Part-Load Cogeneration Technology Meets Chilled Water and Steam Requirements

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Louisiana State University's Energy Savings Performance Contract with CES/Way was a groundbreaking project that applied part-load cogeneration technology to a large university campus to meet chilled water and steam requirements for expansion needs. Simultaneously, the project provided these utilities at no additional out of pocket cost to the institution by using the innovative financing mechanism of performance contracting, in which project savings pay for the investment.

In addition, the work is performed via a cogeneration system operating most of the year at part-load. This mechanical cogeneration project could also be termed a "thermal cogeneration" project, as it provides a dual thermal benefit from a single input energy source.

Not only did the project achieve the projected energy savings, but the savings proved to be so dependable that the University opted for an early buyout of the project from CES/Way in 1994, after only about two years of documented savings.

Louisiana State University in Baton Rouge had been in a growth mode since the 1970's, and with continuing emphasis on research and extension course work for the State's growing industrial base, the University had fought hard to keep up financially. Unfortunately, the financial base in the state has been impaired for the last decade, leading to smaller and smaller appropriations for infrastructure at the institution; such items include buildings, utilities, repairs, capital renewable items, space conditioning equipment and personnel to operate them.

LSU continued to build new research and teaching facilities to accommodate the growing demand in the State for education, but funds for physical plant improvements have been very limited or non-existent since moneys available have been channeled into new buildings. In the mid-1980's it became apparent that unless some funding changes occurred, new buildings without proper heating, cooling and power facilities might result.

To help remedy this situation, a state law was passed in Louisiana in 1987 allowing for energy performance contracting with state agencies (similar laws have been passed in other states, including Texas in 1991), with new equipment to be paid for out of energy cost savings resulting from installation of new energy efficient equipment. In 1988, LSU issued a Request for Proposal (RFP) to seek a developer for a utility based performance contracting project.

CES/Way International, Inc. of Houston, Texas was the successful proposer to accomplish this work.

LSU's original concept was to generate chilled water from a gas turbine driven chiller and utilize waste heat recovery for campus-wide steam distribution. The CES/Way team developed a design for implementing variable chilled water pumping and addition of a state-of-the-art Energy Management System (EMS) throughout the campus, among other energy savings enhancements.

LSU had already aggressively attacked utility consumption and costs through various programs, including negotiating with the local electric utility for a demand charge reduction for not implementing an electrical cogeneration project for an extended period of time. The local utility had relatively low rates, but large consumption still resulted in large costs.

Notwithstanding LSU's work, the need for new utilities and the state's limited funds meant that new money was required from a third party source, and CES/Way provided this mechanism of financing. The overall plan was for a turbine to drive a large chiller to respond to variable campus cooling loads, and in the process reduce electrical consumption. This variable mechanical load requirement was at odds with most traditional gas turbine applications in that most electrical cogeneration jobs run "flat out" all the time.

A distinctive feature of this project was that it was planned to NOT run at heavy load most of the year, and hence the need arose for innovative planning if the project was to pay from savings. The overall objective of this project was to generate chilled water and steam as efficiently as possible within the demand parameters of the campus, and provide as much chilled water and steam as possible consistent with good economics.

Therefore, this project became mostly a supply side project, with the only demand side efforts focused on an Energy Management System and its relationship to equipment consumption[1]. From a systems economics standpoint, it would have been desirable that a comprehensive attack of all building energy using systems occur simultaneously; however, the RFP did not allow for such efforts, and LSU was independently pursuing such efforts concurrently utilizing the Institutional Conservation Program (ICP) oil overcharge funds; therefore, the challenge to the developer was intensified.

EXISTING SITUATION

The original campus utility situation was one of a central power plant located in the center of campus, which only fed a modest number of buildings, coupled with eight (8) additional "mini" plants which fed multiple buildings and generally consisted of a plant for a building tied together to create multiple building "plants." In view of the facts that each building or building expansion was allocated its own construction budget by the state, and central plant upgrades or enhancements were not (because of fiscal constraints) considered attractive by the state, the primary reason for these mini plants was economics. In addition, state procurement regulations severely hampered the desirability of the facility to buy higher first cost/lower life cycle cost equipment and systems.

The equipment in place ranged from 1950 to 1985 vintage. Due to the large number of additions, modifications, and new buildings in the last decade, the overall efficiency and reliability of these plants had significantly degraded.

Energy efficiency was down for a number of reasons: 1) age, 2) flow rate changes common to research institutions as (a) new projects, additions and modifications occurred on an on-going basis, (b) as local conditions caused shortages which were handled through "best-fit" methods, including manual water flow adjustments, 3) limited repair funds for normal maintenance which mandated deferral, and 4) tie-ins in which the chilled water differential temperatures were different, thus resulting in compromises in efficiency in return for operational reliability improvements. The same maladies are common to many other research institutions, based on personal past experience of the author.

Each plant design called for constant flow, and all building air handling units (AHUs) were designed originally with 3-way valves, thus resulting in an artificially high, continuous demand for chilled water with attendant excessive pumping. The buildings generally had local building pumps for positive water flow control; the typical configuration in the before retrofit case is shown in Figure 1; CES/Way's revised piping arrangement is shown in Figure 2.

This new approach bypasses the local building pump, but allows its automatic turn on should unusual, abnormal conditions at the power plant occur which would require a "temporary" boost of flow and/or head pressure in order to pump sufficient water through the building (much more in the way of pressure safeties were involved in the "After" case, but the approach shown provides the generic concept).

Although taken one at a time, the ideas and efforts were probably appropriate and the best use of severely limited funds, the overall cumulative effect, in retrospect, was one of lots of dissimilar pieces of equipment, operating inefficiently and scattered throughout a campus, so that either full time personnel were assigned at disparate points over

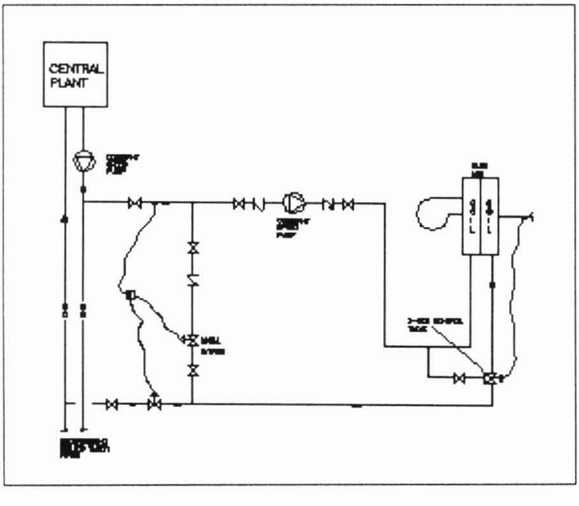

Figure 1. Typical Building CHW Interface Schematics (before)

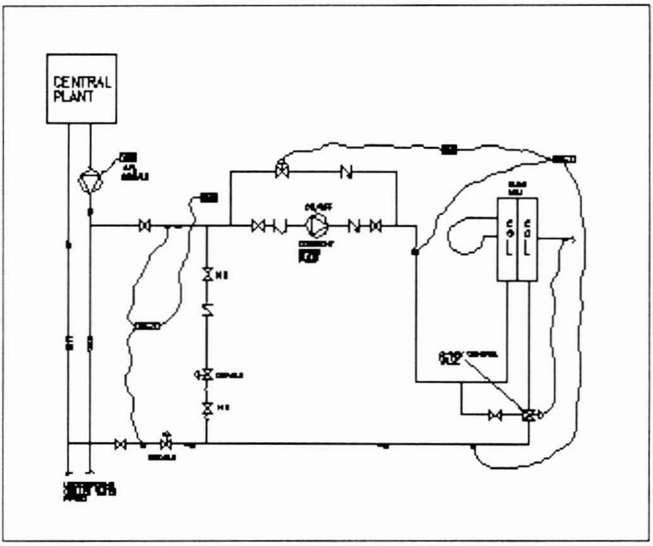

Figure 2. Typical Building CHW Interface Schematics (after)

the campus instead of a smaller crew confined to a central plant, or personnel were floating around periodically checking and adjusting the equipment.

Also, as more cooling demands occurred and with limited funds for such work available, more and more "fix-ups" occurred, such as installation of bigger pumps to provide more head pressure. These modifications also had the effect of upsetting the system flow since only limited funds were available to repair perceived problems, and at the time of the modifications the peak demands were not clear, hence the perception that the "fix" was sufficient.

This meant that, in addition to equipment which did not operate in an energy efficient manner anymore, there was also the added problem of using up safety margins of heating and cooling capacity as new buildings and additions were added, but without major increases in heating/ cooling load generation capacity. This is tantamount to an electric utility which has not added generating capacity for many years while load growth has occurred; at some point, shortages due to maintenance outages or simply lack of overall output results. LSU did not wish to be in this position, despite the lack of capital renewal funds.

Overall, the campus had over 24,000 tons of installed chiller capacity for an instantaneous peak load of about 14,000 tons. This is another inefficiency attributable to the design in which each building has its own chillers: load diversity, in which different buildings peak at different times cannot be utilized. The inability of the campus to take advantage of load diversity results in the refrigeration systems in low load factor buildings idling for a significant portion of the year. If system-wide load diversity could be taken advantage of, the refrigeration chillers could operate more fully loaded and thus more efficiently[2]. Such diversity had always been the compelling argument for a central plant in the case of a "new" design. But in LSU's case, a larger share of critical capital funds went to the heating/cooling generation for each new building or addition, rather than a one time upgrade in the central plant, all due to economic constraints.

PROPOSED NEW SYSTEM

The proposed new system was to install a gas turbine direct driving an open drive chiller, with a waste heat boiler. The turbine would produce enough power to drive a 4200 ton chiller, and generate about 85,000 pounds of steam through a waste heat boiler with supplemental firing.

After evaluation of the project, the CES/Way team learned that the RFP load estimates were high, the projected energy costs (rates) were also high, and the estimated installation costs were low! To make the project pay from savings successfully would therefore require much more cooling load to generate necessary greater savings.

At this point, the consulting firm of Texas Energy Engineers/ccrd Partners was hired to augment the in-house CES/Way staff and assist in a detailed energy study and preliminary design. It was confirmed that a significant growth of the size of the project was necessary to effect a paid-from-savings undertaking. From this design effort, it was determined that tying on to more of the satellite plants was needed to capture more load, especially to fill the valleys of load encountered during winter and shoulder periods.

The factory-produced "iron" for the chiller and turbine components necessary for an expanded project cost only slightly more for a 50% increase in output. Again, an apparently obvious solution of electrical cogeneration was not utilized because the in-place contract with the local electric utility precluded its implementation. Since no electricity was to be generated, QF status was not relevant, so no PURPA issues entered the picture.

In addition, a remote central plant for the Veterinary Medicine facility needed cooling system upgrades, but since it was too far away (and across a state highway), the team chose to upgrade this plant separately with a new high efficiency chiller and modify the chilled water pumping system to improve system differential temperature and reduce overall energy consumption required for pumping.

The analysis methodology employed to ascertain the savings opportunities, load profiles, ton-hrs and overall operation was the same as for the main central power plant upgrade. The Vet Med plant required about 2000 tons of actual peak cooling, and together with the remaining central power plant, there was a physical anticipated normal peak of about 14,000 tons for the buildings affected (which represents the majority of square footage, but there were still a few thousand tons of cooling unaffected).

CES/Way has become an industry leader in the performance contracting business in the development of innovative methods of measuring savings that often can only be imputed, due to the difficulties of calculating baseline adjustments associated with changes in variables such as degree days, occupancy of the facilities (i.e., number of students or faculty), hours of use, and the malady of load creep as clients add more computers, copy machines and other energy consuming electronic equipment. CES/Way worked with LSU personnel and their technical consultant, ABB Impell, to develop a model that accurately emulated the energy production efficiency of the displaced LSU equipment to compare it to the cost to produce the new utilities provided by the new central plant equipment.

In this manner, essentially only the MMBtus of thermal energy produced by the new central plant needed to be measured and compared via computer simulation to the old utility production scenario in order to closely approximate savings. This approach was the only feasible methodology to calculate savings, as the CES/Way project only addressed a portion of the LSU campus, and the project could not be coupled to the overall campus utility bill, which was and will be influenced by additions of facilities and other variables beyond the control of CES/Way.

The use of the CES/Way " Thermal Emulator" was a key factor in making both partners in this shared savings project comfortable with the payment procedures. The process was scrutinized by a battery of competent engineering and financial professionals, from both LSU and their consultants and the CES/Way/ccrd team. It also withstood an aggressive attack from the local utility which ultimately agreed that the project economics and the model were accurate, and that an electric chiller project could not compete with the thermal cogeneration system of mechanically derived chilled water and steam, produced simultaneously in the manner that the CES/Way project delivered.

To obtain more cooling load required more underground chilled water piping, but judicious choice of loops and location of piping kept the cost down, and increased the winter, (i.e. low load) conditions on the turbine chiller. The system eventually evolved into a 6300 ton chiller, a 5000 HP gas turbine, a 115,000 lb/hr waste heat boiler (of which 25,000 lb/hr was from waste heat recovery), an initial EMS installation to control 99 campus buildings (there were over 160 buildings on the main Baton Rouge campus), heat recovery tie-in and related pumping modifications.

With this configuration, the project would pay from savings. It should be stated that this is at a distinct variance to most projects in which a budget crunch is encountered and the project necessarily shrinks in size. Economies of scale were a critical element in making this a viable project; the original turbine plans were for a 4200 ton unit driven chiller, but evaluation of costs and standard equipment sizes showed that for almost the same money a 6300 ton chiller/turbine combination could be effected.

Fortunately, the loads were also available since LSU could provide it through existing or planned facilities. Further, throughout the project, additional opportunities arose and were successfully exploited. For example, the team constantly sought more winter load to keep the overall chiller load factor up, even when the system could not handle the summer peak, so when a new building was added to the campus, the CES/Way project tied it onto the chilled water loop for winter use, even though the new building had its own stand-alone chillers to be used for summer loads. Multiple examples such as this helped to increase load on the new plant.

The new turbine chiller was tied into the existing central power plant, and along with the added piping, a newer backup 1100 ton chiller that was only used for emergencies in one of the remote mini plants was moved to the new central plant, which collectively increased the effective size of the coupled central power plant from about 4,000 tons to 12,000 tons; this tonnage and the associated Veterinary Medicine plant of about 2,000 more tons of load means that the CES/Way project involves a total of about 14,000 tons of chiller control.

Simultaneously, new variable speed drive pumping was utilized for the secondary pumps in the plant, with the added unusual feature that this secondary pumping, instead of only pumping the chilled water around the campus, also pumped through the buildings without the use of local building pumps. This overall combination saved thousands of horsepower that otherwise had to run continuously due to the nature of the imbedded past designs, common to research institutions.

This system was a difficult design consideration since the existing piping was Class 125 (meaning a maximum of 150 psi was allowed on the chilled water system) and the distances involved, coupled with pumping through the buildings, made it very difficult to stay within the pressure limits. New cooling towers for the added capacity, new towers to replace worn out, inefficient old cooling towers, and various enhancements for improving existing chiller energy efficiency were included to round out a series of energy cost savings measures.

The configuration of the CES/Way newly designed plant and its relationship to the old mini plants and LSU's original concept is shown in Figure 3. As can be seen, additional loads, far removed from the existing central plant, were added to the system.

This mandated a design that would account for the significantly higher distribution losses encountered in pumping chilled water to these distant buildings. Through the diligent efforts of both CES/Way and TEEI, these complex design issues were overcome and contributed significantly to the overall success of the project.

A unique characteristic of the new system was the inherent variable speed drive control of the turbine to aid the chiller in unloading without having to adjust the inlet vanes on the chiller over a wide range of load. In addition, this VSD feature allowed the chiller to turn down to lower output levels without engaging the hot gas bypass to lower the output cooling capability which would otherwise have required a high mechanical load on the shaft.

This would have significantly impaired the energy efficiency capabilities of the resulting system, since hot gas bypass would have been an artificial heat load on the chiller. Although the concern for variable load-

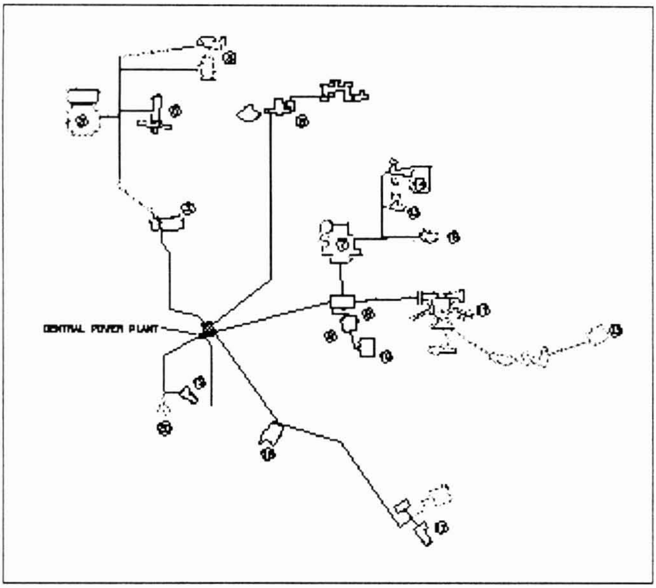

Figure 3. Site Plan

ing was real, the past development work available to optimize performance was sparse; however, a recent paper has touched on the problem[3].

The load characteristics of the turbine are shown in Figure 4, based on planning data from extensive site investigative work performed during the design/build phase of the project. From these data, it was clear that substantial part load activity would occur, and hence relatively high energy efficiency at such low loads was essential for the success of the project.

Simultaneously, the low turbine output would result in drastically reduced boiler supplemental firing capability (due to low mass flow), so the availability of sufficient winter boiler capacity beyond the new HRSG was vital to the effectiveness of the project. Luckily, such excess capacity was already available, since a new 100,000 Lb/hr boiler had been added recently by LSU with their own funds.

The typical daily load profile of the cooling for the turbine chiller is shown in Figure 5 for selected weekdays throughout the year. It is clear that a fixed, high load level did not occur much of the year, as is generally the case in traditional cogeneration cases. The campus steam de-

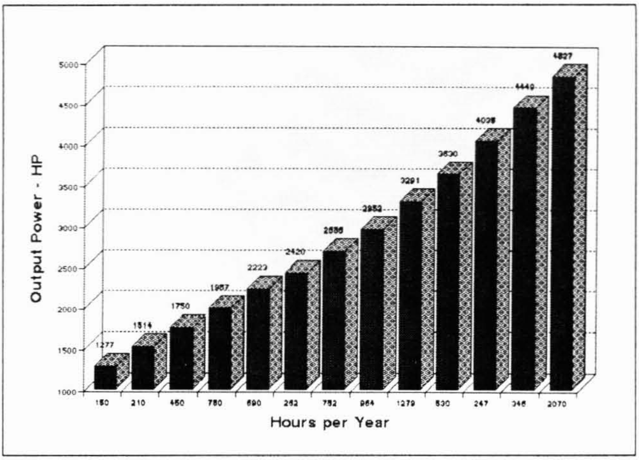

Figure 4. Turbine Load Profile

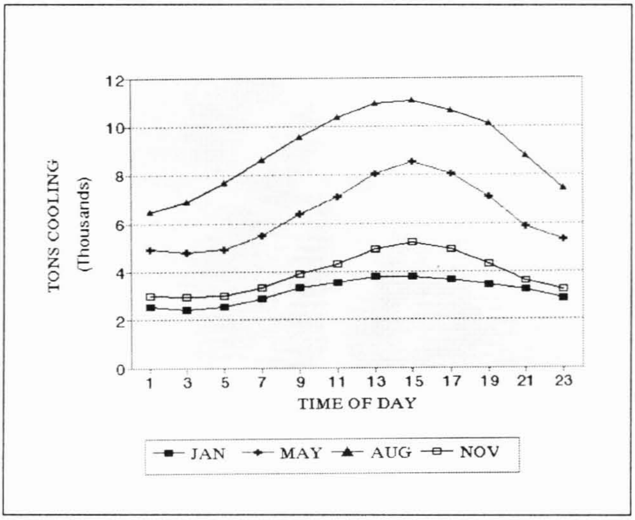

Figure 5. Central Plant CHW Load Profiles

mand varies from a low of about 25,000 Lb/hr in the summer to as much as 170,000 Lb/hr in the winter; the low end could be provided by the cogen system, but the upper end required use of additional LSU supplemental boilers.

Because the project was a pay-from-savings effort, safety margins (or the lack thereof) had to be carefully evaluated. Substantial "what-if" scenarios were performed, and much internal design debate occurred in regard to appropriate safety margins. Additionally, statistical analyses of financial impacts were periodically updated to track probabilities to ensure that overall the project would in fact perform as intended. Many past projects performed by others have apparently failed to achieve expectations, as witnessed both by the author, as well as other researchers and developers[4,5].

To ensure savings were realized in practice, a sophisticated remote monitoring system was put in place to track performance and identify deficiencies quickly so remedial action could be taken to return the project to performance objectives. In addition, a full time turbine/chiller operations manager was placed on site to monitor and control the coupled systems for the life of the project, with special emphasis upon the turbine; turbine reliability was paramount since there is no backup equipment in this prime mover category.

An added sideline benefit to this project was the reduction in air emissions, when the reduction in kWh and hence adjustments from the utility company's power plants were taken into account. Two of the utility's plants were located near the LSU campus and both had their output favorably affected by this project. The reduction in NO_x and SO_x was significant, thus assisting the overall air quality in the local community.

As a result of this project, approximate reductions of 8 MW of peak electrical demand kW, and 70 million kWh/Yr, and modest natural gas displacement resulted from what would otherwise have been required to achieve the same levels of heating and cooling load delivery, in addition to reduced NO_x emissions into the local/regional atmosphere.

In terms of air pollution control, the CES/Way energy conservation project assisted air quality via reduced pollution from existing plant standard boilers and from reduced electric utility power plant emissions from reduced kWh and kW loads. This resulted in total NO_x emissions reduction for the greater Baton Rouge area of approximately 85 tons/yr, with simultaneous lowering of the corollary SO_x emissions.

Example

The project began full time operation in May, 1992, although the Vet Medicine plant system has been in full operation since February 1991. Through June 1994, just prior to LSU purchasing the installation from CES/Way, the project had achieved total savings of $7,537,927. The breakdown of savings is as follows:

Total:	$7,537,927
Lease Payments	$5,441,704
Insurance	$ 63,339
Maintenance Cost	$742,939
Project Savings	$1,289,945

An important element in turbine use was the heat rate, normally defined as Btu/kWh in cogeneration applications; the only problem with this definition was that this project had no electrical generation. Additionally, it was common for equipment vendors to not clarify that the Btu referred to in their data sheets was expressed in lower heating value (LHV), whereas almost all gas purchases are made in terms of higher heating value (HHV).

For purposes of this project, the turbine fuel input was Btu of HHV natural gas, and the output was ton-hrs; both measured on-line, real-time and then integrated, so both instantaneous rates and total consumptions could be measured. Thus, Btu/ton-hour was the efficiency basis of concern in tracking the turbine performance in this project.

Initial data during the start up period were not fully metered, so only the longer term data were available to track turbine performance and the central plant chiller performance compared to LSU's projected loads. The actual performance period of the paid-from-savings project commenced in late August of 1992, and Figure 6 displays the output from the central plant compared to the projected loads analyzed as occurring after the new plant was completed.

As is evident, the facility responded to the increase in loads at LSU University by delivering significantly more chilled water tonnage on a cumulative basis than projected by the university as a result of the study, even though individual months vary.

The turbine has performed above expectations, even when accounting for the degradation from operation after water wash (which followed the standard performance curves for after water wash). Both on-line power wash and off-line wash are available and experimentation is underway by CES/Way's on-site operations manager to ascertain the best approach for long term performance.

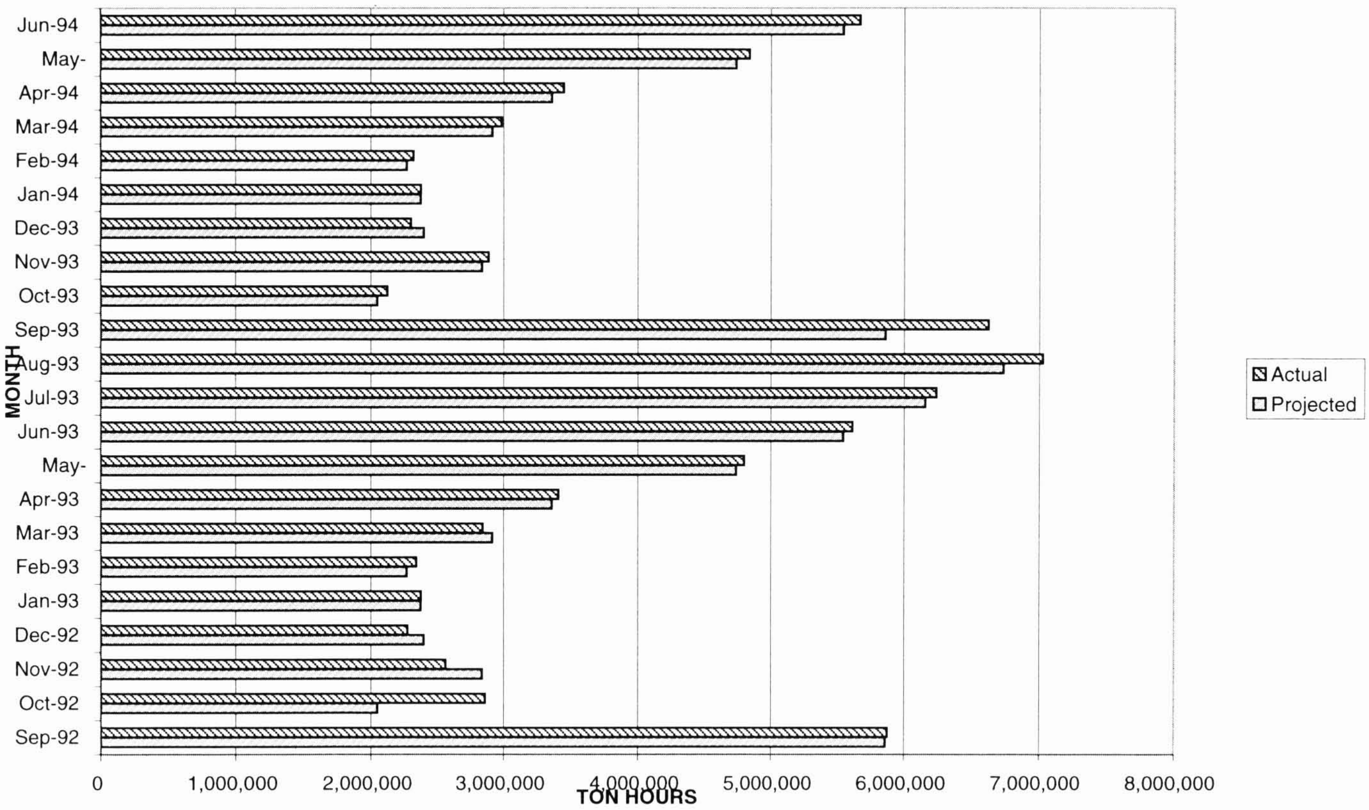

Figure 6. LSU Central Plant Cumulative Ton Hours

SUMMARY

This pacesetting energy conservation project has solved an overwhelming financial and capacity problem at LSU when funds were not available for expansion or deferred capital renewal projects. The CES/Way paid from savings project saved the University nearly $6 million per year in energy costs ($4.6 million) and avoided maintenance expenditures ($1 million). By design, there was always positive cash flow to the University after all costs are covered.

The technical, financial and legal considerations involved in the design, construction and implementation of this project were considerable, but with a knowledgeable team of professionals working together to make the project a win-win success, the project was implemented on time, within budget and is achieving planned savings.

In fact, in June of 1994, the University exercised its option to buy out CES/Way's participation in the savings and realized an increase in its value of a reported $10 million in net present value.

Acknowledgments

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References

(1) Newman, D.E., "Cogeneration as Demand Side Management," *The Cogeneration Journal*, Vol. 6, No. 4, Fall 1991, pp. 6-10.

(2) Hayner, A.M., "University of Miami scores with teamwork," *Engineering Systems*, January/February, 1993, pp. 22-25.

(3) Turner, W.C.; Wong, J.B.; Viswanathan, G., "Sizing Cogeneration Systems Under Variable Loads," *The Cogeneration Journal*, Vol. 7, No. 2, Spring 1992, pp. 23-37.

(4) Armstrong, C.H., "How To Avoid Cogeneration Pitfalls," *The Cogeneration Journal*, Vol. 1, No. 3, May 1986, pp. 44-51.

(5) Peyrot, M.E., and Warren, R.H., "Pitfalls to Avoid in Packaged Cogeneration System Startup and Operation," *The Cogeneration Journal*, Vol. 6, No. 3, Summer 1991.

ABOUT THE AUTHOR

A graduate of Texas A&M University and Wharton School of Business, **Michael D. Leach, P.E., CEM**, was involved in the energy industry for over 20 years. In 1986, CES/Way was founded through a joint venture to develop a relatively new concept, the performance contracting business. Through his vision and leadership, Mike brought CES/Way to national prominence as the premium provider of energy savings performance contracts in just 10 years. The company was recently acquired by Sempra Energy Solutions, one of the country's leading integrated energy companies.

By his participation as an officer and contributor in numerous energy industry associations, Mike readily shared his knowledge and experience with his peers. In 1996, he was chosen Energy Management Executive of the Year by the Association of Energy Engineers (AEE).

CES/Way's track record of over 40 successful projects throughout the country attests to Mike's outstanding accomplishment in implementing the concepts and ideals of energy management and energy development.

ABOUT CES/Way Sempra

CES/Way International, Inc., A Sempra Energy Solutions Company, is the premium provider of energy savings performance contracts—a comprehensive package of paid-from-savings energy efficiency services including energy audits, engineering design, project management, construction, financing and monitoring. With seven branches throughout the country, Houston-based CES/Way operates as an independent, wholly owned subsidiary of Sempra Energy Solutions, a national integrated energy services company. Sempra Energy Solutions is a joint venture of the unregulated entities of the merger between Enova Corporation and Pacific Enterprises, which is expected to be completed in the summer of 1998.

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