Identifying and Implementing Improved Operation and Maintenance Measures in Texas LoanSTAR Buildings

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Traditionally, O&M opportunities have been identified as part of the energy audit process using information gathered only from one-time walk-throughs. In some cases, hand measurements have been taken to identify existing conditions. Rarely have long term measurements been taken and then used to identify and implement retrofits. In the Texas LoanSTAR program a new approach has been developed that uses long-term hourly whole-building (and sometimes submetered) measurements after the retrofit is installed, together with an engineering analysis and site visits with the facility personnel, to determine if HVAC systems are operating within an efficient range.

As of April 1994, this approach has identified over $3.5 million in annual savings opportunities in buildings that have already been retrofitted. O&M measures identified include the correction of inefficient practices such as excess operation of heating, ventilation and air conditioning (HVAC) systems, excess lighting levels, and failure to turn lights and office equipment off after the building closes. Optimization of HVAC system operation, which includes hot deck shut-off, partial cold-deck shut-off, and simultaneous cold-deck and hot-deck reset, has also been identified as a promising O&M measure. The hourly monitored data provide the opportunity for immediate feedback on the success of such measures and also show when a return to poor operating practices has occurred. Implementation of these measures in buildings can maintain indoor comfort levels (and in some cases, improve them) while reducing energy costs substantially. This paper discusses the methodology used to identify O&M opportunities in LoanSTAR buildings using monitored data following retrofits, and the methodology used to measure savings. It also presents the basic methods for analyzing these problems and presents findings from several case study buildings. The savings (realized and potential) from post-retrofit O&M measures are also presented and compared with the retrofit savings measured in the LoanSTAR buildings.

Introduction

Opportunities for realizing operating savings from improved operation and maintenance practice have been traditionally identified as part of the energy audit process. Energy auditors customarily identify damaged or malfunctioning equipment, the possibility of reducing excessive operation hours, and the feasibility of implementing nighttime setback (Schliesing et al., 1993). A number of studies [including Athar et al. (1992), Herzog and Lavine (1992), Tamblyn (1992), and Haberl and Vajda (1988)] have reported substantial energy savings due to the identification and remedy of O&M problems. Recently, measured hourly whole-building and submetered energy consumption data have been shown to be very useful in identifying O&M opportunities [Koran (1994), Haberl et al. (1989a,b), Houcek et al. (1993) and Liu et al. (1993a,b,c, 1994b)].

Monitored hourly whole-building and sub-metered energy consumption data have routinely been used to measure retrofit savings and verify O&M opportunities in the Texas LoanSTAR program [Turner (1990)], a state wide energy conservation program that covers 19,137,000 ft^2 in 201 buildings at 71 sites. LoanSTAR O&M staff have surveyed 4.5 million ft^2 of these buildings and have identified a total of $3,997,000/yr in potential O&M savings in 33 of these buildings and 104 schools. More than $953,000/yr O&M savings have been implemented, and $2,106,000/yr are being implemented as of April 1994.

Methodology

In the LoanSTAR program, the methodology developed for the O&M heavily utilizes available measured hourly whole-building, submetered energy consumption data, and detailed site description information. The measured hourly energy consumption data make it possible to identify O&M opportunities quickly as well as to identify measures that would have been difficult or impossible to identify during the walk-through audit when hourly energy use data are not available. The data also permits the staff to determine whether a measure has been implemented and provides weekly follow-up as needed to the facility engineers. This section describes the process of O&M identification from site selection to O&M implementation.

Site or Building Selection

Because there are currently 201 buildings at 71 sites within the LoanSTAR program, the sites with the largest potential O&M savings are examined first. Sites whose facility personnel had requested O&M assistance are also given top priority. The sites examined for O&M opportunities have been required to meet one or more of the following criteria:

- High average energy consumption indices (e.g., Btu/hr-ft^2 chilled water use or steam use).
- Relatively large ratio of nighttime to daytime electricity consumption. This ratio indicates potential savings by nighttime shutdown of office equipment, lighting and HVAC systems (i.e., W/ft^2 index)
- A large ratio of steam to chilled water consumption. This ratio often indicates high reheat levels in the building with consequent opportunities for optimizing the HVAC system (Liu et al. 1993c, 1994a).
- Unexpected consumption patterns. An irregular energy consumption behavior often indicates damaged or malfunctioning equipment.
- Requested an O&M survey.

These criteria are applied to LoanSTAR buildings by examining the Monthly Energy Consumption Report (MECR), the Annual Energy Consumption Report (AECR), and weekly Inspection Plot Notebooks (IPN) (Claridge et al., 1992). The MECR typically contains hourly time series plots (2-D and 3-D formats) for heating, cooling and electricity consumption, weather data for the current month, and heating and cooling versus ambient temperature charts. The AECR contains the measured monthly heating, cooling, and electricity consumption for each building. The annual energy consumption index (e.g. kWh/ft^2) per ft^2 for each energy type is also listed. The IPN is used by the LoanSTAR staff to spot metering problems each week as part of the data polling operation.

Identify O&M Opportunities Using LoanSTAR Measured Data

After a site or a building is chosen, candidate O&M measures are identified using the LoanSTAR-measured hourly energy consumption data for individual channels (e.g., chilled water, steam, and electricity) and the audit report, as well as the MECR, AECR, and IPN. The extensive hourly data sets are best handled with specialized software, such as EModel (Kissock et al., 1993) or Voyager (Lantern 1994). More conventional spreadsheet software is also used. The specific procedures that have been found useful in identifying O&M opportunities include:

- Hourly time series consumption plots to identify excess operating hours, malfunctioning equipment, over-sizing of systems, and building operation patterns.

  If the nighttime electricity consumption on weekdays is the same as the nighttime consumption on weekends and if air handling units are on at night, a shutdown opportunity usually exists. If the nighttime lighting consumption is also determined to be high, then a nighttime walk-through is scheduled to identify the location in the building where lights and equipment are being left on.

  The measured energy consumption, such as fan power consumption, can easily be compared with the design capacity. This simple comparison can uncover interesting facts. For example, two 100 hp (149 kW) variable frequency drives are installed in one LoanSTAR building in April 1991 to convert constant volume systems to variable air volume systems. During the next three years, the controlled peak electricity consumption of these two VAV motors is less than 54 hp (40 kW) which indicates that if the consulting engineers had estimated the fan power requirement properly and had selected smaller variable frequency drives, the retrofit cost could have been reduced by $8,000.

- Inefficient operation and malfunctioning equipment are often identified by plotting the hourly chilled water and steam consumption versus the ambient temperature.

Figure 1 shows the measured hourly chilled water use during the pre-O&M baseline period (1/92 - 7/92) and the data during the post O&M period (2/94 - 3/94) in a medical research building where almost 100% outside air is used 24 hours per day. The baseline data show high chilled water consumption even when the ambient temperature is lower than 50F. A site visit and conversations

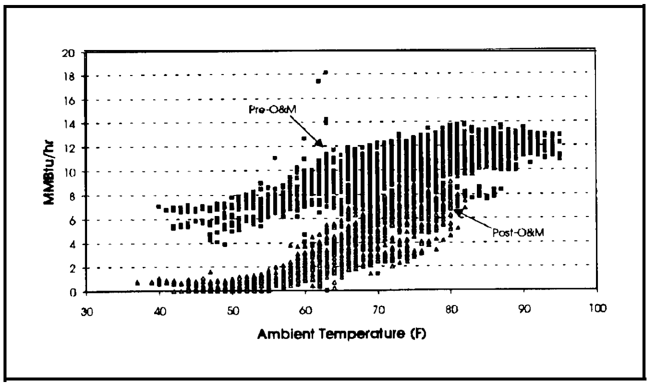


Figure 1. Comparison of Measured Pre-O&M and Post O&M Chilled Water Consumption at the Basic Research Building at MDA. Pre-O&M data are from 02/01/92 to 06/28/92. The Post O&M data are from 02/18/94 to 03/07/94.

with the facility staff discovered that this is due to chilled water valves that are wide open. The agency personnel repaired the chilled water valves and adopted an optimized control strategy provided by LoanSTAR O&M staff in February 1994 (i.e., post-O&M data). This O&M measure reduced the building's annual energy cost by $434,000 (Liu et al., 1994b).

- The potential savings from improved operation are also identified by plotting the measured energy consumption or efficiencies, such as the kW/ton or COP for chillers, versus the key influential parameters, such as chilled water return temperature.

Site Visit

After the candidate O&M measures are identified, a site visit is scheduled during which the feasibility of these measures is examined, new O&M opportunities are identified, and necessary information for the detailed O&M analysis is collected.

- The feasibility of candidate O&M measures are checked by 1) examining the physical conditions of the HVAC systems, 2) examining the capacity of the HVAC control system, and 3) discussing the operation and management with the agency's staff.

- The possibility of delamping is usually determined by measuring the lighting levels at selected places during a daytime walk-through. The potential savings from unoccupied period lighting and office equipment shut-off is usually determined during a nighttime walk-through.

- The building envelope and occupancy information are collected by either visual assessment and examination or interviews with building operators, office workers, and custodial staff. The building energy systems, such as AHUs and their control systems, are examined carefully. The important operation parameters and control methods, such as cold deck setting, total air flow rate, fraction of outside air intake, etc., are inspected and measured where possible. When available, sub-metered energy use data measured by the agency, is also collected. These measurements provide sufficient information for a detailed O&M analysis.

Prediction of Potential O&M Savings

A "quick and dirty" estimation of potential O&M savings is important for both the agency and the LoanSTAR program in order to justify additional time and resources. The potential O&M savings are generally estimated by one or more methods described below according to the nature of the O&M measures:

- Simple capacity drop using a short-term test. In a case of delamping or turning off lights and office equipment at night, the capacity drop of such equipment can be accounted for reasonably by using data measurements made during the site visit. Therefore, the potential savings can be estimated as the product of the drop-in capacity times the number of hours during which these lights and office equipment can be turned off in a year. In a case of shutdown of AHUs, a short-term test may have to be conducted (often to convince the on-site personnel that interior environmental conditions can be maintained). In order to perform such a test, the AHUs are turned off for a few hours with the data logger used to record data every five minutes. The savings from turning off AHUs can then be directly measured. This short-term test can demonstrate how much electricity, and thermal energy use (chilled water and steam) can be saved under the test conditions. These savings can then be analyzed to determine the annual potential savings of turning off AHUs for the building where the short-term test is performed.

- Estimation of savings due to equipment malfunction. In a case where equipment is observed to be malfunctioning, the problem is usually identified because previous data had been recorded under normal operation. In such cases the normal operation data are used to construct a simple empirical model and the model used to calculate the savings potential.

- Analysis of savings due to inefficient operation. In cases of inefficient operation, a specialized engineering model is developed for the building and HVAC system. This baseline model is first calibrated against LoanSTAR measured chilled water and steam data. Then, by trial and error, the cold deck and hot deck setting are optimized using this specialized model. The potential savings are estimated as the difference between the annual energy consumption of the base model and the optimized model under a normal year of weather conditions. This process also produces optimized operation schedules.

O&M Implementation

Although the implementation of O&M measures is performed by facility personnel at the agencies, the LoanSTAR staff sometimes play key roles in this stage too, especially doing the nighttime shutdown test. The LoanSTAR O&M staff's function in implementing O&M measures is described below:

- Design of the nighttime shutdown tests. During the nighttime shutdown test, detailed plans are made of which equipment to shut down and for how long, and where in the building it is located. The number of hours for the shutdown test needs to consider how many different end-use categories are being considered, how long it will take the staff to physically shut off the devices, and any other special features such as indoor temperature monitoring, etc. Each end-use type is shut off in distinct phases which usually requires several passes through a building. The length of time between each phase needs to be sufficient to record enough "events" on the logger to assure an accurate reading. The logger is usually set at 1 to 5 minute intervals depending on the site.

- Supply specific suggestions. In cases of malfunction, it is important to determine the nature of the problem and how to fix it. The agency personnel then perform the necessary work.

- Supply optimized control strategies. When necessary, optimized control strategies are supplied in a format that can be easily incorporated into the EMCS control program. The site agency control engineers can then change their control program accordingly.

Timely Follow Ups

After the suggested O&Ms are implemented, two more important follow up activities are performed.

- Commission and stabilize the O&M measures. In cases of O&M measures such as nighttime shutdown and malfunction, measured hourly energy consumption plots are inspected to determine whether the measures are being effective over time. In many cases, additional tests and extended trial shutdowns are necessary to assure that systems can be turned off without jeopardizing indoor environmental conditions.

- Fine-tuning the O&M measures. In some cases, there may be one or more zones that have unacceptable humidity swings. In these instances it is important to identify the specific zone so individual zone equipment can be inspected to determine the cause of the problem. This has proven to be an important issue because facility operators sometimes can't correct a problem properly, which may cause extra energy costs. For example, complaints about high indoor relative humidity (60%) in a small animal research area at a hospital led the operation engineer to decrease the cold deck setting by 2°F for all conditions. A more efficient strategy of decreasing the cold deck temperature by 2°F only when the ambient temperature is between 60 and 70°F is suggested, which could have saved more than $10,000/yr.

Savings Calculation

After the O&M measures are implemented, the savings are estimated using the standard methodology developed for determining retrofit savings in the LoanSTAR program (Kissock et al., 1992, Reddy et al., 1994). Because measured data are generally available for both the baseline pre-O&M and post-O&M periods, regression methods are usually used although a number of other savings calculation methods have also been developed. For example, calibrated simplified models (Katipamula and Claridge, ASME 1992) and bin-method models (Thamilseran and Haberl, 1994) are sometimes used.

Regression Model Identification

In general, statistical models of baseline energy use of each energy type influenced by the O&M measure are developed. Typically, this includes daily cooling energy use, heating energy use, and electricity use. The functional form of each model is determined both by the physical understanding of how a particular type of energy use should vary with time and also by the operating schedules. For example, electricity use of a CAV air handler is usually independent of weather conditions, but can vary from weekday to weekend. Therefore, this use is normally modeled as the mean electricity use during each operational period. 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. In some cases, hourly day-typing (i.e., grouping the daily data sets into separate subsets and identifying models for each day-type) is needed to separate weekdays and weekends from holidays such as Christmas, Thanksgiving, semester breaks, etc. (Katipamula and Haberl, 1991; Thamilseran and Haberl, 1994).

Changes in quantities such as cooling and heating energy are primarily influenced by weather, internal loads and day-type. Because day-types are in effect dictated by internal loads, which are a good surrogate for how the building is operated, regression models with weather parameters only are mostly adequate provided modeling for each day-type is done separately.

Predicting Energy Use of Building

The set of regression models (usually identified using daily data) is then used to predict daily energy consumption of the pre-O&M building under similar building operation and weather conditions corresponding to each day of the post-O&M period.

Estimation of Savings

Finally, the savings over a certain number of post-O&M days are estimated by subtracting the daily measured energy consumption from the daily energy consumption predicted by the pre-O&M model and summing the daily savings over the time period in question. The difference between each daily point and the baseline regression model represents the energy savings on that particular day. Summing the daily values over days yields the net energy savings during a specific time interval.

The general procedure for computing total O&M savings of either chilled water, hot water or electricity can be summarized by:

$$\sum_{j=1}^{m} E_{Save,j} = \sum_{j=1}^{m} \hat{E}_{Base,j} - \sum_{j=1}^{m} E_{Meas,j}$$

or

$$E_{Save,Tot} = E_{Base,Tot} - E_{Meas,Tot}$$

where j = subscript representing a particular day over the post-O&M period,
m = number of post-O&M days over which savings being calculated,
$E_{Save,j}$ = energy savings over day j,
$E_{Base,j}$ = model predicted baseline daily energy use of pre-O&M building,
$E_{Meas,j}$ = measured post-O&M daily energy use, and
Tot = script denoting total over the entire post O&M period.

Case Studies

The O&M procedures demonstrated in this section use three different types of examples: 1) equipment shutdown, 2) malfunction recommissioning, and 3) optimization of HVAC system operation.

Typical Example of Nighttime Shutdown

Nighttime shutdowns have been successfully accomplished in 3 out of 10 buildings where excessive nighttime energy use has been observed and specific offending systems identified. One of these sites is the Stephen F. Austin building at the Texas State Capitol complex.

LoanSTAR O&M staff have successfully performed a nighttime shutdown in the Stephen F. Austin building at the State Capitol Complex. This eleven-story building contains a total of 470,000 ft^2 of conditioned area. The building is occupied from 7:00 a.m. to 6:00 p.m. during weekdays while the third and eighth floor are occupied until 11:30 p.m. and 1:00 a.m. respectively because these two floors contain large main frame computers. The annual utility costs totaled $1,118,000 from September 1, 1990 to August 31, 1991.

Potential of Nighttime Shutdown of Lights and Receptacle Loads. Figure 2 shows a typical weekday hourly consumption profile with the chiller consumption omitted. This figure shows a ratio of minimum nighttime electricity consumption to the daytime peak consumption of 0.61, which indicated potential for nighttime shut down. Because the nighttime minimum electricity consumption is only 1,000 kW lower than the daytime peak consumption while the building has a lighting capacity of 1,010 kW, substantial amount of the lighting and the office equipment are left on at night. If these lights and office equipment could be turned off, significant amount of energy could be saved.

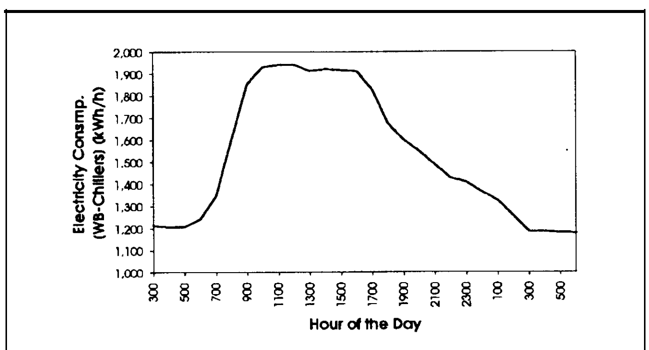


Figure 2. Typical Daily Electricity Consumption Profile for SFA Building

Short-term Test and Results. In April 1993, we performed a field test of the recommended O&Ms at SFA and two other buildings. The object of the field test is to turn off as many AHUs, exhaust fans, lights, PCs and office machines as possible in each building, and consequently establish the minimum base load and confirm the extent to which the O&Ms could be implemented. Notices had been sent out the week before the test informing the workers of the impending "Building Electrical Test" and asked for their co-operation by turning off all PCs and office machines as they left work on the evening of the test.

Before beginning the test, a meeting is held with State Capitol Complex personnel to finalize the test procedure, and identify areas where the shutdown is not to be performed. In the original report the estimated AHU power savings at night are 405 kW. However, because of special agency requests to leave certain equipment and AH Us running, the staff is only able to turn off AHUs amounting to 386 kW (95%).

Figure 3 displays the results of AHU shutdown and lighting turn-off test that is performed on April 17. The shutdown reduced the chiller load by 3 MMBtu/hr and electricity use by 450 kW at the SFA 'building.

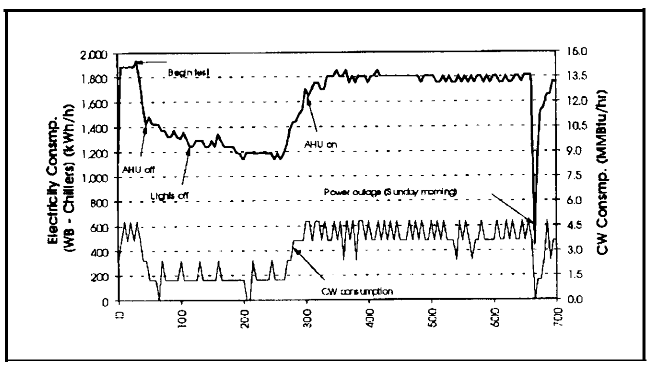


Figure 3. Short Term Test Results at SFA Building

AHU Nighttime Shutdown and Results. Several meetings with the administrative and building operations personnel from the State Capitol Complex are held during which the test results are presented and discussed. After all the concerns of the facility operators had been met, a decision is made to begin an AHU shutdown at the SFA building. Phase 1 of the shutdown is scheduled to begin on the evening of Friday, September 3, 1993, with five air handlers shutdown for a duration of four hours each night. Recording thermometers are placed in areas affected by the shutdown to determine the extent to which the temperature changed, if at all. Weekly graphs of the hourly building energy consumption are faxed to the building operators to provide positive feedback about the results of their actions.

Phase 2 began during the first week of October when an additional five air handlers are turned off each night, followed by six more each night during the second week of October. By mid-October, 16 out of a total of 25 air handlers are being turned off each night for a period of four hours.

Figure 4 displays the results of the progressive AHU shutdown at the SFA building in terms of whole-building electricity minus chiller electricity use. The graph shows that prior to the first week in September, average nighttime consumption is approximately 1,250 kW. After Phase 1 implementation, average nighttime consumption dropped to approximately 1,100 kW. After Phase 2 implementation, the average nighttime consumption dropped to approximately 800 kW. During the second week of January 1994 the duration of the nightly shutdown is extended to six hours for all 16 air handlers.

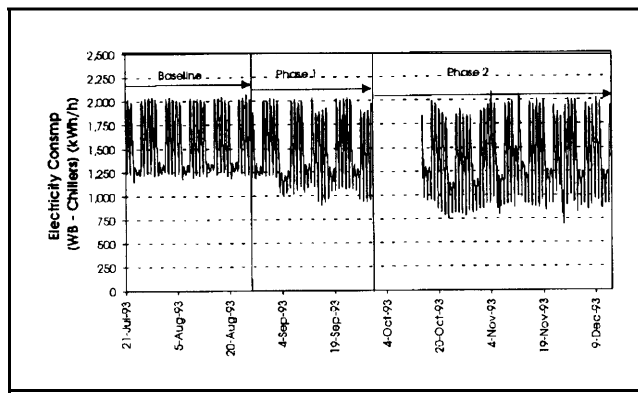


Figure 4. Nighttime Shutdown Results from SFA Building

On the basis of preliminary measurements, the savings based on both electrical and chilled water consumption is $300/night. Building operator feedback indicated no comfort complaints as a result of the shutdown.

Example of Malfunction Recommissioning Project

One example of a malfunction problem is recommissioning the economizer controller in the Nursing Building (NUR) at the University of Texas in Austin. This building was a five-story structure built in 1974, with a gross area of approximately 94,815 square feet. The building houses nursing classrooms and lecture halls, workshops, lounges and faculty offices. Electricity, chilled water and steam are supplied by the main physical plant, located on the UT campus.

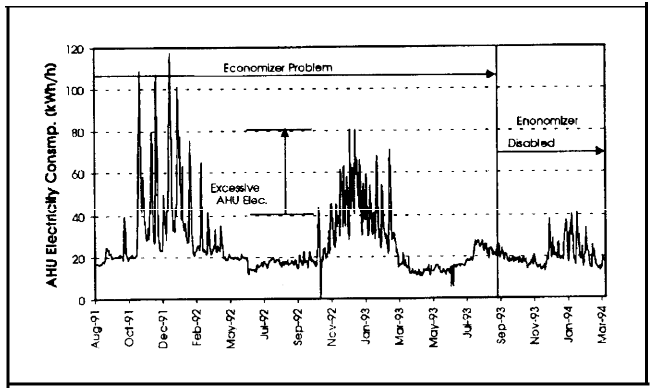
The building is retrofitted in April 1991 with variable air volume and variable speed pumping. The new HVAC systems consist of two variable-volume, dual-duct AHUs (100 hp each) and a 30 hp variable speed chilled water pump supplying chilled water to the air handling units. The building is in use for 15 hours per day (6:00 a.m. to 9:00 p.m.) while the HVAC system operates 24 hours per day. Figures 5a, 5b and 5C show daily electricity, steam, and chilled water consumption data from October 1991 to January 1994.

As shown in Figure 5a, the electricity consumption by the two air handlers during the evening is steady at about 20 to 25 kWh/hr after the April 1991 retrofit. A sharp increase in the electricity consumption is first noted on September 19, 1991 and again on October 29, 1991. The 100 kW increase corresponded to outside air temperature falling below 55F. The facility personnel are immediately informed of this increase but were unable to investigate the problem until the following summer. The site personnel attributed this increase to a lack of capacity in the heating coil. Consequently, they increased the steam pressure from 5 psi to 15 psi and the size of the pressure regulating valve from 1/2" to 2" in September 1992. At this time we are requested by UT personnel to monitor the change closely. In October 1992, when the temperature went below 55°F and the economizer cycle started operating, we noticed some decrease in the AHU electricity and chilled water consumption compared to Fall 1991. Unfortunately, LoanSTAR O&M staff also noticed a sharp increase in steam consumption compared to fall 1991. The economizer cycle caused air handler electricity use and chilled water use to decline and generated positive savings of approximately $4,000/yr when compared to 1991. The steam usage during 1992, on the other hand, increased and generated negative savings of $6,000/yr, thus giving an overall negative savings of about $2,000/yr when compared to 1991.

Analysis of data prior to the winter of 1993 revealed problems with the economizer cycle. The economizer seemed to take in too much outside air when the ambient temperature is lower than the cold deck supply air temperature, and also seemed to increase the outside air intake as the ambient temperature decreases. Consequently, two suggestions are given: 1) to change the economizer control strategy; or 2) to simply disable the economizer during the winter.

In September 1993, UT physical plant personnel disabled the economizer cycle. Sharp drops in electricity and steam consumption are noticed from October 1993 to February 1994. A slight increase in chilled water consumption due to the use of a fixed fraction of the outside air intake is also noticed.

Drops in steam and AHU electricity consumption and an increase in chilled water use were noticed after October 1993. Daily data from October 1992 to January 1994 are used to calculate savings. As of February 1994, the Nursing building has saved approximately $5,700, which is about $7,000 for 1994 winter (10/93 - 4/94).



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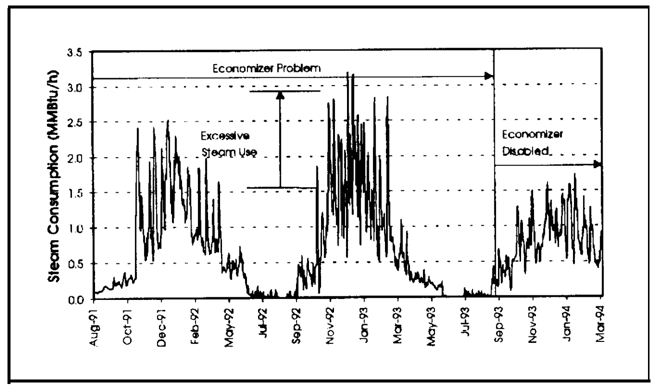

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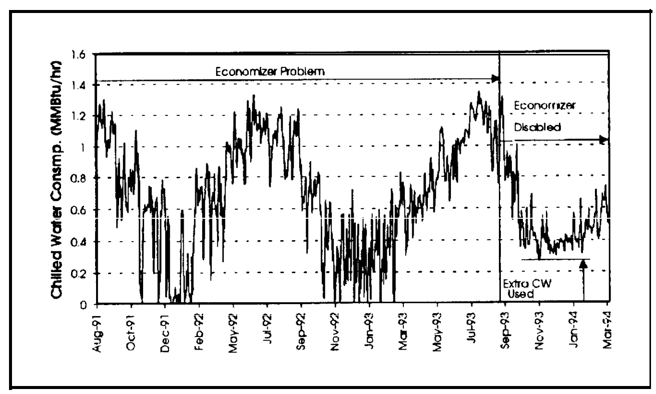

(5C)

Figure 5. The Measured Electricity, Steam, and Chilled Water Consumption in the Nursing Building at the University of Texas, Austin

Example of Optimized HVAC System Operation

Optimization of the AHU operation schedules is performed at eight buildings (Liu et al., 1993c, 1994b). The results from the Basic Science Building are shown as an example here. This building is a 137,856 ft^2, free-standing, seven-story building at the University of Texas Medical Branch at Galveston, TX. The building consists primarily of offices, classrooms, labs and storage. The building is provided with 75% outside air by two 150-hp constant-volume, dual-duct AHUs, each capable of 110,000 cfm. Currently the fans supply air at a rate of 1.24 cfm/ft^{2}0f conditioned area. Chilled water and steam are supplied by the main chiller plant. The building HVAC system is operated 24 hours a day all year long.

Identification of O&M Potential. Figure 6 shows measured average daily chilled water and steam energy consumption versus the ambient temperature for the period from July 1, 1992 through June 30, 1993. Substantial steam consumption occurred during the hot summer days, increasing only slightly with an ambient temperature drop, a symptom of substantial reheat. This suggests that large amounts of chilled water and steam could be saved by optimizing the operation schedules and minimizing the reheat.

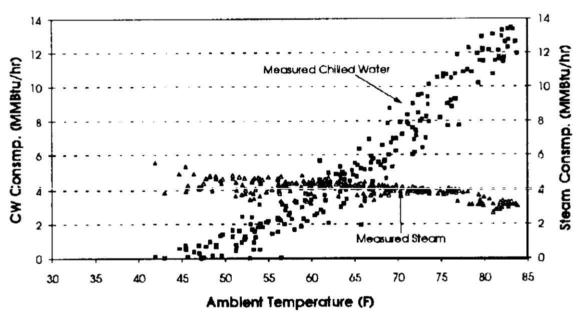

Figure 6. Measured Chilled Water and Steam Energy Consumption Versus Average Daily Ambient Temperature in the Basic Science Building at UTMB

Specialized Model and Calibration. A specialized engineering model is developed to model the building's HVAC system (Liu et al. 1993 f). This model is calibrated against the measured chilled water and steam consumption. Figure 7 compares the measured data with the model's predicted chilled water and steam consumption from December 1992 to June 1993.

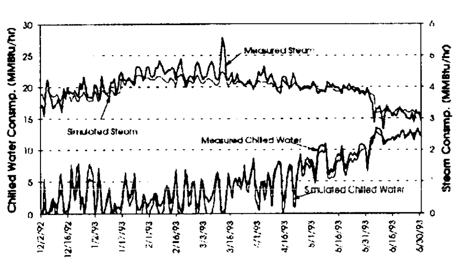

Figure 7. Comparison of Simulated and Measured Daily Average Steam and Chilled Water Energy Consumption in the Basic Science Building at UTMB

Optimized Schedule. Optimized operation schedules are determined by trial and error using the calibrated models. The base and the optimized schedules are shown in Figure 8. The cold deck temperature is increased under the optimized schedule. This cold deck temperature increase can reduce chilled water and steam consumption substantially as discussed below.

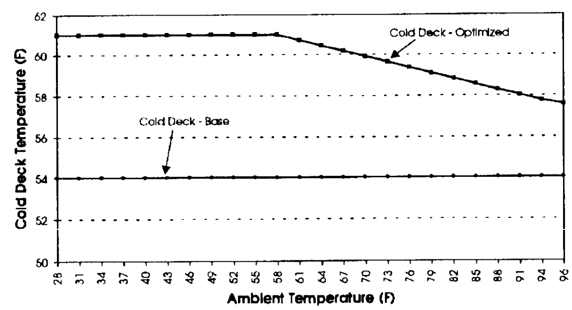

Figure 8. Base and Optimized Cold Deck Schedules for the Basic Science Building at UTMB

Comparison of Energy Performance. Figure 9 compares the optimized energy performance with the baseline energy performance. The horizontal axis is the dry bulb ambient temperature. The vertical axes show the chilled water and the steam consumption in MMBtu/hr calculated using the specialized model for each 30 F temperature bin and its mean coincident dew point temperature. Figure 9 also shows that the optimized schedule can reduce chilled water consumption by approximately 1.9 MMBtu/hr and steam consumption by approximately 1.2 MMBtu/hr with very weak dependence on the ambient temperature. The simultaneous reductions of the chilled water and the steam consumption indicate that the major part of the savings is due to elimination of simultaneous heating and cooling.

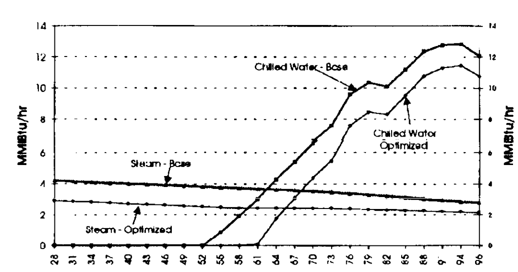

Figure 9. Comparison of the Predicted Chilled Water and Steam Energy Consumption Under Base and the Optimized Operation Schedule in the Basic Science Building at UTMB

The optimized schedule can reduce annual chilled water consumption from 55,500 MMBtu to 40,600 MMBtu, with a savings of 14,900 MMBtu/yr and also reduce the annual steam energy consumption from 30,600 MMBtu to 21,200 MMBtu with a savings of 9,400 MMBtu/yr. These energy savings reduce the annual cost by $108,700 for chilled water and $47,300 for steam. The total potential savings are $156,000/yr, which is a decrease of 23% of the building's current annual energy cost, or 27% of the building's thermal energy costs using the baseline cold-deck schedule.

O&M Implementation and Measured Savings. The cold deck temperature for the air handling units is raised from 54°F to 59°F on July 2, 1993. As a result, a reduction in the chilled water use and steam consumption is immediately noticed. Data from July 2, 1993 to February 28, 1994 are used to calculate the savings by using a simple linear regression model. Figure 10a shows the baseline and the post-implementation chilled water consumption. Figure 10b shows the baseline and the post-implementation steam consumption. The drop in energy consumption is distinctly noticeable for all seasons. As of February 28, 1994 the Basic Science Building had saved 6,950 MMBtu in chilled water energy and 5,950 MMBtu in steam energy, which corresponds to $50,900 and $30,100, respectively for total savings from July 2, 1993 to February 28, 1994 of $81,000. This is consistent with what the model prediction for the same period.

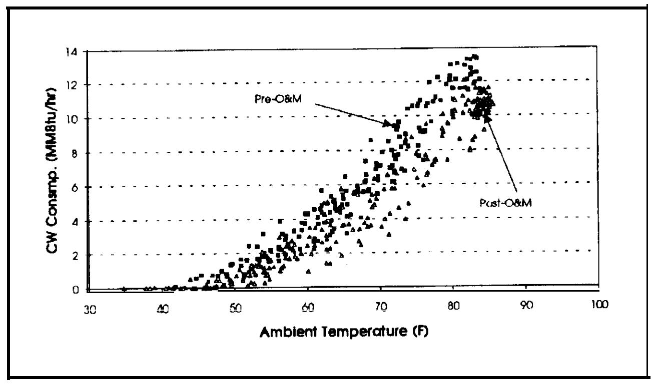

Figure l0a. Pre-O&M (Baseline) and Post-O&M Chilled Water Consumption (January 1993 to February 1994) in the Basic Science Building at UTMB

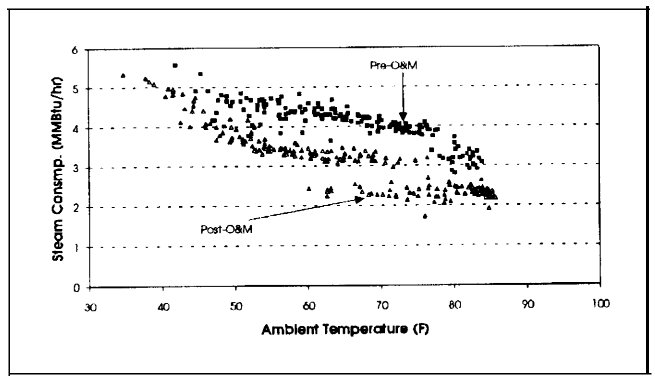

Figure 10b. Pre-O&M (Baseline) and Post-O&M Steam Consumption (January 1993 to February 1994) in the Basic Science Building at UTMB

Summary of LoanSTAR O&M Program

Development of the LoanSTAR O&M Program

Table 1 summarizes the identified O&M potential savings, those that have been implemented, those that are being implementing, and those that have yet to be implemented. Before 1993, the LoanSTAR O&M program looked for opportunities to correct malfunction problems and to initiate nighttime shutdowns. An equivalent annual savings of $662,000/yr is identified, and $303,000/yr is implemented.

In 1993, the LoanSTAR staff found that the EMCS control had been disabled in more than 100 schools in the Fort Worth area, and that the EMCS systems are being severely underutilized with an estimated potential savings of $1,658,000 per year. Beginning with the UTMB Medical Center in Galveston, the LoanSTAR O&M program headed in a new direction: optimization of energy systems using measured data and calibrated engineering models. In 1993, a total of $2,330,000/yr potential O&M savings are identified. As of December 1993, 9% of these opportunities had been implemented, 71% are being implemented and 20% remained to be implemented in 1994.

During the period from January through May 1994 an additional $1,005,000/yr potential savings had been identified in three medical buildings. In contrast to 1993, 43% of these savings have been implemented, 45% are being implemented, and 12% remain to be implemented.

Distribution of the LoanSTAR O&M Savings

Table 2 summarizes the O&M savings in the following categories: delamping, traditional O&Ms, reactivation of EMCS systems, and optimization of HVAC energy systems.

Delamping is recommended when field measurements confirmed that a building was overlit and one or more lamps can be removed from the lighting fixtures without additional changes. LoanSTAR auditors looked for lighting retrofit opportunities and many lighting retrofits have been implemented, so delamping was not a major O&M in

Table 1. Summary of Identified and Implemented O&M Savings in Chronicle Order

Time	~12/92	1/93 ~ 12/93	1/94 ~ 3/94	Total
Identified	$662,000	$2,330,000	$1,005,000	$3,997,000
Implemented (%)	47	9	43	$953,000
Implementing (%)	0	71	45	$2,106,000
To be implemented (%)	53	20	12	$937,000

Table 2. Summary of Identified and Implemented O&M Savings for Different Type of O&Ms

Category	Number of Buildings	Identified O&M Savings ($/yr)	Savings/ Costs*	Implemented and Implementing
Delamping	1	$46,000	5%	0%
Traditional O&M	21	$742,000	11%	42%
EMCS Restoration	104*	$1,658,000	27%	100%
EMCS Recommission	7	$1,551,000	34%	67%
Total	132	$3,997,000	23%	75%

*Ratio of potential savings to the buildings annual energy costs.

the LoanSTAR buildings. However one medical building was found in which some lighting levels are much higher than IES suggested levels.

The traditional LoanSTAR O&Ms include repair of malfunctioning equipment, failure due to a lack of routine maintenance, and nighttime or unoccupied period "shutdowns". The major portion of traditional O&M savings is due to nighttime shutdown of AHUs and turning off lights and office machines. LoanSTAR O&M staff have identified $742,000/yr potential savings with 42% of these measures implemented as of April 1994. The implementation of shutdowns is extremely difficult in some places for a number of non-technical reasons.

One major effort of the LoanSTAR O&M program has been the restoration and recommissioning of Energy Management and Control System (EMCS). LoanSTAR O&M staff found the following problems: 1) control systems are disabled without the knowledge of EMCS personnel and/or facility management; 2) EMCS sensors gave incorrect values that caused the EMCS to perform poorly; and 3) EMCS control commands are not properly assigned or are being ignored. Loa.nSTAR O&M staff found that recommissioning of the EMCS system in one school district alone has the potential to reduce their energy bills by 27%, or $1,658,000/yr. In some of the LoanSTAR agencies with EMCS, it appears that little effort had been put into proper EMCS maintenance, which has led to total system failures within one year after installation.

Another important O&M measure in the LoanSTAR program is the optimization of HVAC system operation by tuning the EMCS control strategies. This measure seems to be applicable to most of the buildings and can reduce the building energy cost from 10% to 60%. In the eight buildings where optimized HVAC system tuning has been applied, $1,597,000/yr have been identified. Optimized control strategies have been implemented in two of the eight buildings, and are saving $588,000/yr. Four of the seven buildings are scheduled to be implemented in the near future.

Figure 11 shows the fraction of potential savings for each O&M measure for the entire program through December

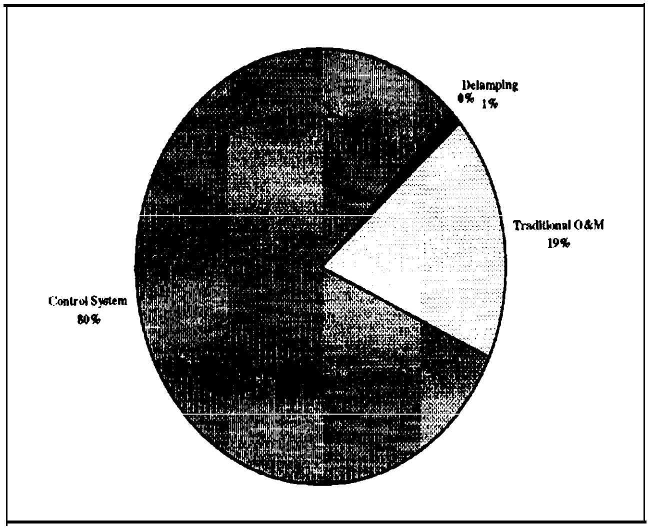

Figure 11. Distribution of Potential O&M Savings

1993. Recommissioning of EMCS and optimizing the HVAC operation resulted in about 80% of the total LoanSTAR O&M savings while traditional O&M and delamping are about 20%. Similar results are anticipated from future O&M efforts.

O&M Savings and Retrofit Savings

Table 3 summarizes the LoanSTAR measured savings for 1992 from 38 buildings and for 1993 from 50 buildings which reported savings. These savings mostly represent capitalized retrofits. Measured savings in 1992 totaled $2,303,000 or 27% of the baseline energy costs and in 1993 totaled $2,610,000 or 23% of the baseline building energy costs. When one considers the $3,997,000 potential O&M savings in Table 2, it appears that a strong O&M program provide the savings comparable to those from capitalized retrofits.

Impact of O&M Work on the Site Agency

The LoanSTAR O&M staff have completed O&M studies at four major LoanSTAR agencies: the State Capitol Complex, the Fort Worth Independent School District, the University of Texas at Arlington, and the University of Texas Medical Branch at Galveston. At each of these agencies, the LoanSTAR O&M staff's O&M work helped them to considerably improve efficiency and has led to some unexpected new developments.

At one agency a new Energy Management Department was established after the LoanSTAR staff identified more than $500,000 potential savings in the agency's LoanSTAR program buildings by optimizing the operation schedules. The agency has since shown a willingness to spend money to identify and implement energy saving opportunities in other buildings at the site. At the Texas State Capitol Complex, the O&M study led to the creation of a newsletter that stressed the importance of energy conservation with respect to preserving the environment. Finally, at another site, a lighting study helped avoid an unnecessary retrofit investment of $500,000 because it is determined that current lighting levels are already at or below IES standards.

Conclusions

As of April 1994, the LoanSTAR O&M program has identified potential annual savings amounting to $3,997,000/yr in 35 buildings and 104 schools, or 23% of the total building energy costs. These potential O&M savings are larger than the measured retrofit savings of $2,610,000 in 50 buildings in 1993. The O&M measures implemented and currently being implementing reached $3,059,000/yr as of the April 1994. Clearly, the O&M savings will greatly increase the savings produced by the LoanSTAR program.

Table 3. Summary of the LoanSTAR Measured Total Retrofit Savings

	Electricity ($)	Ch-water ($)	Steam ($)	Total
Savings in 1992 for 38 Bldg.	$750,000	$1,029,000	$524,000	$2,303,000
Savings/Cost* (%)	9%	12%	6%	27%
Savings in 1993 for 50 Bldg.	$1,045,000	$1,112,000	$453,000	$2,610,000
Savings/Costs* (%)	10%	10%	4%	24%

*Ratio of potential savings to the building annual energy cost.

The majority of O&M savings come from optimization of HVAC operation. These savings are more easily implemented when an advanced controller or EMCS is present. Fortunately, the price of control systems has decreased while their functions have increased greatly in recent years. Most control systems installed today can accommodate the optimization task if the system can be fully utilized.

Detailed hourly monitoring of building energy consumption is essential to the LoanSTAR O&M program. The detailed data provides LoanSTAR O&M staff with important information about O&M opportunities, such as the need to optimize the AHUs, which can be easily overlooked in a normal audit process. The detailed hourly measured data also provided timely feedback about the progress of O&M implementation, and make it possible to keep O&M measures in place.

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