight variable volume single duct AHUs (75 hp each), twelve variable volume dual duct AHUs (two 100 hp and ten 75 hp), four variable volume hot deck AHUs (one 50 hp and three 40 hp), twelve variable frequency drive return AHUs (25 hp each) and one variable volume chilled water pump (60 hp).

Chilled water and steam are supplied by the main physical plant, located on campus. Steam at 165 psi from the campus loop enters the building and is immediately reduced to 10 psi. Part of this low pressure steam is used to heat domestic water. The remainder is piped to reheat coils in the single duct units and to the dual-ducts units. The electricity consumption per square foot from January 1991 to Dec. 1991 is shown in Figure 3 as a three-dimensional plot, where the x-axis represents the day of the year and the y-axis (into the page) represents the hour of the day. energy use is measured as the height above the x-y plane.

Questions were raised about the high steam consumption at the site in June 1991. A visit was scheduled to check the metering hardware installation. The matter was discussed in detail with the building operator, who suggested the closure of the reheat valves for the single duct air handling units. Detailed data regarding the building was sent to the building operator towards the end of June. Following another site visit, and a careful analysis of the data, partial closure of the valves to the reheat coils was accomplished on

July 3, 1991. The result was a sharp decline in the usage of steam from 1.5 million Btu/hr to about 0.5 million Btu/hr as shown in the Figure 4. A second visit was made on July 10, 1991 accompanied by the facility and the design engineer. After a consensus was reached, the remaining valves were also shut off. An additional drop in chilled water consumption for the 8 single duct air handling units occurred and was confirmed through monitored data. Figures 4 and 5 show the drop in steam and chilled water use when plotted against time and outdoor dry bulb temperature. The closure of these valves resulted in savings of approximately $7,000 per month. These savings may not have been achieved without the monitoring and close attention to detail.

Zachry Engineering Center

The Zachry Engineering Center (ZEC), built in 1973, is a four-story (plus basement parking level) building on the A&M campus with approximately 342,000 gross square feet of floor area (Figure 6). It is a heavy structure with 6-inch concrete floors. Hot water and chilled water are supplied by the central campus plant. The windows consist of single pane glass and cover approximately 22% of the exterior wall area. Major uses of the building include: 1) offices, 2) classrooms, 3) computer rooms, and 4) laboratories. The building was retrofitted with a double-duct variable air volume HVAC system in March 1991. Under the new system the, building is served by twelve variable-volume dual-duct air handling units (40 hp each) along with ten 36 hp constant volume systems. The building also includes hallways and a large atrium area which serves as a common space. The electricity consumption (Watts/sq.-ft) from January 1991 to December 1991 is shown in Figure 7. Originally, the building was designed to allow for one or two floors to be added, hence the AHUs were oversized.

In the ZEC it was observed that a 20 hp hot water pump was running continuously during the summer, when there was little demand for hot water. The building operator, when interviewed, was under the impression that all the pumps in the building were shut-off and also confirmed that there was no need to run the pump in the summer months. So, it was recommended that the pump should be turned-off. The pump was turned-off on August 24, 1991 and remained off for about four days. Then it was started again on August 27, 1991 because of hot water requirements in one of the laboratories. The drop in MCC electrical consumption can be seen in Figure 8. The potential savings from this recommended action are approximately $2,700 per year. Even though this matter is still under investigation, it is clear that without monitoring this problem would have gone unnoticed.

Nursing Building

The Nursing Building (NUR) is a five-story structure built in 1974, with a gross area of approximately 94,815 square feet (Figure 9). The building has steel frame, reinforced concrete floors and exterior walls of precast concrete panels. The windows consist of single-pane clear glass and cover approximately 30% of the exterior wall area. The building houses nursing classrooms and lecture halls, workshops, lounges and faculty offices. Chilled water and steam are supplied by the main physical plant, located on the UT campus. The building HVAC system consists of two variable volume, dual-duct AHUs (100 hp each). The building also has a 30 hp chilled water pump supplying chilled water to the air handling units. The HVAC system operates 24 hours per day. The electricity consumption per square foot from January 1991 to December 1991 is shown in Figure 10. General Schematics of the AHU at the Nursing Building is shown in Figure 11.

As shown in Figure 12 electricity consumption by the two air handlers was steady at about 20 to 25 kWh/hr after the April 1991 retrofit. A sharp increase in the electricity consumption was first noted on September 19, 1991 and again on October 29, 1991. The 120 kW (350%) increase corresponded to outside air temperature falling below 55° F. The coincidence in the electricity consumption with dropping temperature can be seen in Figure 12.

The site contact at U.T. Austin was informed immediately of this increase. After further investigation it was found that the variable frequency drives for the two air handling units were controlled by either the cold duct static pressure or the hot duct static pressure (i.e., the lower of the two). The steam pressure on the steam coils supplying steam to the hot deck coils is kept at approximately 5 psi. When the temperature dropped below 55° F, the building operator decided to operate the vent (economizer) cycle, which was added as a part of the retrofit. When there was a call for heat, the cold side of the mixing boxes closed which raised the cold duct static pressure. When the hot side of the mixing boxes opened (as the building needed more heat) it lowered the static pressure of the hot duct thus controlling the variable frequency drives, and forced the motors to run at very high speed. When the operator noticed this, the vent cycle was immediately closed because the required hot deck temperature could not be maintained and cold air was being delivered to the zones. The air handling units continued to run at very high speeds thus consuming more electricity as the temperature dropped. This phenomenon can be seen in Figure 13, where electricity consumption of the air handling units is plotted against out-door dry bulb temperature. One of the possible reasons for this increase is a lack of heating capacity. This matter is still under investigation.

CONCLUSIONS

The importance of monitoring energy retrofits after they are installed to better understand and operate commercial buildings have been discussed in this paper. Also discussed is the importance of feedback to/from the facility engineer and/or the building operator, and how it improves retrofit performance. Three forms of reporting monitored building energy consumption data (i.e. weekly inspection plots, monthly reports and browsing software) have proven highly useful for building operators, Facility engineers and design engineers. Finally, the importance of tracking O&Ms has been outlined. Three O&M opportunities identified by LoanSTAR monitored data have been discussed in detail. The process of outlining the problem, investigating the problem and tracking the final outcome is also discussed.

ACKNOWLEDGMENTS

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AREA Sq.ft	BUILDING/ FACILITY	SOURCE OF O&M		O&M RECOMMENDATIONS	DATE IDENT.	DATE IMP.	SAVINGS $/YR	IMPL. COST ($)	COMMENTS/STATUS
				TEXAS A&M UNIVERSITY					
324,000	Zachry Engg. Center	Audit Report	1	Patch air leaks around AHU's in basement.	10/5/88		N.C.	N.C.	Completed
		Building Op.	2	Delamping Hallway Lighting	Aug-90	May-Jul. 91	N.C.	N.C.	Every other light fixture in the hallways has been disconnected
		Building Op.	3	Replace Incandescent lamps with screw-in fluorescent lamps.	Aug-90	In progress	N.A.	N.A.	All the incandescent lamps (several hundred) are in the process of replacement
				U.T. AUSTIN					
251,161	Education	Audit Report	1	Fix the steam leak in the basement pressure relief valve.	1986		$232	N .C	Completed, Positive shut off regulators installed
		Audit Report	2	Delamp to 2/3 of the office area fixtures and delamp bathroom incandescent.	1986		$4,670	N .C	Not Completed
152,690	U.T.C	Audit Report	1	Turn off escalators from 2-3. Reset Thermostats	1986		$438	N .C	Not Completed, no plans for reseting the thermostat
		Audit Report	2	Reset Thermostats.	1986		$149	N .C	Not implementing
483,895	PCL	Audit Report	1	Time clock control for exhaust fans.	1986		$620	$0	No plans for doing that
54,069	Garrison	Audit Report	1	Summer shut down of hot water pumps.	8/25/89		$183	$0	Not implemented
		Building Op.	2	Delamping corridoor fluorescent (4' x 2') fixtures.	8/25/89	Dec. 1990	N.A	N.A	Completed by U.T. maintenance crew
61,000	Gearing	Audit Report	1	Repair filter bank and clean coil.	3/07/89		$804	$880	Completed as a regular maintenence work
		Audit Report	2	Summer shut down of hot water pumps.	3/07/89	May 1991	$457	$0	Completed as a part of a retrofit
57,600	Waggener	Audit Report	1	Repair filter bank and clean coil.	3/07/89		$705	$660	Completed as a regular maintenence work
		Audit Report	2	Summer shut down of hot water pumps.	3/07/89	May 1991	$122	$0	Completed as a part of the retrofit
243,000	Welch	Audit Report	1	Time clock on chiller.	1986		$934	N .C	Work is in process
		Audit Report	2	Raise space temparature	1986		$2,025	N .C	24 hrs/day operation
		Audit Report	3	Delamp	1986		$2,810	N .C	Not implemented yet
		Audit Report	4	Grow room light change out.	1986		$4,272	N .C	Nothing done yet, may work in future
109,000	Winship	Audit Report	1	Repair filter bank and clean coils.	3/07/89		$1,483	$1,320	Completed (regular maintenance program)
		Audit Report	2	Omit outside air economiser.	3/07/89	April 1991	$2,191	$528	Hot deck fan added (vent cycle on AC-1)
56,800	Steindam	Audit Report	1	Repair filter bank and clean coil.	3/07/89		$395	$660	Completed (regular maintenance program)
		Audit Report	2	Summer shut down and hot water pumps.	3/07/89	April 1991	$70	$0	Completed as a part of a retrofit
		Audit Report	3	Omit outside air economiser.	3/07/89	April 1991	$772	$176	Added Vent Cycle controls
45,905	W.C.Hogg	Audit Report	1	Chilled water valve AC-2	8/25/89	May 1991	$5,654	$2,373	Completed
N.C = Not Calculated									
N.A= Not Applicable									

Table 1: Recommended O&Ms for the Buildings monitored at Texas A&M University and U.T. Austin under LoanSTAR Program.

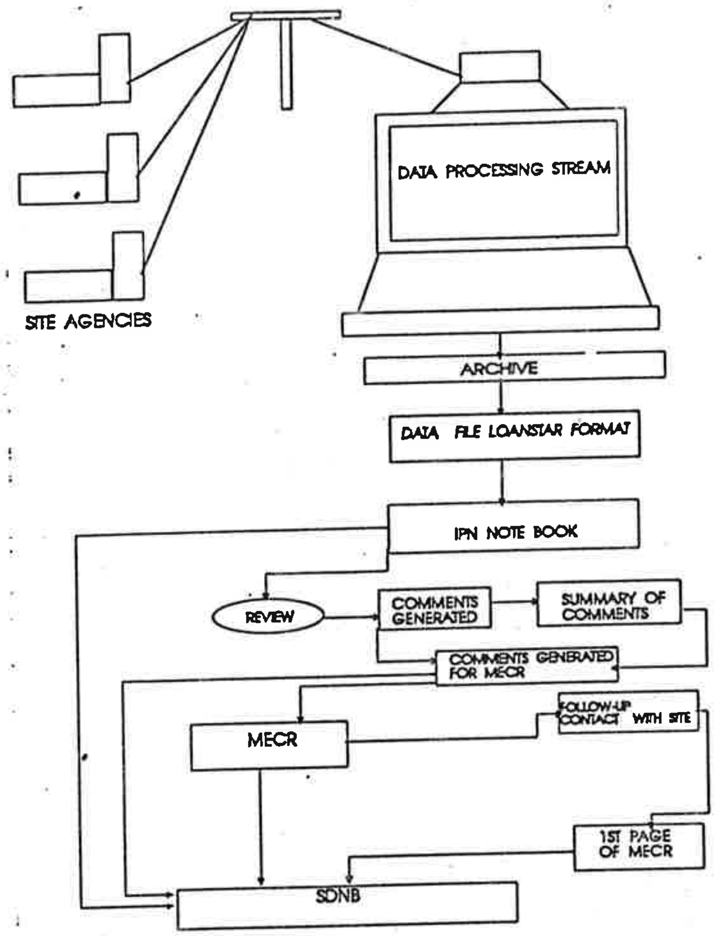

Figure 1: Data handling procedure for the LoanSTAR Program. Illustration of the process from retrieving the data from micro-processor based data recorder to the storage of the feedback from the buildings operators into the Site Description Notebooks.

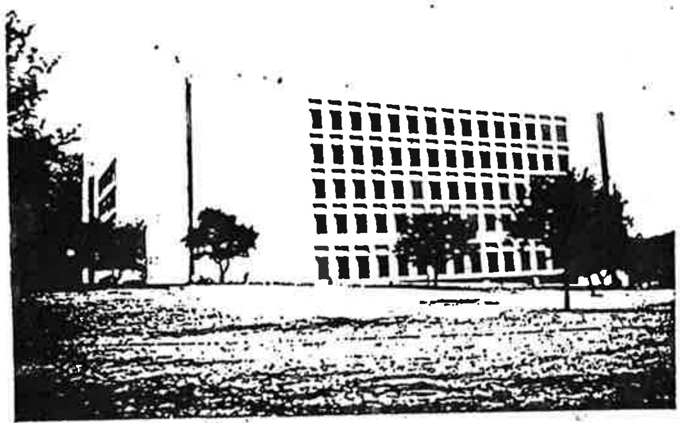

Figure 2: Example Building - Perry Castaneda Library. One of the biggest building on the U.T. Austin Campus, covering an area of about 484,000 square feet. The library is an open-stack library, with most of the floors occupied by book shelves and study tables.

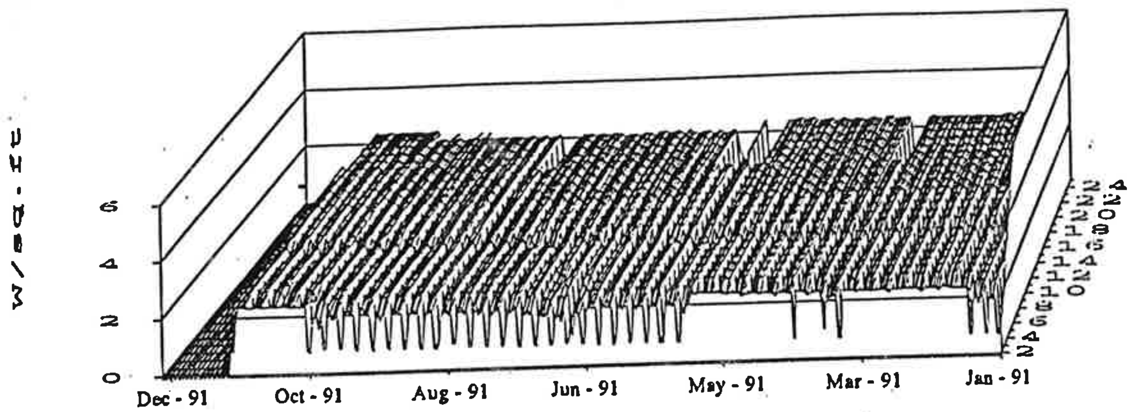

Figure 3: Hourly whole-building electricity consumption per square foot for the Perry-Castaneda Library from January 1991 through December 1991.

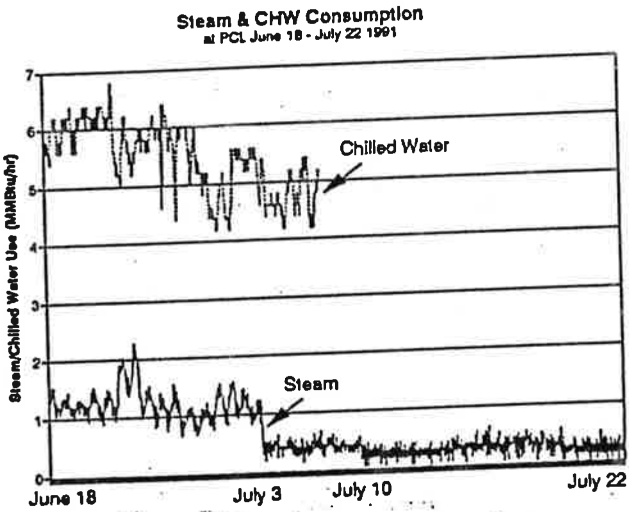

Figure 4: Steam consumption from June 18 - July 22, 1991 and chilled water consumption from June 18 - July 7, 1991 at the Perry Castaneda Library. Chilled water data for the period July 8, 1991 through July 22, 1991 experienced hardware problems.

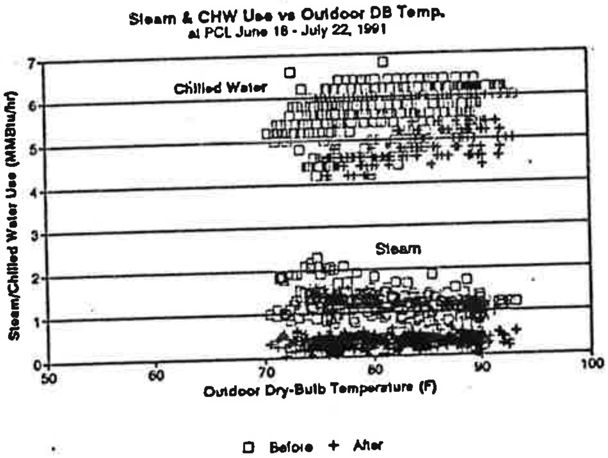

Figure 5: Steam consumption from June 18 - July 22, 1991 and chilled water consumption from June 18 - July 7, 1991 at the Perry Castaneda Library plotted against outdoor dry-bulb temperature for Austin, Texas.

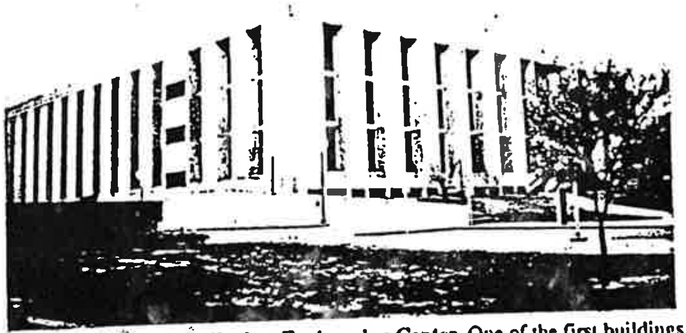

Figure 6: Example Building - The Zachry Engineering Center. One of the first buildings to participate in the LoanSTAR Program was the Zachry Engineering Center on the Texas A&M Campus. It covers an area of approximately 324,000 square foot and contains classrooms, offices and laboratories.

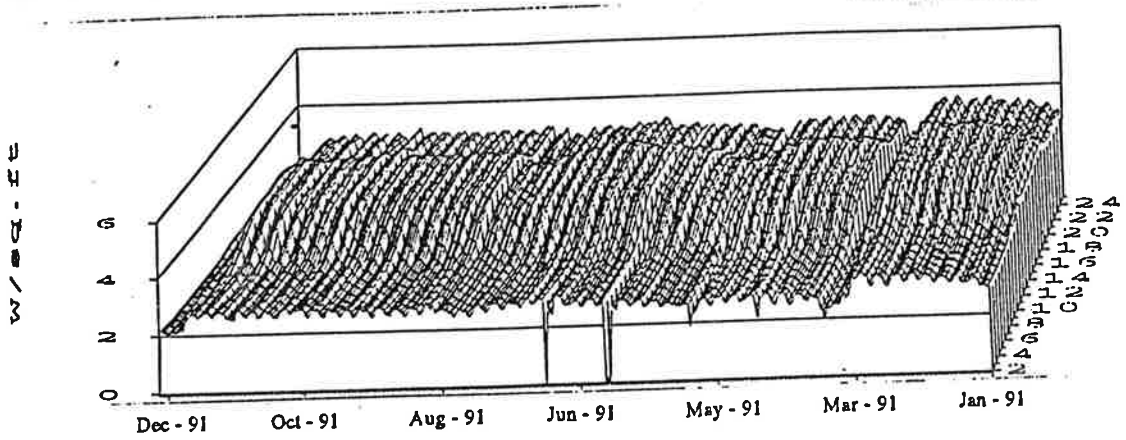

Figure 7: Hourly whole-building electricity consumption per square foot for the Zachry Engineering Center from January 1991 through December 1991.

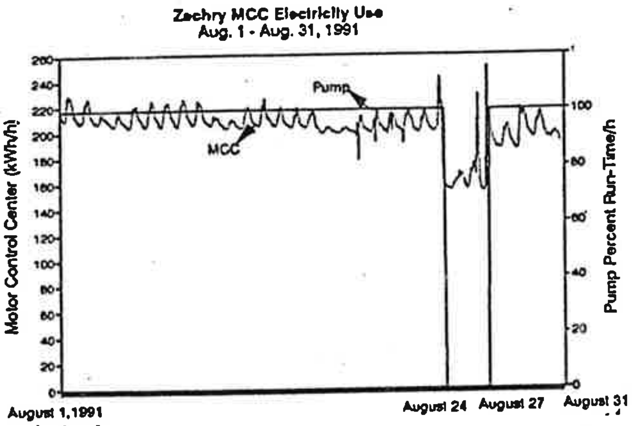

Figure 8: Electricity consumption for the Motor Control Center and percent run-time of the hot water Pump at the Zachry Engineering Center (TAMU) from August 1 to August 31, 1991.

Figure 9: Example Building - The Nursing Building. A 99,815 square foot, five story building. Constructed in 1984. This building houses nursing classrooms and lecture halls, workshops, lounges and faculty offices.

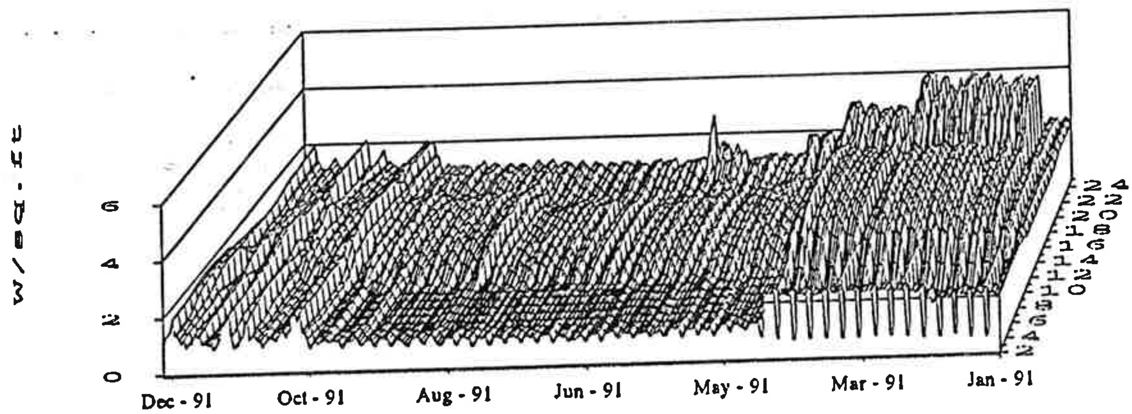

Figure 10: Hourly whole-building electricity consumption per square foot for the Nursing building from January 1991 through December 1991. The large evening-time spikes in electricity use during Jan.-Mar. 1991 are due to tennis court lights, which were later removed by rewiring the data logger.

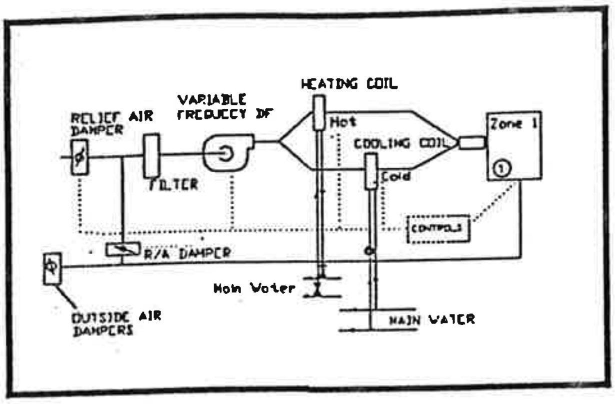

Figure 11: Nursing Building AHU Schematics. The variable frequency drive is controlled by either cold or hot duct static pressure sensors. The lower of the two controls the speed. Two-way chilled water valves controls the supply of chilled water to the AHU.

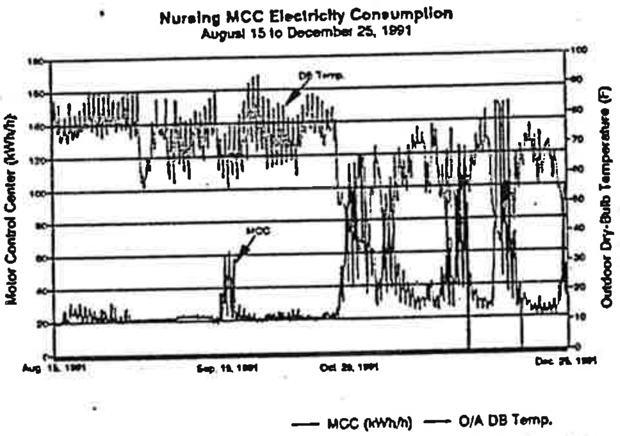

Figure 12: Electricity consumption by Motor Control Center at the Nursing building and outdoor dry-bulb temperature for Austin, Texas from August 1, to December 25, 1991.

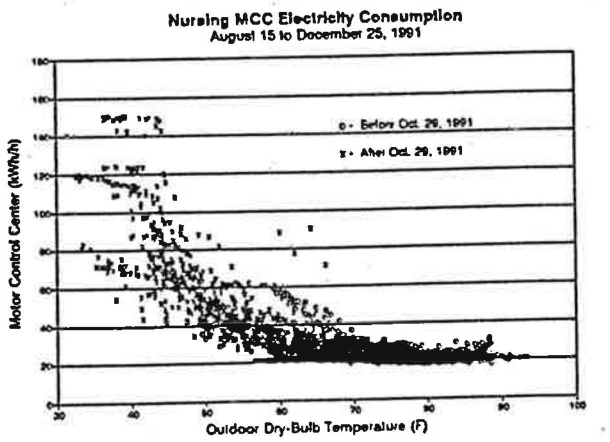

Figure 13: Electricity consumption by the Motor Control Center at the Nursing building plotted against outdoor dry-bulb temperature for Austin, Texas from August 15 to December 25, 1991.

APPENDIX A (O&M OPPORTUNITIES)

Operational and Maintenance recommendations (O&Ms) are actions to reduce energy cost that building staff can perform, as part of their regular duties. Typically they are relatively in-expensive (low cost or no cost) to implement, but this does not mean that O&Ms are not important. Often , O&Ms save hundreds of dollars worth of energy after implementation.

For commercial and institutional buildings, O&Ms can be separated into eight categories. They are :

1. Building Envelope
   a) Install weather-stripping
   b) Replace caulking
   c) Windows and doors closure
2. Heating system
   a) Turn off hot valve during summer
   b) Adjust outside reset temperature
   c) Lower thermostat setting (during unoccupied periods)
   e) Eliminate reheat
   f) Domestic HW temp. setback or turn off
3. Cooling System
   a) Raise thermostat setting (during unoccupied periods)
   b) Clean evaporator and condenser coils
4. HVAC Distribution System
   a) Replace faulty steam traps
   b) Fix or clean filters
   c) Repair air leaks
   d) Omit non-functional outside economizers
   e) HVAC system repair or adjustment
   f) Clean steam & CHW coils
   g) Insulate steam/hot water and chilled water lines
   h) Shut fans and pumps off when not in use
5. Lighting System
   a) Delamp or reduce lighting levels
   b) Turning-off lights
   c) Replace incandescent with screw-in fluorescent
   d) Clean fixtures and diffusers
   e) Disconnect ballast
6. Power Systems
   a) Turn-off elevators/escalators on the weekends
   b) Turn-off non essential pumps
   c) Turn-off equipment manually or through time clocks
7. Regular Maintenance
   a) Repair/adjust fan belts
   b) Repair leaky systems/components
   c) Cleaning
8. Controls
   a) Calibration
   b) Turning on/off the energy consuming equipment through existing control system

Table 1, provides summarized information for the O&Ms recommended by the audit firms, or performed by the building operators for fourteen LoanSTAR sites. Estimated implementation cost and the estimated savings (if calculated) along with the status of the procedure are also provided.