CASE STUDY: UTILITY COST REDUCTION AT A LARGE MANUFACTURING FACILITY

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ABSTRACT

This case study presents results of a systematic utility cost reduction plan implemented at a 450,000 sq. ft. manufacturing facility in a hot and humid climate. Electricity, natural gas, and water usage were all reduced on an absolute basis in both 2002 and 2003 relative to the baseline year of 2001.

That is, "new" utility usage associated with a 36,000 sq. ft. office addition in 2002; a 9,600 sq. ft. assembly / test expansion in 2002; a 46,000 sq. ft. office addition in 2003; and a 96% increase in production in 2003 were entirely offset, plus "old" utility usage was reduced.

"Hard" utility cost savings totaled $442,000 (32.6%) in 2002 and $235,000 (17.4%) in 2003 – both relative to 2001. Cumulative utility cost savings totaled $677,000 over this 2-year period (Figure 1).

These results were achieved by a well-balanced portfolio of cost-effective utility-saving measures targeted at high pay-off opportunities that are readily repeatable in most industrial / manufacturing facilities.

Utility usage reduction measures ranged from no-cost / simple operation and maintenance improvements, e.g., turning-off lighting and air-conditioning equipment during unoccupied periods; to low-cost expense improvements, e.g., polarized refrigerant oil additives; to higher-cost / more complex capital projects, e.g., variable speed fan drives, cooling tower replacements, and water chiller replacements.

In addition, utility-saving technologies, e.g., occupancy motion sensors, were successfully integrated into new building design and construction.

Also, $725,000 of "hard" operations and maintenance cost savings were realized over a 5-year term by outsourcing of operation and maintenance of air-conditioning systems and associated controls.

INTRODUCTION

This case study will demonstrate how these significant utility cost savings were achieved at a 450,000 sq. ft. manufacturing facility in Houston, Texas. The facility consists of roughly 225,000 sq. ft. of office spaces with 12 hour / day, 5 day / week occupancy and 225,000 sq. ft. of manufacturing spaces with 18 hour / day, 6 day / week occupancy.

The facility was initially constructed in 1969 and subsequently grew via a series of expansions and additions - the most recent including a 36,000 sq. ft. office addition and a 9,600 sq. ft. assembly / test expansion in 2002, plus a 46,000 sq. ft. office addition in 2003.

Approximately 1,000 employees work at the facility. Business functions conducted at the facility include research, design, manufacturing, assembly, and testing of surface and sub-sea energy production equipment, plus engineering, sales / marketing, accounting, management, etc.

In the baseline year (2001), 225,000 sq. ft. of air-conditioned manufacturing spaces and 50,000 sq. ft. of air-conditioned office spaces were heated and cooled by approx. 50 four-pipe, single-zone, constant-volume, water-coil air-conditioning units; a central chilled-water cooling system consisting of four water-cooled, electric-driven centrifugal water chillers (totaling 1,195 tons / 840 kW electrical demand); and a central hot water heating system consisting of one natural gas-fired, fire-tube boiler (200 boiler hp / 8.375 million btu/hour heat input).

The remaining 18,000 sq. ft. of air-conditioned office spaces (in a separate building) were cooled by two variable-air volume, multi-zone, direct expansion unitary rooftop air-conditioning systems with air-cooled condensers and reciprocating compressors.

The remaining 19,000 sq. ft. of assembly / test spaces were not air-conditioned. Instead, they were cooled by induced-draft rooftop ventilation fans and heated by natural gas-fired infrared unitary heaters.

UTILITY COST REDUCTION PLAN

The first step in achieving and sustaining these significant "hard" savings was to prepare a systematic utility cost reduction plan consisting of the following elements:

1. Objectives
2. Strategy to achieve objectives
3. Baselines and profiles of existing utility usage / price / cost
4. Audits and estimates of utility cost reduction opportunities
5. Measures to implement the strategy
6. Resources to implement the strategy
7. Metrics to measure achievement of objectives

OBJECTIVES

In this case, the objective was to reduce and sustain overall utility costs below the 2001 (baseline) level of $1.35 million/year.

This objective is simple, clear, achievable, and measurable. Importantly, it references a fixed, historical baseline.

STRATEGY

A two-prong strategy was adopted to achieve the objective.

Utility Cost = Utility Usage x Utility Price

Electricity $/Year = kWh/Year x $/kWh

Natural Gas $/Year = Cu. Ft./Year x $/Cu. Ft.

Water $/Year = Gallons/Year x $/Gallon

Simply put, utility cost reductions are the product of utility usage reductions <u>and</u> utility price reductions. Focusing entirely on usage reductions or entirely on price reductions is not a well-balanced strategy.

BASELINES AND PROFILES

It's important to review past utility bills and establish a month-by-month historical baseline for each utility. As will be discussed later, metrics measure progress against these historical baselines.

It's also important to account for total annual consumption of each utility by end-use in an energy usage profile (Figure 2). Profiles indicate which end-uses, e.g., lighting, are the best targets for audits.

AUDITS AND ESTIMATES

An audit identifies specific utility usage reduction opportunities. Associated data collection and analysis establish utility usage reduction estimates for each usage reduction opportunity.

In order to correctly estimate utility usage and cost savings, two estimates must be prepared. Annual utility usage savings and cost savings are the difference between the "before" usage / cost estimate and the "after" usage / cost estimate:

Annual "Before-Retrofit" Utility Usage /Cost

\- <u>Annual "After-Retrofit" Utility Usage / Cost</u>

= Annual Utility Usage / Cost Savings

Because this is a multi-factor analysis, e.g., before and after levels of equipment loading / efficiency / demand, before and after annual hours of operation, before and after utility prices, etc, there are lots of opportunities for errors. Thus, the uncertainty of the utility usage and cost reduction estimates must be taken into account. The conservative approach is to discount the estimates by the associated level of uncertainty.

MEASURES

A variety of well-targeted utility cost reduction measures (in priority order) were developed and implemented on a sustained basis.

1. Efficient operation and effective maintenance of utility-consuming equipment
2. Competitive procurement of utilities

3. Cost-effective expense improvements

4. Cost-effective capital projects and retrofits

5. Efficient design of new buildings and plant expansions

Each measure is built upon the one preceding it - just as a multi-story building is constructed. In this case, the foundation is efficient operation and effective maintenance. Until operation and maintenance are mastered, performance issues, reliability issues, excessive repair costs, and excessive utility usage / cost will dominate the agenda and expense budget of the facilities and maintenance organization.

RESOURCES

Utility costs are one of the largest categories in the annual expense budget for facilities and maintenance organizations. Unlike property taxes and depreciation costs, utility costs can be readily reduced.

Efficient operation and preventative maintenance of assets are funded by the annual expense budget for facilities and equipment. These are routine expenses. Preventative maintenance is 67% to 75% less expensive than repair-upon-failure, so it's a measure that reduces net expenses concurrent with implementation. Preventative maintenance need not be applied wholesale – it can be implemented in stages and / or for selected categories of assets.

Likewise, expense improvements apply against the annual expense budget. These non-routine expenses must be identified, quantified, and justified during the annual expense budgeting period in order to be included in the budget. Those expense improvements with a simple payback period of less than one year will be entirely offset by reductions in utility costs, thereby reducing net annual expenses.

Capital projects and retrofits apply against the annual capital budget. These non-routine expenditures must be identified, quantified, and justified during the annual capital budgeting period in order to be included in the budget. Capital assets must be depreciated and are ordinarily subject to formal "rate-of-return" analysis rather than simple payback calculations.

Energy efficiency measures must be included in the design of new buildings and plant expansions in order to be included in the preliminary cost estimates that later become the project budgets. Fortunately, high levels of energy efficiency are now prescribed in many building codes.

An important insight is to have expense improvement projects and capital / retrofit projects developed in advance of the expense and capital budgeting process – ordinarily conducted in July for the succeeding year. Otherwise, the available resources will be committed to other projects. Another opportunity for resources is unexecuted expense and capital funding – ordinarily available in October.

METRICS

Well-designed metrics (Figure 3) measure progress towards the objective.

In order to assure that annual objectives will be met or surpassed, monthly metrics are monitored. Monthly metrics include monthly utility usage and costs. Intermediate-term corrective actions can then be identified and applied in time to affect the annual metric.

Likewise, in order to assure that monthly metrics are met or surpassed, daily metrics are monitored. These include daily utility meter readings, daily trend charts of air-conditioning system operating data, etc. Short-term corrective actions can then be identified and applied in time to affect the monthly metric.

This "multi-level" approach requires continuous effort and yields continuous improvement.

YEAR 1 (2002) OPERATIONS AND MAINTENANCE MEASURES

An example of efficient operation of utility-consuming equipment was automatically turning-off the 200 hp hot water boiler during unoccupied periods, e.g., at nights and on weekends, plus whenever the outside air dry-bulb temperature was above 60^{o}F during occupied periods. The previous scheme of operation had supplied heat and consumed natural gas when not required.

An example of effective maintenance of energy-consuming equipment was competitive out-sourcing of operation and maintenance of air-conditioning systems and associated controls via a comprehensive, full-service contract. This approach yielded "hard" savings of $725,000 (47%) over a 5-year term vice the historical baseline.

YEAR 1 (2002) COMPETITIVE UTILITY PROCUREMENT MEASURES

The newly-deregulated retail electricity market in Texas provided the opportunity to procure electricity at lower price than from the regulated local electric company.

In a deregulated retail electricity market, generation prices are "unbundled" from transmission and distribution prices. So electricity can be purchased from the lowest-priced generator. However, transmission and distribution remain regulated and must be purchased from the local electric company at regulated prices with a variety of regulated "add-on" fees.

In 2002, the $0.036/kWh generation price plus the $0.009/kWh transmission and distribution price totaled $0.045/kWh. This was $0.021/kWh (32%) less expensive than the "tariff" price of $0.066/kWh paid in 2001. The contract term was one year.

YEAR 1 (2002) EXPENSE IMPROVEMENTS

Replacement of the eroded impeller and diffuser on the 500-ton medium pressure centrifugal water chiller restored its capacity and renewed its service life. This water chiller had operated in an impaired condition since initial start-up in 1993. The replacement impeller had much thicker vanes and the replacement diffuser had more refrigerant ports to better distribute the cold gas around the perimeter of the impeller.

Also, replacement of non-functioning purge units on one 275-ton and two 210-ton low-pressure centrifugal water chillers allowed them to eliminate their non-condensable gases / moisture and operate with lower condensing pressures.

YEAR 1 (2002) CAPITAL PROJECTS AND RETROFITS

One retrofit project was installation of digitally-controlled variable-speed drives on 35 fans ranging from 10 – 20 hp (Figure 4). These fans - on existing air-conditioning units located in manufacturing and warehouse areas – were automatically shut-off from 23:30 to 05:30 Monday – Saturday and all day on Sunday. Also, fan speed was modulated with outdoor air dry-bulb temperature in a linear manner from 100% speed at 100^{o}F to 32% speed at 32^{o}F. Direct digital control and monitoring were extended from the existing site controls network.

This project cost $100,000 and saved 1.9 million kWh/year. At Year 2's electricity price of $0.063/kWh, this yielded a 10-month simple payback and a 120% simple return-on-investment.

Another retrofit project was replacement of two deteriorated wood-frame cooling towers serving the East Mechanical Room with an 800-ton, two-cell, induced-draft, stainless-steel, cross-flow cooling tower with 20 hp premium efficiency motors (0.0375 kW/ton fan horsepower).

YEAR 1 (2002) BUILDING ADDITIONS AND PLANT EXPANSIONS

Energy-efficient design was practiced on a 36,000 sq. ft., two-story office addition. The design incorporated fan-powered variable air volume boxes and two 75-ton air-cooled unitary air-conditioning units. The air-conditioning units featured four scroll compressors, variable-speed evaporator fans, and outdoor air economizers.

Power was supplied from the existing site 13.8 kV primary / 480 volt secondary electrical distribution system. Direct digital control and monitoring were extended from the existing site controls network. The controls automatically turned-off the air-conditioning units and fan-powered variable-air volume boxes during unoccupied periods and reduced air flow volumes at part-load conditions during occupied periods.

YEAR 1 (2002 VICE 2001) RESULTS

<u>Electricity</u>:

Volume Savings: 339,016 kWh (1.9%) - more efficient operation / controls and improved maintenance entirely offset "new" electricity usage by a 36,000 sq. ft. office addition and a 9,600 sq. ft. assembly bay expansion

Cost Savings: $379,313 (32.7%) – significantly lower prices and slightly lower usage

Off-Site Emissions Savings - approximately 283 tons (1.9%) of CO_2 (a greenhouse gas)

Natural Gas:

Volume Savings: 2,974,000 cu. ft. (17.5%) - more efficient operation / controls and improved maintenance

Cost Savings: $54,070 (35.9%) - significantly lower prices and significantly lower volume

On-Site Emissions Savings - approximately 177 tons (17.5%) of CO_2 (a greenhouse gas)

Water/Sewer:

Volume Savings: 6,791,000 gallons (21.2%) - more efficient operation / controls entirely offset additional usage by a 36,000 sq. ft. office addition and a new 180,000 gallon test tank

Cost Savings: $8,605 (19.8%) - slightly higher prices were offset by significantly lower volume

Total Utility Cost Savings: $441,988 (32.6%) vice baseline

YEAR 2 (2003) OPERATIONS AND MAINTENANCE MEASURES

An example of efficient operation and maintenance of utility-consuming equipment was operating the water chillers to maintain 57^oF entering evaporator temperature rather than 45^oF leaving evaporator temperature. This provided an automatic leaving chilled-water temperature “reset” function and reduced compressor electricity demand by approx. 1.5% per 1^oF upward reset in the leaving evaporator water temperature.

Another example of efficient operation and maintenance of utility-consuming equipment was operating the 200 hp rotary-screw air compressors with turn valve control rather than inlet valve control. The turn valve varies the capacity of the compressor from 40 – 100% in a more efficient manner than the inlet valve by opening and closing ports in the compressor cylinder.

An example of effective maintenance of utility-consuming equipment was procurement, installation, and implementation of a Computerized Maintenance Management System (CMMS). This was a site-wide project including the Facilities and Maintenance; Manufacturing; and Information Technology departments.

The CMMS program was installed on the existing site information technology network and provided preventative maintenance for 400 facilities and manufacturing assets; service requests from 1,000 employees, and inventory control for three tool cribs.

Now preventative maintenance checks and services; office and building service requests; and inventory of tools and parts are systematically initiated, assigned, and closed while being fully-documented and transparent. Metrics and reports regarding backlogs, completion times, sorts by selected categories, etc are reviewed and managed on a daily and weekly basis.

YEAR 2 (2003) COMPETITIVE UTILITY PROCUREMENT MEASURES

Competitive procurement of electricity was not as lucrative in 2003 as in 2002 due largely to sustained higher natural gas prices and less predatory competition among electric generators.

The competitive generation price increased by $0.018/kWh (50%) – from $0.036/kWh in 2002 to $0.054/kWh in 2003. The regulated transmission and distribution price remained at $0.009/kWh. So the total electricity price increased by $0.018/kWh (40%) - from $0.045/kWh in 2002 to $0.063/kWh in 2003. The contract term was two years.

In perspective, the 2003 total electricity price of $0.063/kWh was still $0.003 (5%) lower than the “tariff” electricity price of $0.066/kWh paid in 2001. What had increased was the interim volatility of retail electricity prices.

YEAR 2 (2003) EXPENSE IMPROVEMENTS

An example of an expense improvement was installing polarized refrigerant oil additive in air-conditioning equipment in order to reduce resistance to heat transfer due to insulative oil accumulation (approximately 2% per year) on the refrigerant-side of heat exchange tubes in condensers and evaporators.

This refrigerant-side "fouling" can impede heat transfer by up to 30%. The polarized refrigerant oil additive (totaling 5% of oil volume) forms a one molecule thick coating on the surface of the tubes and restores original heat transfer efficiency.

This was applied to unitary air-cooled air-conditioning equipment and applied water-cooled equipment. Electricity savings varied depending on the extent of oil accumulation / heat transfer impedence as well as annual run hours, annual load profile, etc. The 10-year old, 500-ton medium pressure centrifugal water-chiller enjoyed an 11.8% improvement in "before" versus "after" performance at full-load operating conditions.

Another example of an expense improvement was installing tanks / pumps / piping to recycle condensate from large unitary and applied air-conditioning units for use as make-up water for the cooling towers. This worked particularly well because air-conditioning condensate is cooler and cleaner than domestic water. Also, the availability of air-conditioning condensate and the demand for cooling tower make-up water are concurrent.

Another example of an expense improvement was replacing existing flush urinals in restrooms with new water-free urinals. These eliminated water consumption of up to 4 gallons/flush and also eliminated maintenance expenses associated with automatic flush valves.

YEAR 2 (2003) CAPITAL PROJECTS AND RETROFITS

One retrofit project was replacement of a variety of gas-fired low and high-intensity infrared heaters in the assembly / test area with eight 400,000 btu/hour natural-gas forced-air heaters. The infrared heaters were not effective because, due to bridge crane travel, the locations of the infrared heaters were limited to the perimeter of the 28,635 sq. ft. area to be heated.

The forced-air heaters were 80% efficient and provided a 56^{o}F air temperature rise. The 42,400 cfm of forced-air supply air yielded 1.5 cfm/sq. ft. of air distribution and achieved uniform temperature levels. Also, individual thermostatic controls turned-off the forced-air heaters when space temperatures exceeded 65^{o}F.

Another retrofit project was installation of a 7.5 hp pump, 2,000 linear feet of 2" diameter piping, and a shell & tube heat exchanger between the existing cooling tower at the West Mechanical Room and the pump test station in the Research Area. This open hydronic cooling system removed 320,000 btu/hour of waste heat from the test fluid and rejected it to the atmosphere. This single measure eliminated 1.1 million gallons/month of "once-thru" domestic water cooling and reduced total annual site water usage by 52%.

Another retrofit project was replacement of three old, inefficient, unreliable, CFC-11 water chillers averaging 0.75 kW/ton with two new, 275-ton, HFC-134a, high-efficiency, variable-speed water chillers at 0.58 kW/ton (Figure 5). This retrofit project reduced peak cooling electrical demand by 195 kW (23%) and annual cooling electricity usage by 538,000 kWh/year (20%).

The annual electricity usage reduction estimate was determined by a "before" and "after" bin-hour simulation model of the entire chilled-water plant. The local electric company provided a large incentive payment that reduced the net cost of the project.

YEAR 2 (2003) BUILDING ADDITIONS AND PLANT EXPANSIONS

Energy-efficient design was practiced on a 46,000 sq. ft., two-story office addition. The design incorporated fan-powered variable-air volume boxes and two 75-ton air-cooled unitary air-conditioning units. The air-conditioning units featured four scroll compressors, variable-speed evaporator fans, and outdoor air economizers. Power was supplied from the existing site 13.8 kV primary / 480 volt secondary electrical distribution system. Direct digital control and monitoring were extended from the existing site controls network. The controls automatically turned-off the air-conditioning units and fan-powered variable-air volume boxes during unoccupied periods and reduced air flow volumes at part-load conditions during occupied periods.

This project also featured insulated glass and automatic occupancy sensors in accordance with the latest energy code for new building design.

YEAR 2 (2003 VICE 2001) RESULTS

Electricity:

Volume Savings: 1,633,630 kWh (9.3%) – variable-speed drives on air-handling units and polarized refrigerant oil additive in heat exchangers entirely offset "new" electricity usage by the 46,000 sq. ft. office addition

Cost Savings: $196,722 (17.0%) – slightly lower prices and moderately lower usage

Off-Site Emissions Savings - approximately 1,408 tons (9.3%) of CO_2 (a greenhouse gas)

Natural Gas:

Volume Savings: 3,741,000 cu. ft. (22.0%) – thermostatic-controlled forced-air heaters

Cost Savings: $29,095 (19.3%) - slightly higher prices offset by significantly lower volume

On-Site Emissions Savings - approximately 222 tons (22.0%) of CO_2 (a greenhouse gas)

Water/Sewer:

Volume Savings: 14,233,000 gal (44.4%) – hydronic cooling for test pump station, recycling of condensate from air-conditioning units, and water-free urinals

Cost Savings: $9,150 (21.1%) – significantly higher prices offset by significantly lower volume

Total Utility Cost Savings: $234,967 (17.4%) vice baseline

SUMMARY

The objective of reducing and sustaining overall utility costs below the 2001 (baseline) level of $1.35 million/year was achieved in 2002 and 2003 by systematic implementation of a comprehensive utility cost reduction plan.

Over a 2-year period, cumulative "hard" utility cost savings totaling $677,000 have been realized (Figure 1) by a combination of utility usage reductions and utility price reductions.

In addition, "hard" operations and maintenance cost savings of $725,000 are being realized over a 5-year term by out-sourcing operation and maintenance of air-conditioning systems and associated controls.

This case study demonstrates that significant utility cost reductions are achievable and sustainable in industrial / manufacturing facilities.

It also demonstrates than "new" utility usage related to office additions and manufacturing expansions can be entirely offset by steep reductions in "old" utility usage elsewhere in the facility.

Figure 1. Cumulative Utility Cost Reduction

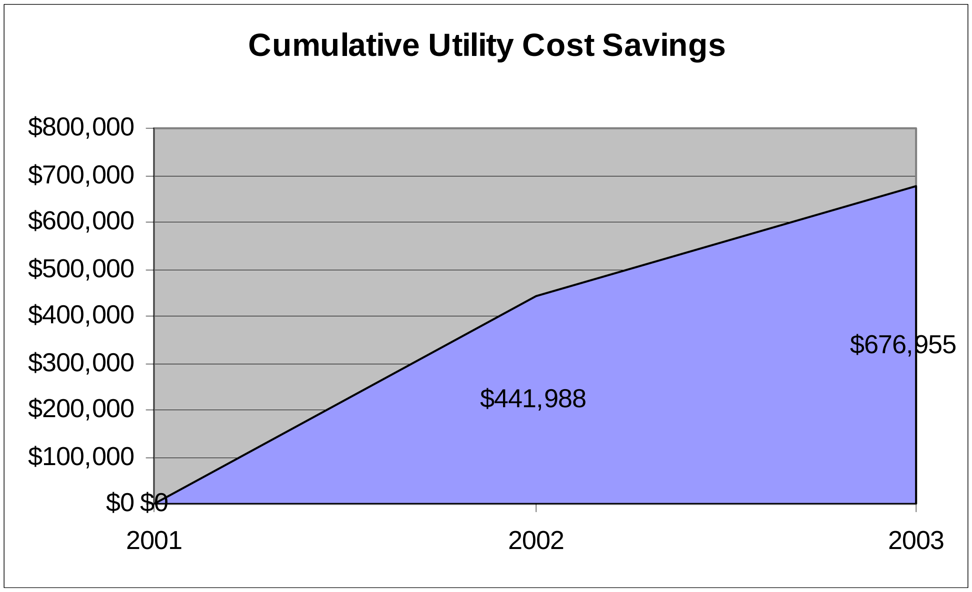


Figure 2. Electricity Usage Profile

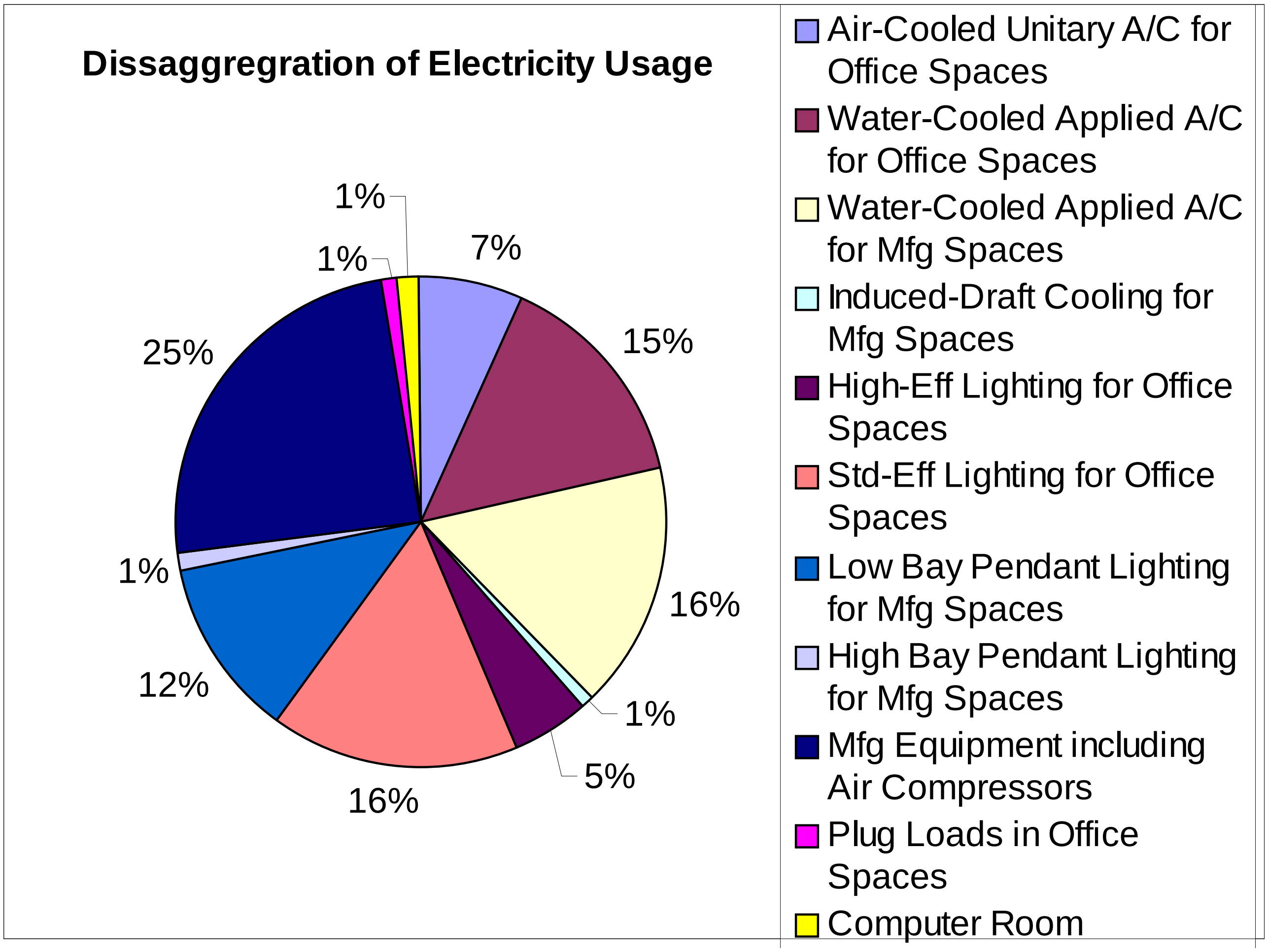
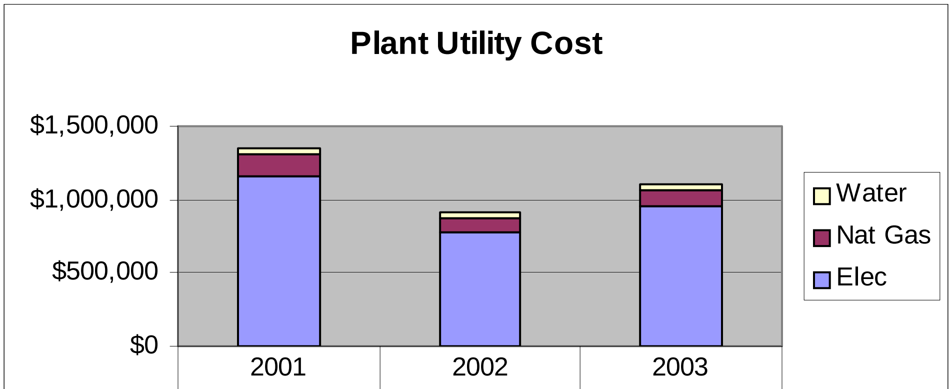


Figure 3. Utility Cost Metric



	2001	2002	2003
Water	$43,444	$34,838	$38,187
Nat Gas	$150,446	$96,376	$115,952
Elec	$1,160,492	$781,179	$952,830

Figure 4. Air-Handler VFD Retrofit

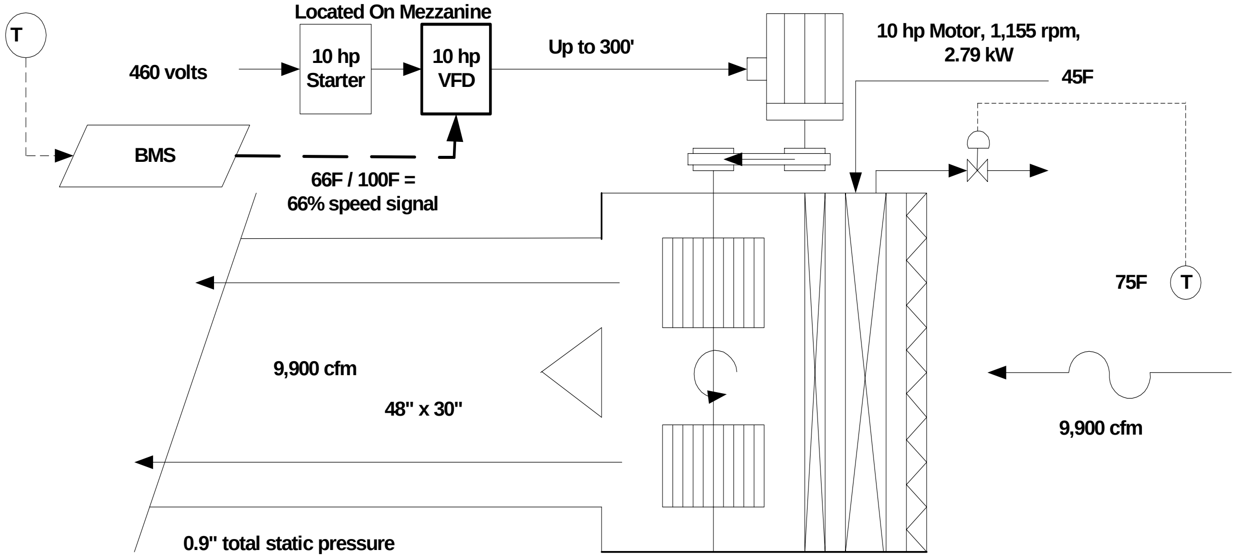


Figure 5. Chiller Plant Retrofit