Can You Achieve 150% of Predicted Retrofit Savings? Is It Time for Recommissioning?

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The process of improving the energy efficiency of an existing building generally begins with the identification and implementation of no-cost/low-cost measures often called O&M (Operations and Maintenance) measures. Most of these measures can be categorized as the turn-off of lights and equipment when the building is unoccupied, use of efficient temperature settings, and use of efficient system operation strategies/settings. Lists of such measures are plentiful and measures applicable to a specific building are typically identified by the building operator/engineer or an outside consultant based on the results of a site visit or audit.

This paper describes the progress of building O&M over the last twenty years and presents seven case studies which illustrate key elements of a procedure for identifying O&M measures which the authors have developed for application to buildings retrofit under the Texas LoanSTAR program. This procedure emphasizes the use of monitored hourly energy consumption data followed by implementation assistance as needed and rapid feedback on the success of the measures implemented. The procedure, which is described in the paper, has been used to identify $4 million in O&M opportunities over the last two years. Over 80% of these opportunities were present and identified after a traditional audit and retrofit had been implemented.

Introduction

In 1973, the embargo on Mideast oil made energy supply and energy use a front page issue. It was very easy to get people's attention on energy issues when you had to go wait in line at 6:00 a.m. to buy a tank of gasoline to drive to work where everyone had been told to turn off lights when they weren't needed. In a triumph of symbolism over substance, the lights were turned off on the Christmas tree on the White House lawn that year. Plans proliferated advocating any and all approaches for saving energy in all sectors of the economy, including buildings. As a result, thermostat set-backs and set-ups were recommended for all buildings and mandated in federal buildings.

From the beginning, recommendations for improved energy efficiency in commercial buildings started with "operations and Maintenance (O&M)" measures which cost very little to implement. For example, one of the early energy management handbooks (NECA/NEMA, 1976, 1979) contained a 26-point list of General Operating Practices Modifications. The specific recommendations on this list can be summarized in four categories:

a. Turn off lights and equipment when possible - eight items

b. Use efficient temperature settings - eight items

c. Use efficient system operation strategies/settings - five items

d. Other-five items

A classic commercial building energy audit case study (Dubin and Long 1978) examined a 139,400 ft^2 chemistry laboratory. The measures identified were broken into the payback categories shown in Table 1. The first two categories (i.e., immediate and 0-1 year) were primarily measures that would be referred to as O&M measures. The immediate payback savings came almost exclusively from lowering winter thermostat settings to 68 "F and the 0-1 yr payback items were primarily from chiller adjustment and installation of new humidistats to lower steam consumption for humidification in the winter. Over 80% of the savings in the 1-3 year category came from

Table 1. Chemistry Laboratory Measure Categories and Savings Potential Savings (Dubin and Long, 1978)

Payback Category	# Measures	Energy Units	% Building Energy Cost
Immediate	5	0.9kWh/sf-yr, 44.6 kBtu/SF-yr	6.3
0-1 year	4	4.6 kWh/SF-yr, 27.8 kBtu/SF-yr	8.9
1-3 year	5	1.9 kWh/SF-yr,127 kBtu/SF-yr	17.9
3-5 year	3	5.2 kWh/SF-yr, 88.5 kbtu/SF-yr	17.1
5-10	5	0.5 kWh/SF-yr, 43.3 kBtu/SF-yr	6.0
10-20	3	0.02 kWh/SF-yr, 6.3 kBtu/SF-yr	0.8
Other - meters	2		
Totals	27	13.1 kWh/SF-yr, 337.5 kBtu/SF-yr	57.2

installation of an EMCS. These three categories accounted for well over half of the potential savings-identified.

While the problems today are similar to those cited 20 years ago, there are now many more buildings and energy performance has improved significantly. According to the EIA Commercial Buildings Energy Consumption Survey, commercial building floor space increased 45% from 43.5 billion ft^2 in 1979 to 63.2 billion ft^2 in 1989, while the average energy use intensity declined 20% from 115.0 kBtu/ft^2 to 91.6 kBtu/ft^2 (EIA 1992).

During this period of time, efficient operating practices have been recommended by ACEEE, government agencies, ASHRAE, BOMA, and a host of other groups and companies. Energy management and control systems (EMCS) have gone from being a rarity to being the norm for large buildings. This emphasis and the 20% decline in energy use intensity noted above could infer that the cheap savings have already been achieved.

However, there is now a significant resurgence of interest in commissioning and recommissioning of buildings, which is being driven by energy efficiency and indoor air quality. There are 32 papers at this conference dealing with various aspects of commissioning or recommissioning buildings. This same trend can be seen in the *ASHRAE Transactions* where there were no papers dealing with building commissioning in 1990/91 and four papers in 1992 (Elovitz 1992; Solberg and Teeters 1992; Naughton 1992; Friberg et al. 1992) which dealt with commissioning of new systems. The ASH RAE Journal has also addressed the topic (Tamblyn 1992; Schliesing et al. 1993). Recently, a new environmental thrust can be seen in the U.S. E. P. A.'s, Energy Star Buildings Program (EPA 1993) which contains recommendations for careful O&M study/ implementation that are rather similar to the recommendations made 15 years ago.

Although one can be certain that great strides have been made in equipment efficiency and modern control systems the factors suggested above indicate that there is still a lot of efficiency to be gained or reclaimed at very low cost. Our own experience over the last fifteen years strongly supports this observation. The remainder of this paper will present key aspects of case studies the authors have been involved with, emphasizing factors which have influenced the O&M identification or recommissioning process which is now being implemented in the Texas LoanSTAR program.

O&M Case Histories

Student Recreation Center

The Student Recreation Center is a multipurpose university recreation facility which occupies approximately 150,000 ft^2 (13,935m^2) on two main levels. The facilities include a full-size indoor ice rink, indoor swimming and diving pools, a multipurpose gymnasium, handball courts, systems exercise rooms, and locker rooms. Two audits made numerous recommendations for both O&M measures and capital intensive retrofit measures which were based on the traditional engineering practice of estimating a measure's effectiveness with little measured data (Dow 1981; Haberl and Claridge 1985). The measures shown in Table 2 were implemented and resulted in a 30% ($60,000/yr) energy consumption reduction.

Table 2. O&M and Retrofit Measures Recommended in 1983-84 at the Student Recreation Center

Year	Cost, $	Item
1983	0	Reschedule cleaning crew
1983	300	Insulation jacket on ice rink chiller
1984	1,000	Delamp overlit areas
1984	500	Natural gas meter recalibrated
1984	1,000	Tennis court lights no longer used as security lights
1983	25,000	Shower water heated by condenser heat reclaim from ice rink compressors
1983	60,000	Reinsulate women's locker room ceiling
1985	12,500	Install pool cover

After working with the Recreation Center administration for several years it became clear that there was a need for a continuous inspection of all the energy using systems. This motivated the development of a prototype expert system to institutionalize building operating efficiency and predict future utility bills for budgeting purposes (Haberl and Claridge 1987); development of the knowledge base for this expert system relied on 18 months of manual daily readings from seven meters in the building. Examination and analysis of these data identified additional O&M measures (see Table 3) which further improved energy efficiency. Abnormal energy use was detected by comparing daily energy use to energy use predicted by a multiple linear regression model.

The fundamental concept, continually monitoring and analyzing a building's energy consumption, was not new by itself. In the 1970s, Socolowet al. (1978) showed that this kind of feedback could produce energy savings all by itself. However, the application to a large recreation complex was a radical departure from the original experiment that was applied to townhouses at the Twin Rivers complex in New Jersey. The first three measures in Table 3 can be viewed as traditional "turn it off when it isn't needed" measures which were discovered from the careful examination of the consumption data and system operations. In the first measure, the sloping ramp leading to the garbage containers for the building was being heated from September to May, whenever outside temperatures were below 35°F, to prevent icing from snowstorms. This wasted energy since the ramp only needed to be heated when temperatures were below 35°F and when it was snowing (a visual observation). Likewise, heat tapes in the rain gutters were turned on in September and

Table 3. O&M Measures Identified from Measured Data at the Student Recreation Center

Cost, $	Item
0	Modify snow melt - outdoor loading ramp
0	Gutter heat tape usage reduced
250	Cross wiring problem with men's locker room corrected
0	Brine circulation problem corrected
0	Raise ice rink brine temperature
0	Shower heat reclaim from ice rink reactivated and fine tuned by adjusting temperature
200	Use cold water for ice resurfacing
100	Pool leak discovered in surge tank
100	Disconnect steam condensate patch from adjacent buildings

off in May when experience showed they were only needed when large ice dams formed. The lights in the men's locker room were cross wired and could not be switched off. This was corrected so all the lights could be turned off at night.

The next four items involved modification of system operations. In the ice rink refrigeration system, a service valve in the brine loop which freezes the ice rink was partially closed, lowering the flow rate. When this was fully opened, it was possible to raise the brine temperature from 10°F to 17°F, thereby increasing the refrigeration system efficiency. It was also discovered that the shower water heat reclaim from the steam condenser had been disabled. This was reactivated and the shower water temperature was reduced from 140°F to 115°F. The ice resurfacing machine, which was routinely using hot water, was switched to cold water for all resurfacing except those before figure skating and competitive events. Use of cold water for other resurfacing reduced hot water consumption by 2000 gallons per day.

The last two items don't fall in either of the above categories. Daily monitoring of pool water consumption lead to discovery of a 20,000 gallon/day water leak within days of occurrence. The water and chemical expense involved were appreciable, $10-$20 per day, but the significance was much greater, because the building is perched on expansive soils on a bluff above a nearby river and this leakage would have caused massive structural damage had it gone undetected and uncorrected. Observation of steam condensate consumption lead to the discovery that condensate lines from some adjacent smaller buildings had been patched into the Recreation Center's return line and the Recreation Center was being charged for their steam as well. The gas meter recalibration noted in Table 2 was initiated when it was observed that the measured consumption was 3-5 times the rated consumption of the gas clothes dryer, which was the only gas use in the building (except for an emergency generator which was started once every two weeks). The meter was recalibrated when it was verified that the dryer was operating as rated. The puzzle wasn't solved until it was finally learned that the person in charge of the meter reading had been incorrectly scaling the readings by a factor of 10, so the Recreation Center was paying $20,000 per year for gas instead of $2,000!

Implementation of the O&M measures listed in Table 3 resulted in another 15% ($30,000/yr) reduction in the consumption — after typical O&M measures and capital-intensive retrofit measures had cut consumption by 30%. The key lessons from this case study:

- Standard operating practices were based on the operator's convenience with little regard to energy conservation.
- Access by multiple individuals to multiple pieces of equipment caused multiple problems.
- Careful analysis of measured data is a crucial element in procedures for identifying O&M measures.
- Even after measures were identified and implemented, procedures were needed to assure that the old inefficient convenient practices did not come back.

Federal Government Building

In the Fall of 1986, based in part on the success at the Student Recreation Center, the USDOE initiated a continuous metering project at the Forrestal headquarters facility located in Washington, D.C. This 1.3 million ft^2 complex consists of interconnected north, south, and west wings with a large portion of the building (668,000 ft^2) actually below grade. Additional information concerning the building and details about the program can be found in Haberl and Vajda (1988); a summary of the results and approach follows.

Originally, DOE's facility administrator was interested in the continuous metering concept because it could provide him with a means of forecasting his energy bills. This was particularly interesting because he had just been notified that his office would receive full responsibility for the $4 million annual utility bill. Complicating the administrator's task was the fact that no one had kept accurate monthly records of the utility bills since DOE only required quarterly utility reports. There were also problems with a questionable whole-building steam meter and prorated chilled water use.

Within several months, a $250,000 per year steam leak was discovered and immediately fixed. It had gone unnoticed for years because the Forrestal staff never read their own meters or knew how much steam the building was using since the utility expenses were hidden as a prorated portion of DOE's rental fee to GSA. Although the staff had some idea that steam was always being consumed, prior to the continuous metering program, no motivation had existed for finding and fixing the leaks. During the first heating season, fixing the leak involved simply turning off the building's main steam valve Friday evening and turning it back on early Monday morning whenever temperatures were above 35°F. Eventually, a major steam trap replacement and steam converter retubing patched many of the leaks. Since 1986, this single O&M measure has resulted in over $2 million in total steam savings.

The key lessons from this case study:

- O&M opportunities in large buildings do not have to involve complex engineering analysis.
- Many O&M opportunities exist because building operators may not have the proper information to assess their day-to-day actions.
- Involvement and commitment by building administrators is a key ingredient for a successful O&M program.

State Government Buildings

During the Fall of 1992, a comprehensive survey was conducted on eight state government buildings in Austin, Texas to determine potential operations and maintenance (O&M) savings opportunities. None of the buildings had been retrofitted with energy conservation reduction measures (ECRMs), but over $3,000,000 in retrofits were scheduled for these buildings. Hence, the O&M measures investigated for these buildings were primarily shut-off opportunities.

The buildings range in size from 80,000 to 491,000 ft^2, with a total area of approximately 2.2 million ft^2. The annual energy costs vary from $129,736 to $1,117,585, totaling more than $4.2 million for the eight buildings, based on utility billing data from September 1, 1990 through August 31, 1991. The O&M measures identified in these eight buildings had potential annual savings of $486,300 (11.5% of current total energy cost) as shown in Table 4. The savings due to air handler and exhaust fan shutdown (including reduced heating and cooling expense) account for 69% of the total savings. Savings from turning off lights and office machines account for the remaining 31% of the savings.

These findings were presented to the facilities personnel at a briefing in October, 1992 and copies of overheads which summarized the findings and recommendations were provided to the facilities managers. Since three buildings (SFA, LBJ, and WBT) account for 83% of the potential savings shown, it was suggested that the highest priority be given to O&M modification in these three buildings. This was followed with a complete written report in January, 1993 (Houcek et al. 1993).

Monitored data and calls to the facilities manager revealed that no shut-downs had been implemented by March, 1993, despite clear directives from the agency director that energy efficiency was an agency priority. Several barriers which delayed implementation of the O&M measures were encountered. First, it was learned that the agency had operated on a “zero complaints” priority for many years and the facilities manager was afraid that temperature swings would generate complaints. Consequently, a field test was scheduled where O&M staff worked with facilities personnel to conduct a one-time shut-down test in the SFA, LBJ, and WBT buildings to verify shut-down procedures, check for temperature swings, and measure the potential savings from the shut-down.

Table 4. Summary of the O&M Savings Opportunities for Eight State Government Buildings

Building ID Code	Air Handling Units	Exhaust Fans	PCs and Office Machines	Lights	Savings $/year
SFA	$138,500	$1,500	$15,500	$6,900	$162,400
LBJ	94,800	1,300	28,300	10,900	135,300
WBT	69,700	3,800	17,900	10,900	102,300
JER	24,900	-0-	2,900	3,500	31,300
JHR	-0-	-0-	6,100	8,200	26,000
INS	-0-	-0-	3,700	4,300	14,300
ARC	-0-	-0-	4,300	2,400	8,000
JHW	-0-	-0-	18,100	7,900	6,700
Savings $/year	$327,900	$6,600	$96,800	$55,000	$486,300

In the original report, potential AHU savings of $303,000/yr in the three buildings were projected from turning off 819 kW of AHU load over a seven-hour period each night. The scheduled shut-offs specifically excluded AH Us for floors with main-frame computers, which required 24-hour cooling. Due to several special agency requests that additional AHUs be left on, only 677 kW of the AHU load was turned off during the trial shut-down, resulting in revised AHU savings of $247,944/yr. in the three buildings. The data loggers were switched to record at one-minute intervals during this test so the sequential effect of turning off AHUs and lighting could be clearly seen. Counts of PCs and peripherals indicated that 27% of the PCs, 56% of the printers, and 75% of the copiers were left on overnight. Since the potential savings due to exhaust fan, PC, and lighting shutdown was not changed as a result of the test, the originally reported potential O&M savings of $486,300/yr. for all eight buildings was revised to $400,000/yr. based on the test results.

Following additional meetings with both administrative and building operations personnel, a decision was made to begin an AHU shutdown at the SFA building. Phase 1 of the shutdown began on the evening of Friday, September 3, 1993, with five air handlers for a duration of four hours each night. Recording thermometers were located in areas affected by the shutdown to determine to what extent the temperature changed, if at all. Weekly graphs of building energy consumption were faxed to the building operators to provide positive feedback on the results of their actions.

During the first week of October, 1993, Phase 2 began when an additional five air handlers were turned off each night followed by six more air handlers each night during the second week of October. By mid-October, 16 out of a total of 25 air handlers were being turned off each night for a period of four hours.

Figure 1 displays the results of the progressive AHU shutdown at the SFA building in terms of the lights, receptacles, and AHU load. The figure shows that prior to the initial shut-down, average nighttime consumption was approximately 1250 kW. After Phase 1 implementation, average nighttime consumption dropped to approximately 1100 kW. After Phase 2 implementation, the average nighttime consumption dropped to approximately 800 kW. Three months after implementing the shut-off of 16 AHUs for four hours per night, the shut-off was extended to six hours per night.

The savings of electricity, gas, and chilled water consumption are approximately $300/night. Building operator feedback has indicated no comfort complaints as a result of the shutdown. Initial findings from interior temperature recordings also confirm the comfort has not decreased during working hours.

Despite the success of the turn-offs in the SFA building, the facilities personnel in the neighboring LBJ Building also expressed a fear of temperature excursions and occupant complaints and did not want to initiate any turn-offs. In February, 1994, O&M staff gave another presentation

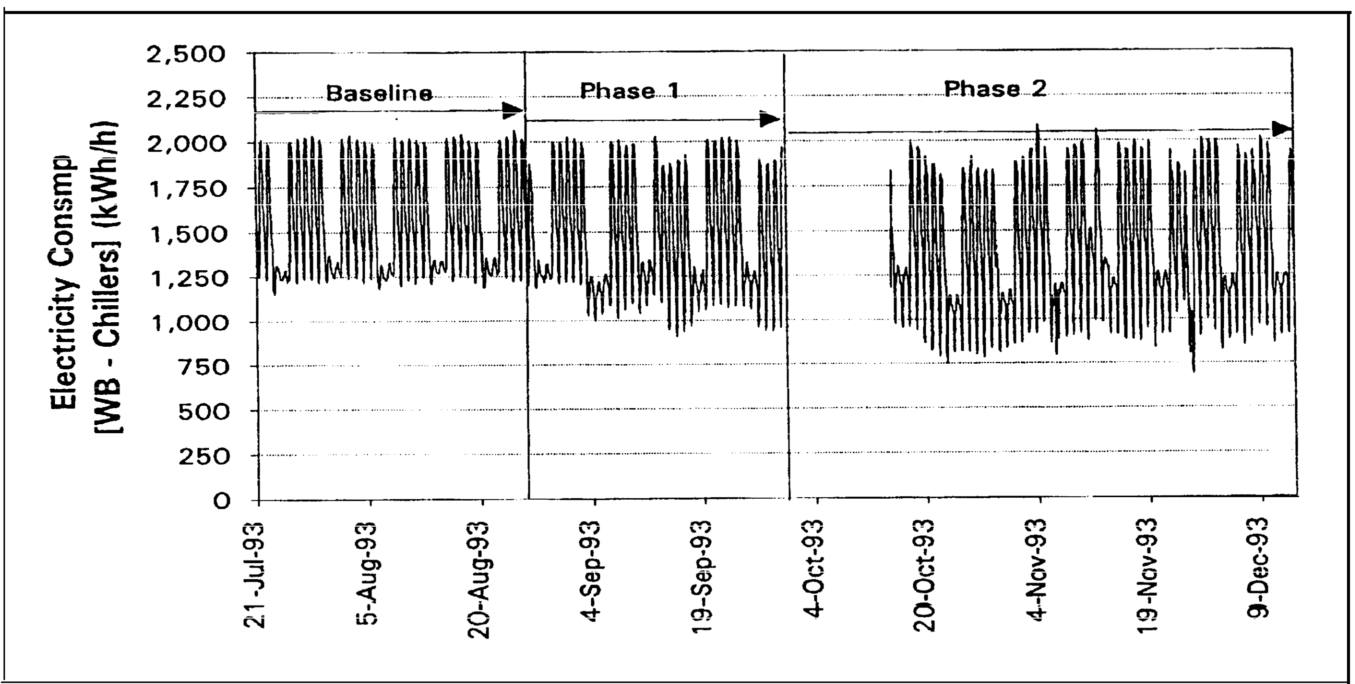

Figure 1. Whole Building Lights, Receptacles and Air Handler Electricity Use at the SFA Building During Implementation of AHU Night Shutdown

and left written materials documenting the success of the SFA shut-downs as well as statements from other state facility operators that they were turning systems off without adverse effects. Turn-offs were initiated in the LBJ building during March, 1994. Key findings include:

- Barriers to implementation of O&M measures must be identified and removed.

- There are still building operators who are afraid to turn systems off at night and on week-ends. Building specific information on the savings possible and procedures for initiating shut-offs and monitoring temperatures are needed.

- Total commitment from upper-level administration is required to break through layers of management, including incentives for a job well done and formal recognition for going above and beyond the traditional job requirements.

- Night walk-throughs to determine the number of lights, copiers, and computers left on are necessary to establish the potential for energy savings.

- Trial shut-downs may be necessary, which include the recording of minute-by-minute consumption to convince operators that an O&M measure is feasible.

School District

In 1991, the LoanSTAR Program funded conversion of four-lamp fixtures to two-lamp fixtures with reflectors in 45 schools in a large school district in north Texas. Based on LoanSTAR monitoring budget guidelines, two of these schools had hourly monitoring equipment installed to meter the electricity and gas consumption with submetering of the lighting circuits. Since the subsequent lighting savings in the two schools monitored were only half to two-thirds the predicted levels, and since these schools were surrogates for 43 others, the O&M staff investigated. Before visiting the sites, they noted that nighttime lighting consumption at one of the schools was typically 20-25 kW while it occasionally dropped to 5 kW. Nighttime whole-building electricity consumption was typically 60-100 kW and was higher in the summer, suggesting that the HVAC systems were operating. The other school showed a similar operating pattern, though the numbers were different.

O&M staff visited both schools at night and verified that security lighting was slightly less than 5 kW and that the HVAC systems were operating. These measurements indicated that the following measures had the potential to save $57,147/yr (33% of the 1992 consumption) of which $48,015 could be implemented by the EMCS, as shown in Table 5.

The school district energy manager immediately informed the EMCS operator and requested that he check programming of the EMCS since both schools were scheduled for night shut-off of the HVAC systems. Consumption data were forwarded to the energy manager the next week which showed a night-time drop at one school but not at the other. A month later, when the high night-time consumption continued at the second school, the O&M staff scheduled another visit, only this time with the energy manager after school hours. The energy manager called the EMCS operator to verify that the HVAC systems were programmed to be off. Then, they went up on the roof and found over 30 of 47 roof-top units operating at 5:00 p.m. in mid-April! Subsequent investigation found that the EMCS had been disabled at three separate points at this school.

Table 5. Summary of Potential O&M Savings for Two Monitored Schools

Item	Savings	Note
Gas	$4,952	Turn off HVAC system by EMCS
Other-than-lighting Electricity	$43,063	Turn off HVAC system by EMCS, install time clock on compact and window A/Cs
Daytime Lighting	$681	Install motion sensors in auditorium, gymnasium, and activity center
Evening Lighting	$4,728	Turn off lights where custodians are not working
Night Lighting	$3,723	Turn off lights when custodians leave
Total	$57,147	

Examination of utility bills for the other schools which had been retrofitted suggested similar operating patterns. When no further action had been taken by early June, the O&M staff scheduled another visit, delivered a rather simple formal report on their findings, and visited eleven schools which were not monitored. They found that the EMCS had been disabled at every one of the schools and the EMCS operator and energy manager were totally unaware that this had happened. Subsequently, school district personnel checked 20 more schools and found all 20 had the EMCS disabled. The energy manager for the school district preferred to receive a report which presented the findings with a minimum of technical detail.

The school district has since hired a contractor to refurbish the EMCS. Potential savings across 104 of the schools in the district are estimated to be $1,658,000/year. The potential electricity savings of $1,499,000 correspond to 27% savings which should approximately balance a 25% rate increase for which the utility received approval last summer! Major lessons:

- Continuous informed feedback is necessary to assure O&M savings are achieved and remain in place.
- Recommissioning of EMCS systems can be a major opportunity.
- Some facilities personnel prefer a minimum of technical and analytical detail in the O&M report.

Medical School Research Center

Five buildings with a total floor area of 779,000 ft^2 at a large medical school research center in Southeast Texas received retrofits under the program. These buildings had a total annual energy bill of $2,709,000 following the retrofits for an average cost of $3.48/ft2, as shown in Table 6. Two of the buildings are hospitals, two are laboratory/classroom buildings, and one is a research library. The major retrofit implemented in all five buildings was installation of facility control and management systems (EMCS) which provide monitoring, temperature control, start/stop control of major AH Us and pumps, and control of some lighting.

All of the buildings at the Medical Center are operated continuously and the library has critical temperature/humidity requirements since it contains a major rare books collection. Examination of these buildings found that the limited opportunities for start/stop control had been implemented and that lighting levels were generally appropriate, although hallway lighting levels in one building (JSS) substantially exceed IES standard levels and delamping in this building offers the potential for annual savings of $45,900.

The HVAC systems in three of these buildings (CSB, JSS, and JSN) are dual duct constant volume systems. They use 50% -100% outside air because of medical requirements, and humidity levels are high at this Gulf of Mexico location, so the systems also utilize a "precooking" coil, primarily to reduce humidity levels. This permits the main cooling coil to primarily provide sensible cooling. A portion of one building (JSN) has a single duct constant volume system using 100% outside air and the other two buildings use a hybrid system which is basically a constant volume reheat system, except it uses a single heating coil to provide reheat to all zones.

The requirements for continuous operation and for very high outside air fractions severely limit the effectiveness of most traditional O&M measures, However, these factors lead to the relatively high operating costs shown in Table 6 and combine to create greater opportunities for optimization of the air handling systems. Consequently,

Table 6. Energy Use Characteristics of Five Medical Center Buildings

Building Type	JSN Hospital In-patient	CSB Lab & Class	BSB Lab & Class	MLB Library	JSS Hospital Operation	Total
Floor Area (ft^2)	75,700*	124,900	137,900	67,400	373,000	778,800
Thermal Energy ($/yr)	$405,300	$235,300	$573,900	$153,200	$759,000	$2,126,600
Electricity ($/yr)	$96,800	$115,200	$97,000	$41,800	$231,600	$582,400
Total Energy ($/yr)	$502,100	$350,500	$670,900	$194,900	$990,600	$2,709,000
Total Energy ($/ft^{2}yr)	$6.64	$2.81	$4.87	$2.89	$2.65	$3.48

*Including a kitchen area (18,000 ft^2)

the O&M staff concentrated on measurements of temperatures and air flows in the air handlers and created relatively detailed calibrated models of the air handling systems. The systems models created were used to conduct an examination of system energy requirements while the reset schedules for the hot deck, cold deck, and pretreatment cold deck were parametrically varied to determine an "optimum" set of reset schedules. Figure 2 shows an example of original or baseline schedules used to control the various deck temperatures as a function of ambient temperature and of the recommended "optimized" schedules.

The $517,800/yr in savings opportunities identified for this site through improved hot deck/cold deck reset schedules or commissioning of the EMCS are shown in Table 7. Note that these opportunities correspond to 19% of the present energy consumption of these buildings and an additional $74,000/yr in opportunities were identified for implementation of an economizer in MLB and delamping in JSN.

It is also noteworthy that most of the commissioning measures are easy to implement, requiring only that the EMCS be reprogrammed. The operations staff have aggressively pursued these opportunities and measures accounting for $122,000/yr of the estimated savings were implemented immediately and the remaining measures are being implemented in 1994. Figure 3 shows hourly chilled water consumption for BSB with the baseline data shown as "+" and the data collected after the cold deck temperature was raised from 54°F to 59°F shown as open circles. The reduced consumption shown corresponds to savings of $42,600 for the 117 days shown and is consistent with the annual savings of $156,000 predicted for this building. Note that this change did not yet incorporate the fully optimized reset schedule. Major findings:

- Recommissioning of EMCS is a major opportunity - even in large facilities with a good facilities engineering staff.
- Some facilities staffs are interested in rather sophisticated analysis of O&M opportunities.
- Many recommissioning opportunities are easy to implement.

Medical Research Building

In a large medical school facility in Houston another building was studied. This facility is an 8-floor medical research facility with 120,370 ft^2 built in 1986. The building exhibits many of the factors present in the previous medical research center case study: the building is in continuous use, has very high outdoor air fraction, and has stringent temperature and humidity requirements because it contains extensive animal research laboratories. The major difference is that this facility has had a much more aggressive energy management program in place for several years. They converted all fluorescent fixtures to T-8 lamps with electronic ballasts and reflectors, and replaced virtually all incandescent lights with screw-in fluorescent in 1991. The water loop and air handlers were commissioned in November. 1992 with measured

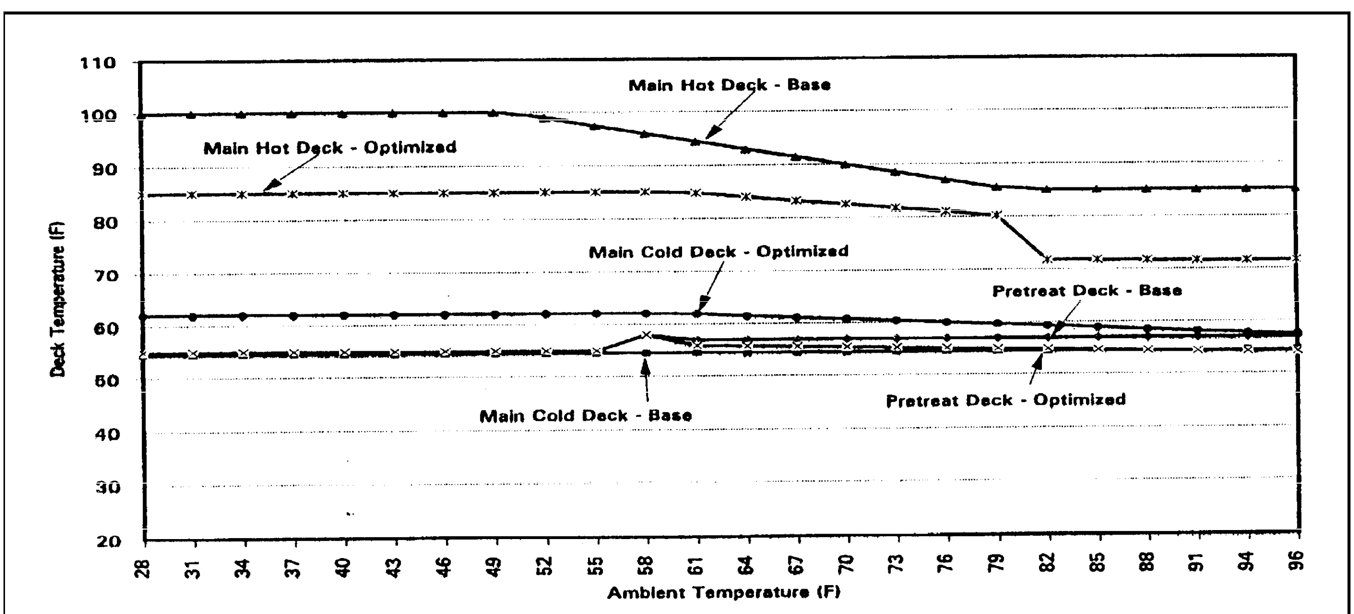

Figure 2. Baseline and Optimized Main Hot Deck, Main Cold Deck and Pretreatment Cold Deck Reset Schedules for the CSB Building at a Medical Research Center

Table 7. Summary of Potential Cost Savings at Five Medical Center Buildings Due to Optimized Schedules

Savings	JSN	CSB	BSB	MLB	JSS	Total
Chilled water $/yr	$54,300	$55,700	$108,700	$27,700	$124,500	$370,900
Condensate $/yr	$12,700	$18,000	$47,300	$18,800	$50,100	$146,900
Total $/yr	$67,000	$73,700	$156,000	$46,500	$174,600	$517,800
$/ft^{2}yr	0.84	0.59	1.13	0.69	0.47	0.66
%	13%	21%	23%	24%	18%	19%

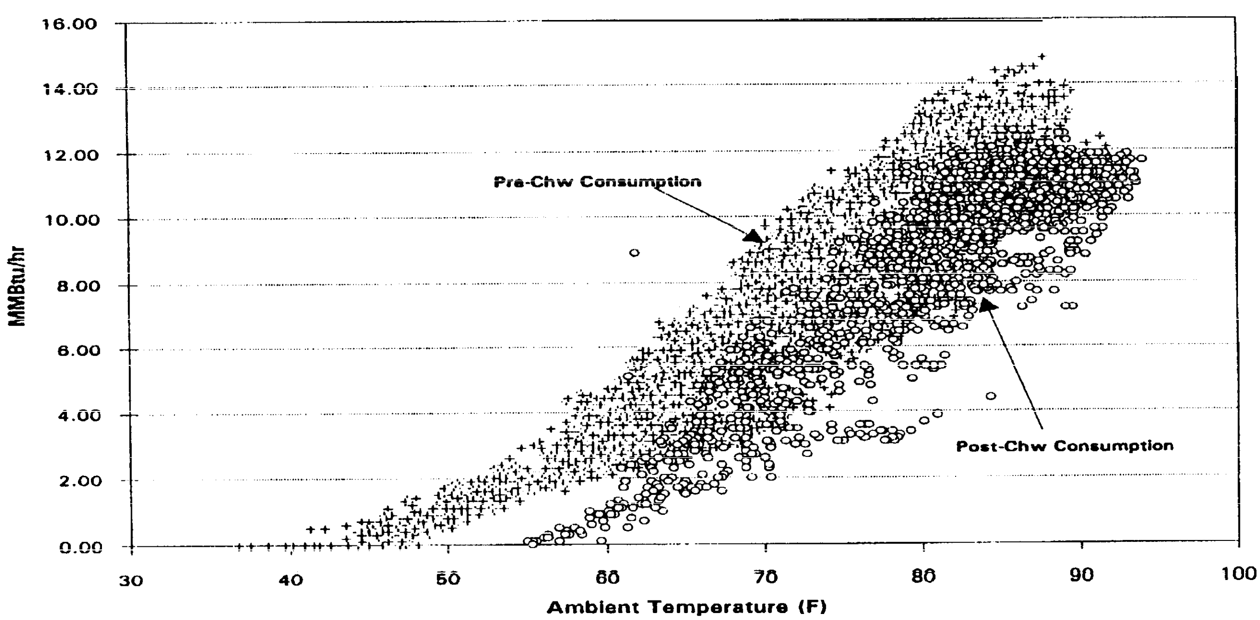

Figure 3. Chilled Water Consumption for January through October 1993 Versus Ambient Dry Bulb Temperature for the BSB Building at a Medical Research Center.

savings in the first year of $145,700 (7915 MMBtu chilled water, 9957 MMBtu steam). Cold-deck reset with ambient temperature was implemented in November, 1993 resulting in measured savings of $62,600 (3723 MMBtu chilled water, 3974 MMBtu steam) during the first two months.

Consequently, when the O&M staff visited this facility in January, 1994, the facility energy management staff primarily expressed interest in obtaining case study examples of the safety and reliability of variable flow fume hoods and documentation of the effectiveness of medical incinerators to counter objections to the operation of such a facility in an urban environment.

However, subsequent examination of the building and its systems found three major opportunities, as shown in Table 8. In one, a temperature sensor calibration problem is costing over $111,000 per year. In a second measure, an “optimized” reset schedule for the cold deck and hot deck could produce additional savings of $143,053/yr. It was also observed that air exchange rates in much of the building were higher than those required by the ASHRAE Standard (ASHRAE 1991) for laboratory spaces and that reduced air flow rates had the potential to save an additional $120,852/yr.

In summary, the facility staff had reduced consumption by 31% from $1,228,000/yr to $844,819/yr. The O&M staff still found opportunities for further systems optimization which could produce an additional 44% reduction to $469,897/yr. Major finding:

Table 8. Summary of Potential Medical Research Building O&M Savings

	Electricity		Condensate				Total
O&M or ECRM	**MMkWh**	**Dollars**	**MMBtu**	**Dollars**	**MMBtu**	**Dollars**	**Dollars**
1. Sensor Calibration			6,072	$48,576	7,523	$62,441	$111,017
2. Optimized Schedule			5,830	$46,640	11,616	$96,413	$143,053
3. Reduced CFM	1.332	$39,962	5,014	$40,112	4,913	$40,778	$120,852
Total	1.332	$39,962	$16,916	$135,328	24,052	$199,632	$374,922

Note: The annualized cost savings were calculated using the following energy price: $8.30/MMBtu for chilled water, $8.00/MMBtu for condensate, and $0.03/kWh for electricity.

- There can be major opportunities for O&M even when the EMCS has been recently commissioned.

University Campus Buildings

Three buildings at a university campus in the Dallas-Fort Worth metroplex had VAV conversions of AHUs, occupancy sensors installed to control lighting and variable speed control for chilled water pumps installed. This campus had a very aggressive energy management program in place and LoanSTAR staff anticipated that retrofit savings might fall below audit predictions. However, 1992-measured savings for the three buildings were only 25%, 48%, and 62% of audit predictions - even lower than expected. Investigation showed that two major audit errors accounted for the bulk of the discrepancy: the auditors had overestimated the annual hours of operation and used the rated power for the AHU motors versus the actual power draw.

While making site visits associated with this investigation, O&M staff learned that the facilities staff were skeptical about some of the recommendations for a lighting retrofit they were about to make in several additional buildings. Subsequent site measurements revealed that over half of the rooms scheduled to receive reflectors and conversion from four-lamp to two-lamp fixtures were already below IES standard lighting levels and the retrofit would lower lighting levels. The retrofit is now being redesigned and it appears that approximately $500,000 in ill-advised retrofit measures will be saved. Major finding:

- This study, which started as an O&M study, saved $500,000 in retrofit expenditures.

What Do These Cases Tell Us?

1. There is so much variation in the O&M opportunities at different sites that a cookbook approach is of limited value.

2. Measured energy consumption data is extremely valuable as a diagnostic tool - annual data can be used to identify promising candidates for recommissioning. Hourly and submetered data are extremely valuable when used in conjunction with site measurements and data in diagnosing specific opportunities for improved efficiency. They also provide immediate feedback on whether system changes have made a difference.

3. The facilities engineers/operators are crucial participants in an O&M improvement effort. An O&M consultant will be most effective if they can build trust and a good working relationship with the facilities personnel. Their knowledge of a facility is crucial, and some sort of incentive should be established for their participation before the project begins.

4. Identification of O&M opportunities is necessary but is often insufficient to achieve implementation. While some facility staffs will take a verbal recommendation and implement it immediately, others require written reports followed by continued consultation on specific steps to take in implementation. In some cases, trial tests of the O&M may be needed to assure the staff that it can work.

5. Requirements for analysis and reporting differ widely. Some facilities staffs prefer to have the O&M opportunities and their savings described with minimal

technical detail and care nothing about the analysis techniques used to estimate the savings. Others want to have a rather detailed analysis performed, (e.g., hourly systems simulation) and have a report that documents the analysis effort in full detail. In either case, an accurate engineering analysis serves as the heart of the program.

These factors indicate that an effective O&M effort should utilize as much measured data as is readily available while being flexible to meet the needs of facility operators with widely varying expertise and interests.

Recommended Procedures - The LoanSTAR O&M Methodology

The LoanSTAR O&M methodology can be viewed as a closed feedback loop, which is illustrated in Figure 4. The process begins with the weekly collection of the LoanSTAR data which is archived in a relational database where hard copy reports can be issued at weekly, monthly, and annual intervals.

Site Selection

The O&M staff normally examines a site after retrofits have been implemented. Hence, a year or more of data is often available. The staff begins by examining the annual report and looking for high annual energy-use indices such as $/ft^2, kWh/ft^2, chilled water Btu/ft^2-h, steam or gas Btu/ft^2-h, etc. Even a small percentage saving at some sites can be substantial! The hourly data as presented in the monthly reports are then examined for high or unexpected nighttime consumption. If nighttime electricity consumption is two-thirds or three-fourths the day-time peak, there are probably opportunities for additional shut-offs. For some sites, such as schools, consumption of 25% of the daytime peak will indicate opportunities for additional shut-offs. An agency inquiry or request for assistance with a specific problem can also result in site selection.

Preliminary Problem Diagnosis Using Measured Energy Data

As noted above, the O&M staff has generally begun to review the data before a site is selected. However, following site selection, the data examination moves to a new level, as indicated in Figure 4. The available weekly, monthly, and annual plots of the data are now examined looking for evidence of specific opportunities for reduced energy use. Browsing software is also used to directly examine the data in the database. Detailed information, including that available in audit reports and site description notebooks which are assembled for each site, is

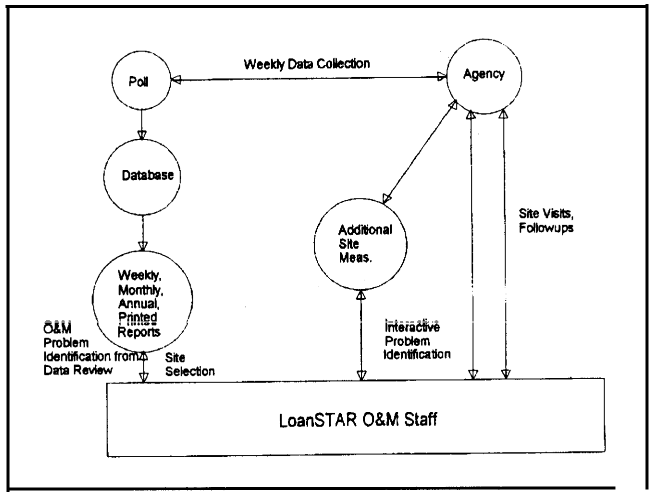

Figure 4. Diagram Illustrating the O&M Identification and Implementation Process

examined in conjunction with the energy data and specifically examined for:

a. Excessive system or subsystem operating hours;

b. Changes in use patterns which may indicate system or component failures; and

c. High levels of simultaneous heating/cooling which suggest need for system optimization.

This process typically results in preliminary identification of one or more major O&M opportunities.

Site Visit Following Examination of LoanSTAR Measured Energy Data

Facilities personnel at the site selected are contacted following preliminary problem diagnosis and their interest in having O&M staff visit their facility to discuss the preliminary findings is ascertained. At the initial meeting, the services which the O&M staff can provide are presented, the preliminary problem diagnoses are presented and discussed, and specific areas in which the facilities staff would like input from the O&M staff are identified. During this visit (and possible subsequent visits) the O&M staff do the following:

- Inspect major energy systems
- Determine/verify building schedules and operating information
- Investigate operation/occupancy history
- Measure key parameters influencing energy use
- Identify additional O&M measures
- Discuss potential O&M measures with facility operator/energy manager

Determination of Potential O&M Savings

Following one or more site visits, the potential O&M savings are quantified. The savings are typically estimated using regression-based analysis which utilizes the measured energy consumption data for the site and one time measurements made during the site visit(s). Short-term shut-off tests are generally conducted to provide hard data upon which to base the shut-off potential. Savings from systems optimization or EMCS recommissioning are normally determined using customized systems models which include detailed treatment of system flows, temperatures and psychometrics with estimated annual savings based on a bin analysis of the model predictions.

O&M Implementation

The implementation process is highly variable and must match the needs of the individual site. In some cases, the recommendations are implemented based on verbal transmission of findings or a faxed outline. More generally, a formal report is prepared, submitted for review in draft form, and then delivered following revision. In other cases, it is necessary to provide additional assistance, and in some cases including step-by-step instructions and/or on-site assistance with initial implementation.

Following initial implementation, weekly follow-up on the savings is typically provided until the measures are fully implemented and part of the normal operating routine. Monthly reports which document facility energy use and savings continue indefinitely.

Summary of O&M Savings Identified and Measures Implemented

This process was initially implemented with one staff member starting in the summer of 1992. At the beginning of 1993, a second staff member was added and for the last six months, a third staff member has provided assistance amounting to about one-third time. Through the end of April, 1994, the process has been applied (at various levels of detail) to 133 buildings totaling over 10 million ft^2. O&M measures with potential savings totaling $3,997,000/yr have been identified in LoanSTAR agencies in addition to saving $500,000 on inappropriate retrofits. As shown in Figure 5, 7% of the savings will come from control system recommissioning, 22% from traditional O&M measures such as nighttime shutdown, and 1% from delamping. It is noteworthy that $3.5 million/yr of the O&M measures identified were in buildings which had already been retrofit.

As shown in Table 9, measures now producing savings at an annual rate of $780,000 have been fully implemented.

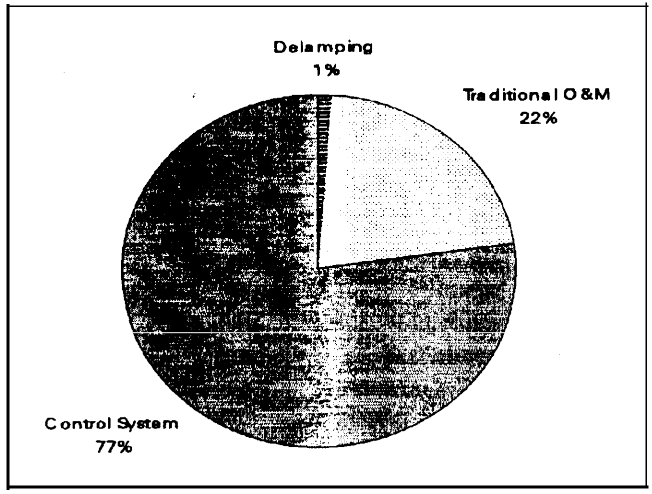

Figure 5. Distribution of Potential O&M Savings Among Major Types of O&M Measures

Determination of measures now in the process of being implemented is imprecise, but appears to total $2,230,000/yr while $987,000/yr have yet to be implemented. However, less than $100,000/yr of the measures identified have been rejected for possible implementation by facilities personnel, so the final implementation rate is expected to exceed 90%.

It is also noteworthy that the O&M measures identified total 23% of the total energy costs at the facilities surveyed. The average LoanSTAR facility undergoing retrofit had saved 27% of its energy use as of the end of 1992 with a payback of slightly over 3 years. This 27% savings is approximately 25% more than predicted by the preretrofit audits. It is too early to be certain of the impact the O&M program will have on total LoanSTAR savings, but it appears clear that the savings will easily exceed 150% of the predicted retrofit savings when all the O&M measures are fully implemented.

Conclusions

This paper has presented seven case studies which illustrate key elements of the procedure for identifying O&M measures which the authors have developed and applied to buildings retrofit under the Texas LoanSTAR program. This procedure emphasizes the use of monitored hourly energy consumption data followed by implementation assistance as needed and rapid feedback on the success of the measures implemented. The procedure, as described in the paper, has been used to identify $4 million/yr in O&M opportunities over the last two years. Over 80% of these opportunities were present and identified after a traditional audit and retrofit had been implemented. It appears clear that total savings in the LoanSTAR Program will exceed 150% of the audit predictions when all the O&M

Table 9. Summary of Identified and Implemented O&M Savings

Time	1992	1993	1/94-4/94	Total ($/yr)
Identified	$176,000	$2,816,000	$1,005,000	$3,997,000
Implemented (%)	100	10	32	$780,000
Being Implemented (%)	0	61	51	$2,230,000
To be implemented (%)	0	29	17	$987,000

measures are fully implemented due to the numerous opportunities for O&M measures which the traditional energy audit failed to identify.

This experience shows that O&M or opportunities are abundant. Many buildings still offer opportunities for lowering energy consumption by 10% to 40% merely by improving the operational strategy of the building. A significant factor in these opportunities is the availability of energy management and control systems which are not fully utilized in many buildings. Hence, we conclude it is time for recommissioning !

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