Capturing Lost Opportunity in the High-Tech Building Market Through Commissioning

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This paper describes the process of adapting a utility's energy conservation program for new *commercial* construction to work with an *industrial* facility. This allowed the utility to capture energy savings during an expansion of the facility, thereby avoiding a lost opportunity for the acquisition of those savings.

The success of this project depended on:

- Offering the right financial incentives to the building owner
- Sustaining a coordinated effort in the areas of design assistance, design and construction oversight, and building commissioning over the two and a half year life of the project

The dynamics of the building design and construction process for this facility presented unique challenges each step of the way for a utility used to involvement with relatively small new construction projects. This project is a large and potentially risky investment for both the building owner and the utility. Commissioning was the key element in minimizing this risk.

The installed energy conservation measures (ECMs) resulted in significant modifications to the chilled water plant and air handling systems from the baseline designs. Over five million kWh are expected to be saved annually, which will reduce baseline facility kWh consumption by over 30%. Incremental design and construction incentives will exceed $700,000.

This paper focuses on the following key questions:

- What characteristics are unique to this type of project compared to commercial new construction opportunities?
- What challenges surfaced during design, construction oversight, and commissioning, and how were they overcome?

Introduction

The ShinEtsu America (SEH) EPI facility is a recently completed 60,000 square foot silicon wafer manufacturing plant located in Clark County Washington. Clark Public Utilities' (CPU) commercial conservation program staff worked with the design team during design and construction of the facility to integrate energy conservation improvements into the new facility. Construction began in 1991 and the building was completed in the fall of 1993.

The energy conservation efforts focused on the water chilling plant and air distribution systems. The estimated energy savings exceed five million kilowatt hours (kWh). The incentive costs for the ECMs totaled to over $700,000. The project's levelized cost (present value divided by energy savings), including incentives and project overhead, is about 1.2 cents per kWh.

Energy Conservation Measures

The energy conservation measures were focused on reducing the energy needed to cool and transport water and air through the building, which was estimated at over 12.5 million kWh per year. Table 1 presents a summary of the installed ECMs.

Changes to the water and air systems were estimated to provide the greatest savings. These measures included larger pipes and ducts, low pressure drop filters and coils, and premium efficiency pump and fan motors.

Increasing the efficiencies of the chillers was estimated to provide the next largest increment of savings. This was accomplished using chillers with an energy input ratio of 0.57 kW/ton at 80°F entering condenser water temperature and 42°F leaving chilled water temperature. The sizes of the cooling towers were also increased, and floating head pressure capability was specified down to a condenser water inlet temperature of 60°F.

Variable frequency drives (VFDs) were specified to vary the speed of pump and fan motors according to the load. A water-side economizer (free-cooling) capability was added. A relatively small percentage of the estimated savings comes from energy efficient lighting in a portion of the facility expansion.

Project Uniqueness

To avoid the possibility of this industrial project becoming a "lost opportunity" for energy conservation, CPU's commercial conservation program, Energy Smart Design (ESD), was used as the vehicle for utility involvement in the project. ESD is an electric energy conservation program sponsored by Bonneville Power Administration (BPA) which will pay full incremental cost for cost-effective improvements to new construction projects. CPU's ESD program is operated by utility account managers and a program implementation contractor.

This project differed significantly in almost every regard from typical buildings in the program. This fact increased feelings of risk and uncertainty for both the utility and the building owner, as described in the next section.

First, the SEH project was unusual in that it is an industrial rather than a commercial facility. Furthermore, it is large and complex enough to require dedicated technical and program support people. This was also unique to the ESD program.

Because of the high savings potential, the SEH project had unusually high visibility at the BPA area office. This proved to benefit the project, as BPA provided timely and effective program and technical support. BPA also provided additional budget to pay for incentives, technical analyses, inspections, commissioning, and the implementation contractor's overhead, since these were outside the normal ESD project scope.

Other unique aspects of this project include:

- The definition of baseline is even more elusive for industrial facilities than for commercial buildings. The energy code does not apply to industrial facilities, and "standard" practice can vary from contractor to contractor. For SEH, baseline was based on the original design, prior to review by the utility's representatives, since that is "what would have been" present in the absence of the ESD program. Baseline is the systems without the ECMS shown in Table 1.

Table 1. Energy Savings by Measure Type

Energy Conservation Measure	Annual Savings, kWh	Annual Savings, % of Baseline	Incentive Cost Dollars
Low Pressure Drop Pipe & Duct System	2,473,992	19%	$316,530
High Efficiency Chiller	1,221,069	10%	$178,980
Variable Speed Drives	751,676	6%	$123,553
Free Cooling	594,700	5%	$121,463
High Efficiency Lighting	56,103	0.4%	$7,100
Total	**5,097,540**	**40.4%**	**$747,626**

- This type of facility is very energy intensive[1] compared to typical buildings in the program. The estimated annual savings for the SEH EPI Facility are 85 kWh per square foot, compared with 3 kWh per square foot for an average ESD program building. This meant that CPU and BPA had a very strong interest in the project.

- The savings opportunities are in systems that directly affect manufacturing processes. Application and verification issues for ECMs that affect manufacturing processes are different from the issues for ECMs in a typical commercial building, where savings opportunities primarily affect human comfort systems.

- As is typical of new construction, the owner's focus is on getting the building completed, and the owner objects to having energy conservation considerations impact construction timelines. With this project, however, the owner's investment is particularly great, and energy conservation considerations should not even *appear* to compromise the paramount concerns of design and construction timelines and startup of the affected systems. Also, since the design and construction timeline for this project was highly proprietary, utility representatives had to negotiate an acceptable level of project involvement and disclosure.

- For large industrial facilities BPA typically paid only for verified (monitored) savings from energy conservation measures. In this project, the incentive was committed during design. Therefore, this project represented a significant departure from the way the energy savings were usually acquired for a project of this type. Jack Callahan, the BPA technical lead on the project, summed up the dilemma this way:

  "Incentive amounts (of up to full incremental cost) were committed at the time design decisions were made. Design decisions were made according to a very demanding schedule. In order for the customer to make a decision about incorporating an energy-efficient measure into the design, they needed a firm commitment for the amount of the incentive *at the time of the decision.* This meant that it was not practical to make the incentive contingent on some future event, i.e., verification of energy savings. "

Issues and Concerns

The utility emphasized different goals from the building owner. The owner was most concerned that the measures not interfere with building function, and the utility representatives were most concerned that the measures save energy. We believe that this project was successful largely because team members "bought-into" each other's goals.

Owner Issues

SEH and its building design/construction contractor had concerns relating to operation of the recommended measures. These concerns focused on space problems associated with changes to the water piping and air distribution systems, and increased harmonics from the variable speed drives. Originally they evaluated the possibility of installing isolation transformers to mitigate the effects of harmonics, but their VFD expert determined that this would not be necessary with the latest generation of VFDs.

Maintenance of the heat exchanger was also an issue. It is used to exchange heat between the cooling tower water loop and the chilled water loop for free cooling. There were concerns about leaks resulting in a mixing of the water from the two loops. The heat exchanger was also perceived to be prone to fouling, which would increase maintenance costs.

Another concern that came up early in project discussions was that equipment added for energy efficiency is often less familiar to building designers, installers, and operators. Once the building owner and design team became more familiar with the measures, and understood how the utility's commissioning process would help protect their facility investment, they concluded that the potential benefits outweighed the risks, and they decided to install the measures. According to a construction supervisor at the facility, now that the measures are installed and operating satisfactorily, they are just another part the facility. In other words, they do not require special treatment or additional attention, just the ongoing maintenance accorded other equipment in the facility.

Utility Issues

Because ESD is a conservation resource acquisition program, ensuring that the measures are installed and operating as intended is of paramount importance to the utility. BPA and CPU settled on building commissioning as the key to ensuring that the measures performed properly, thereby providing the estimated savings, in lieu of more rigorous savings verification methods such as long-term monitoring.

The strategy for ensuring that the measures paid for were installed and functioning as intended was to:

1. Develop an incentive agreement that included sufficiently detailed descriptions for each ECM.

2. Contract for dedicated design and construction oversight through building startup.

3. Set up an effective commissioning procedure.

ECM Verification

ECM Descriptions

Incentive agreements were developed that included detailed equipment descriptions for each ECM. These agreements were much more detailed than the ECM descriptions commonly used in the program, and served as an enforceable specification during inspection and commissioning. For example, rather than just specifying variable frequency drives to control the speed of the chilled water pumps, the ECM descriptions specified the variable frequency drive, two-way valves rather than three-way valves at the chilled water coils, the location of the pressure sensors, and the estimated pressure differential necessary to provide the design flow through the coils.

Construction Oversight

PECI, the program implementation contractor for CPU, hired a subcontractor to oversee the construction process. The subcontractor had completed the original analysis and was, therefore, very knowledgeable about the ECMs. The subcontractor also had previously established a positive relationship with the relevant personnel at SEH, so they were willing to accept his conclusions regarding the acceptability of the installed equipment.

Construction oversight entailed inspection of the installed equipment and adjustment of the utility incentives if the measures did not meet the specifications. The incentive adjustments were based on engineering estimates of the “measures, as-installed, relative to the previously estimated energy savings.

Several visits to the site during construction permitted in-progress inspections of measures. Visits were scheduled as major equipment groups were being installed. Part of the installation agreement allowed the building owner to be paid 50% of the incentive upon receipt of the equipment at the site. This phase of the project included a review of all invoices to verify that the incentive cost estimates were not greater than the actual incremental cost of the ECM.

As a result of the effective oversight, it was determined that two pieces of delivered equipment did not meet the ECM specifications. The incentives for the associated ECMs were adjusted due to the changes in the equipment. The changes were 1) a larger cooling tower fan motor and 2) six-inch rather than eight-inch piping in one of the condenser water loops. The total incentive package was reduced about 5% as a result.

For several of the measures, including the measures for larger-size piping and efficient lighting, this was the extent of the verification process, and the full incentive was paid on these measures once the on-site verification was complete.

The Commissioning Plan

An effective building commissioning strategy was an essential component of making this a successful project for all parties involved. Without the plan for commissioning to demonstrate and ensure proper equipment operation, the owner would not have chosen to participate in the program. Likewise, the utility required commissioning to demonstrate proper equipment operation to help ensure that the estimated energy savings could be achieved.

Once the on-site inspection confirmed that the measures matched the detailed equipment descriptions, the next step was to commission measures for proper operation. A commissioning plan was developed that included full participation by representatives of both the utility and the owner. BPA and the construction oversight contractor provided review and support as needed.

The building owner/operator has his own on-site team that is charged with bringing the affected systems up to full operation and maintaining those systems over time. Utility representatives formed a team with those personnel from SEH, and together they developed a plan to verify proper ECM operation.

Table 2 shows the scope of testing needed to verify measure performance.

Barriers To Commissioning

One of the first hurdles encountered in developing a commissioning plan was the 24-hour operation of the facility. This precluded typical functional tests of the equipment, since such tests would compromise operation. In place of specific tests, a commissioning plan was developed that utilized the facility’s energy management system (EMS) to obtain data on the ECMs in a variety of operational modes. There was no budget in the commissioning to add points to the EMS for commissioning. Luckily for the process, and because of the owner’s concern with reliable operation of the systems, the vast majority of the points that could be desired for commissioning were already included.

Table 2. Scope of Commissioning Tests

Equipment or System Name	Component	Function/Mode
Chilled Water System	Pressure Sensors	Adjust pressure differential set point to lowest pressure necessary to provide design flow through coils.
	Control Valves	Check operation and control of the valves at the chilled water coils.
	VFD	Check the operation of the control.
Hot Water System	Pumps	Verify the rated power of the motors.
	Pressure Sensors	Adjust pressure differential set point to lowest pressure necessary to provide design flow through coils.
	Control Valves	Check operation and control of the valves at the hot water coils.
	VFD	Check control of the variable frequency drives.
"Free" Cooling	Heat Exchanger	Check heat exchanger approach temperature or effectiveness.
	Controls	Check "switch-over" control set point and operation.
Chiller	Chillers	Verify rated efficiency.
Systems	Cooling Tower	Check flow rates and performance/approach temperatures (5°F).
	Tower/condenser Water Temp Control	Check operation and set points of condenser water temperature control.
Local	Fans	Check maximum fan flows.
Recirculation	Cooling Coils	Verify the low pressure drop.
Units	Filters	Verify the low pressure drop.
	VFDs	Check the control.
Air Systems	Fans	Check maximum fan flows.
	Coils	Verify the low pressure drop.
	Filters	Verify the low pressure drop.
Office Air Handlers	VFDs	Adjust static pressure set point to the lowest setting possible and still maintain the design airflow through the VAV terminal boxes; check operation of the control.
Glycol Chiller System	Chiller	Verify rated efficiency.
	Cooling Tower	Check flow rates and performance/approach temperatures (5°F).
	Tower/condenser Water Temp Control	Check operation and set points of condenser water temperature control.

On the basis of the commissioning results discussed in the next section, the utilization of EMS data proved very successful. The values of the important parameters were trended over time to observe the measure performance under a variety of operating conditions. Many parameters were cross-plotted versus other, related parameters by comparing values at the same points in time. For example, plotting the hot water valve position versus the chilled water valve position for a given coil facilitated checking for simultaneous heating and cooling.

One potential weakness of the commissioning process was that, due to budget constraints, utility representatives did not specifically commission the EMS prior to the initiation of trending. (It is our experience that utilities should require commissioning of energy management systems if they incorporate any utility-funded energy-saving strategies.) Lack of specific EMS commissioning was not expected to be a major problem in this case, for the following reasons:

- The facility had been operational for several months, and the owner was very focused on proper operation, so a great deal of attention was paid to the control system.
- SEH had a maintenance agreement with the controls contractor and the controls contractor was regularly on-site. The commissioning team assumed that the contractor's ongoing involvement would provide "de-facto" commissioning by assuring that most of the functions related to the ECMs were properly implemented.
- The commissioning team assumed that most omissions or errors in the EMS controls would be discovered through the trending.

The results of the commissioning seem to have verified these assumptions. Engineering calculations, such as heat and mass balance checks, were used to verify that the trended data was reasonable.

Commissioning Results

Variable Air Flows

Some air handling units were initially operating at much higher pressure than the design intent. In some cases, variable speed drives that were supposed to handle variable loads were found to be at full load all the time, and the design airflow was not achieved. The problem was not related to the ECM, but was a result of poor duct design and construction by one of the subcontractors. This brought up the issue of whether an incentive should be paid on measures that contain the specified hardware, and have properly implemented controls, but still may not be saving energy. The ESD program estimates, but does not guarantee savings. Consistent with this, the incentive agreements for this project require that design intent be fulfilled, but the agreements do not require savings verification. We note that it seems highly unlikely that customers would sign on to a program indicating that they would receive incentive payments from the utility only if the savings *estimated by the utility* were achieved.

Fortunately for the ESD program, SEH went to considerable expense to correct this problem and obtain the design airflow, and the original savings estimates may now be achieved.

Variable Water Flows

Another problem is that some of the variable speed drives on the chilled and hot water pumps operate at nearly constant speed. The design intent, specified in the incentive agreement, was that the pump speed would be varied as needed to provide a constant pressure differential across the water valves. However, only a supply pressure transducer was installed, and it was located near the pump discharge rather than at the valve. At this location, the pressure is nearly independent of flow if the flow is much less than the pump's capacity. Therefore, the pump speed is nearly constant. The commissioning engineer proposed a software-only solution utilizing valve position rather than pressure as the controlling parameter. This solution would cause at least one of the chilled water valves to always be nearly full open, thereby reducing the overall system resistance. Therefore, this approach would save more energy than had the design intent been fulfilled. (This approach would make the chilled water distribution system operate similarly to a terminal-regulated air volume, or TRAV, air system.) SEH is evaluating this proposed solution.

As a result of the detail in the ECM exhibits, the incentive will not be paid unless the ECM installation is changed to meet the specification, or modified as described above to meet the intent for the ECM.

Pressure Regulation

An interesting aspect of the system design involved the pressure regulation of the condenser water and primary chilled water loops. While the flow demand in these loops varies, the pressure is regulated by bypassing flow around the load. This, in essence, causes the pump flow to be fairly constant. Energy savings may occur when the flow is allowed to vary with the load. The engineers at SEH foresaw this possibility, and installed variable frequency drives on the condenser water and primary chilled water pumps. The commissioning engineer recommended varying the pump speed to regulate the pressure, rather than opening and closing the bypass valves. This possibility is being considered by SEH.

Free Cooling

The original design for the water-side economizer did not integrate the free-cooling heat exchanger with the chiller:

the cooling could come from either the heat exchanger or the chiller, but not both. Therefore, the original design ignored the savings potential during moderate ambient conditions of "pre-cooling" using the heat exchanger, and using the chiller to complete the chilling of the water down to the required supply temperature. The design was subsequently modified to allow a combination of "free" and mechanical cooling. The design team dubbed this combination "partial free cooling," and the situation when all the cooling demand could be met by the economizer was dubbed "total free cooling."

During the commissioning process some anomalies and opportunities were discovered. First, the valve used to control the supply temperature during total free cooling was cycling from full open to full closed—the control algorithm needed tuning. This was quickly corrected by the controls contractor. The improvement had the additional benefit of tightening the control of the chilled-water temperature.

Second, the two valves used to control the supply temperature during partial free cooling were not controlled; they remained 50% open during all conditions. This reduced the capacity during total free cooling by 50%, and forced the chiller to come on at very low load when it would otherwise have remained off. This problem was fixed the same day it was first discussed with SEH. If this problem had remained present in the summer months, the system would not have been able to meet the cooling demand. SEH personnel made a telephone call to the controls contractor, discussed the software program controlling the free cooling, and added code to correct the problem.

During the free cooling evaluation, it was also discovered that the control set points and chilled water piping were not optimized. They were not set up to integrate the economizer and chiller, and would not take full advantage of the potential for partial free cooling. The commissioning engineer estimated that changing the control set points could save 97,000 kWh annually. If a few short pipes could be changed to put the heat exchanger in series with the chiller, rather than in parallel, and reset the chiller leaving chilled water temperature while keeping the secondary chilled water loop temperature the same, then another 80,000 kWh savings are possible. The commissioning engineer also recommended larger chilled water coils for future facility expansion, which has the potential for annual savings of 194,000 kWh. It was also recommended that the secondary chilled water temperature be reset, consistent with dehumidification requirements, to a higher temperature during partial free cooling conditions. This could save up to 390,000 kWh annually. All of these savings are dependent on correcting the operation of the variable-speed chilled water pumps, and are being considered by SEH.

Other Commissioning Corrections and Discussion

The commissioning also uncovered some simultaneous heating and cooling at one of the air handlers. The hot water valve was not closing fully, making it impossible to achieve the supply air temperature setpoint. This was easily corrected within the control software.

Reviewing the data from the EMS, the commissioning engineer noted that one of the chillers had a temperature sensor out of calibration. There are two temperature sensors located in the condenser cooling water upstream of the condenser, and they differ in temperature reading by 3 to 5 degrees Fahrenheit. This problem does not increase energy use, but in this case it could compromise chiller performance by allowing flash gas into the expansion valve, so it will be corrected as part of the SEH preventive maintenance program.

Lessons Learned from Commissioning

The authors note that a large industrial facility differs from a commercial building in how commissioning can be of benefit. This facility has well-educated and well-trained engineers and technicians to maintain and operate the systems. The facility was operating satisfactorily prior to the commissioning. The problems uncovered during commissioning would, in many cases, have been corrected by SEH personnel in a reasonable period of time. There have been two major benefits of the commissioning process in this facility:

1. Attention was focused on the energy consumption and use patterns of the systems with the participation of the owner's facility operators, so that efficient as well as reliable operation is now considered by the operators.

2. The commissioning recommended improvements that correct for installation deficiencies and/or improve overall system efficiency beyond the design intent.

These benefits should significantly enhance the energy performance of the systems by improving both the reliability and longevity of the energy savings. The synergy between the utility's and the industrial customer's expertise made these benefits possible.

Conclusions

Building commissioning was successfully used to help meet utility and building owner concerns over participation in this project. The installation verification and commissioning were made possible, in large measure, by relatively detailed ECM specifications in the incentive agreements. We believe that clear, complete, enforceable specifications are critical to successful energy conservation programs.

The commissioning also revealed significant additional opportunities for savings from equipment that was not part of the utility program as well as from the installed ECMs.

More broadly, the success of this project demonstrates that utilities can combine demand-side management implementation expertise in commercial programs, and engineering expertise in energy-using systems, to provide mutually beneficial services to their industrial customers.

Endnote

1. Office buildings use an average of 21 kWh per square foot annually (according to a BPA-conducted electric energy end-use study called ELCAP) compared to an estimated 213 kWh per square foot for non-process equipment loads at this facility.