Energy Efficiency in Industrial Process Cooling Systems: A Systems Approach

Michael M. Tillou, etc Group, Inc.
Mark E. Case, etc Group, Inc.
Patti Lynn Case, etc Group, Inc.

ABSTRACT

This paper will present results from a recent study of energy efficiency opportunities in an industrial process cooling system. We will discuss the importance of using a systems approach to evaluate energy efficiency potential rather than relying on rule-of-thumb engineering.

The facility we studied had an existing, vendor driven plan for system upgrades that only identified two energy efficiency measures. The vendor significantly overestimated both the cost and energy savings in their proposal. We will discuss why rule-of-thumb engineering, in this case, overstated the potential savings.

Furthermore we will show how using a systems approach improved the overall impact of the project by accurately identifying both load reductions and opportunities to improve equipment efficiency. An additional six energy efficiency measures were identified increasing estimated energy savings from 814,700 kWh to 1,479,500 kWh, and estimated cost savings from $37,800 to $70,500.

Introduction

This case study examines process cooling systems at a Utah manufacturing facility making large blow molded plastic products. The study was performed as part of Utah Power's FinAnswer program which offers incentives for reducing energy use by improving electrical energy efficiency.[1] Vendor proposed efficiency improvements were being planned for one of the four process cooling systems at the facility when involvement in the FinAnswer program began. The scope of the FinAnswer study was expanded to include a second process cooling system so the vendor's proposal was adjusted to allow for an equal comparison.

The vendor proposal had identified two energy efficiency measures that were being considered by the manufacturer. Evaluating the same process cooling systems using a systems approach identified an additional six energy efficiency measures increasing energy savings by 86.5%. All eight opportunities are listed below; the first two were identified by the vendor while the remaining six were identified during the FinAnswer study.

- Evaporative cooling with a flat plate heat exchanger (Tower Free Cooling)
- VFD Control of the cooling tower fan
- Improve pump efficiency

[1] Information regarding Utah Power's FinAnswer Program is available on the internet at http://www.utahpower.net/Navigation/Navigation926.html

- Lower chiller condenser water temperature
- Install premium efficiency pump motors
- Variable speed process chilled water pumping
- Improve chiller performance by increasing load factor
- Digital control of process cooling system

We will discuss in more detail the importance of using a systems approach to evaluate potential energy savings and show how it can improve industrial processes, increase energy savings and maximize the return on investment of efficiency projects.

Furthermore we will argue that vendor based, rule of thumb engineering should not be relied on for a successful energy efficiency project. While this type of analysis is usually provided free of charge, it is rarely accurate and generally overstates the potential economic benefit.

Rule-of-Thumb Engineering

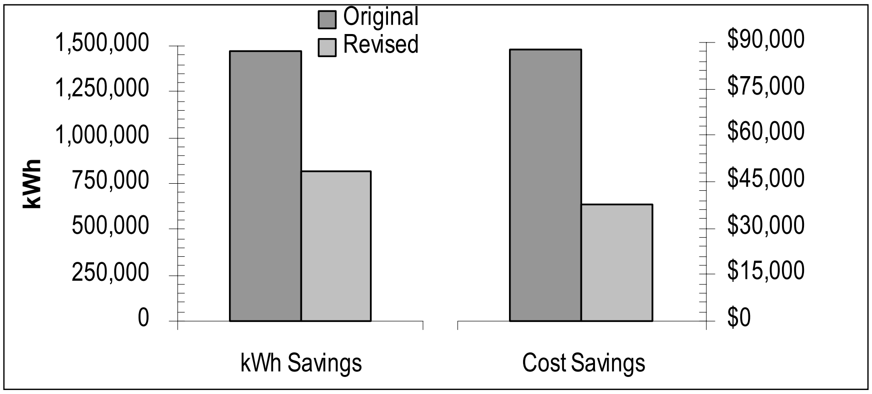
Even though avoiding energy efficiency project pitfalls is well documented, industrial decision makers still make mistakes.

In our experience industrial systems that support manufacturing processes (compressed air, process cooling, etc..) are rarely designed by an engineer that understands the countless interactions. Design help is provided by equipment vendors who are only supplying one piece or component of an entire system. Furthermore equipment suppliers don't worry about how their equipment interacts with other equipment, how much energy it uses or whether it's oversized; they just make sure it works.

When vendors use energy savings as justification for purchasing their product they do so with little understanding of how the equipment will operate within the system. Therefore they rely on rule-of-thumb engineering to make a guess how equipment will perform. Unfortunately rules-of-thumb are usually just bad assumptions which should never be used to estimate actual energy savings.

In this case, the vendor claimed $88,000 in annual electrical cost savings with a total of 1,467,600 kWh electrical energy savings. As part of the FinAnswer study we recalculated the estimated savings claimed by the vendor. Based on the operating conditions of the existing systems, the vendor's proposal would have only saved $37,800 in electrical costs and 814,700 kWh in electrical energy.

Figure 1. Vendor Savings: Original vs Revised Estimates



What Went Wrong

The equipment vendor made several engineering assumptions that were wrong and overstated energy savings. Furthermore the vendor proposed new equipment based on the nominal size of existing equipment rather than taking the time to determine exactly what size was needed. These assumptions, discussed below, are commonly used by equipment vendors. To make matters worse we rarely see industry decision makers question their validity.

Equipment operates at full load. The vendor used a load factor of 100% when calculating the existing energy use of the installed chillers. For example, one chiller has a rated full load power of 245 kW but the measured peak power was only 128 kW and the average power was only 94 kW. The actual chiller load factor was between 38-52% not 100%.

Use a blended electric rate. Vendors often use a blended electric rate to calculate cost savings. A blended electric rate is calculated by dividing annual electric cost by annual electric consumption (kWh). Blended rates do not accurately calculate the true cost of energy savings. In this case not only did the vendor use a blended rate of $0.06 they used one that was 23% higher than the owners actual blended rate of $0.046. Energy cost savings should always be calculated using the correct utility rate schedule.

Overstate run hours. Often energy savings are inflated because run hours are overstated. The vendor in this case assumed evaporative cooling could be used for 3,300 hours annually. This turned out to be close to the 3,000 hours we estimated would be available.

Oversize equipment. To be safe vendors put a large safety factor into their equipment because they don't know how big it really needs to be. Manufacturers pay double for oversized equipment; they pay increased first costs for larger equipment and they pay increased utility costs for equipment running at part loads. Part load operation of most equipment is less efficient than operation at or near full load. In this case the vendor selected equipment was 30% oversized.

Using a Systems Approach

Joël de Rosnay, in 1977, articulated the idea of a systematic approach as it relates to problem solving in his book The Macroscope – A New World Scientific System in which he explains:[2]

> This unifying approach does indeed exist.…It is not a new concept…It is not to be considered a "science," a "theory," or a "discipline," but a *new methodology that makes possible the collection and organization of accumulated knowledge in order to increase the efficiency of our actions*.

[2] *The Macroscope – A New World Scientific System* is available on the internet at http://pespmc1.vub.ac.be/macroscope/. The book was originally published in France under the title *Le Macroscope. Vers une vision globale.* © Editions du Seuil, 1975.

> The systemic approach, as opposed to the analytical approach, includes the totality of the elements in the system under study, as well as their interaction and interdependence.
>
> The systemic approach rests on the conception of system. While often vague and ambiguous, this conception is nevertheless being used today in an increased number of disciplines because of its ability to unify and integrate.

The importance of evaluating systems as a whole rather than as individual components is slowly transforming agriculture, business; health care and engineering as people seek to increase efficiency. The concept of systems approach as it relates to energy use and energy efficiency has been embraced by both the EPA and DOE.

EPA Energy Star has identified a five stage approach for maximizing energy efficiency projects in commercial buildings.[3] They have based the five stages on a systems approach that focuses on reducing lighting loads first, tuning-up existing systems second, reducing other building loads third, optimizing secondary fan systems fourth and then finally addressing primary heating and cooling equipment. Addressing primary and secondary HVAC systems after building loads have been minimized reduces both size and first cost of any new equipment. This is the essence of a systems approach.

The DOE Office of Industrial Technologies (OIT), who helps fund Plant-Wide Energy Assessments for industrial facilities, has published case studies discussing the importance of using a systems approach to maximize energy efficiency potential of motor driven systems.[4] The systems approach embraced by OIT is similar to the one we used for this study and is better suited for evaluating industrial systems than the EPA approach.

A systems approach methodology needs to account for component interactions and how they relate to the overall system. System loads and operational parameters must be identified so that the feasibility of proposed efficiency measures can be evaluated. The systems approach methodology we used includes the following steps.

- Evaluate energy savings potential (from a high level)
- Describe the system including any operating parameters/constraints.
- Evaluate system performance by comparing measured field data against published manufacturer design data. Establish an energy baseline for each system component.
- Identify potential energy efficiency measures and evaluate their feasibility.
- Estimate implementation costs and energy savings for each recommended measures.
- Report the findings.

Facility End-Use Breakdown

An initial energy and demand end-use breakdown of the facility identified that the process cooling systems were the second largest energy user in the facility, see Figure 2. We

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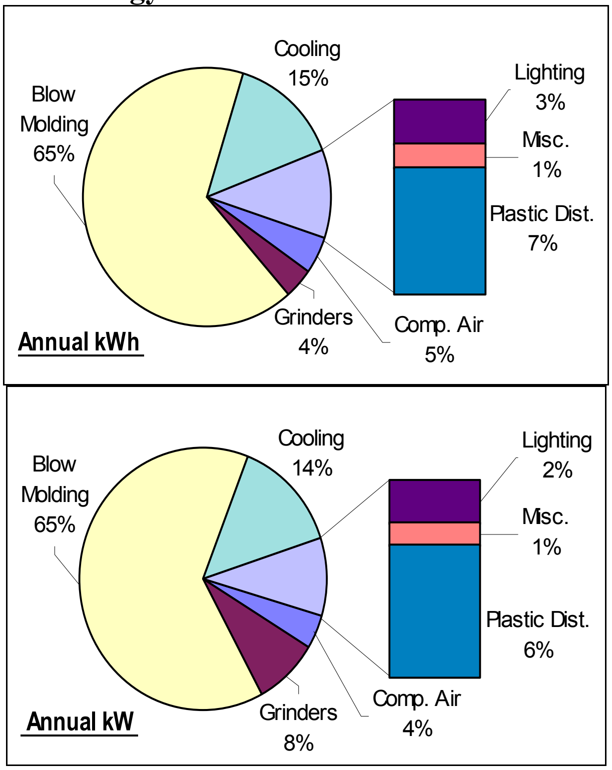
[3] An overview of the Five Stage Approach is included in Energy Star's Draft *Guide for Instituting A Strategic Energy Management Plan* and is described in detail in the *Energy Star Buildings Manual*. Both documents are available on the internet at http://www.energystar.gov.

[4] Office of Industrial Technologies motor driven system case studies are available on the internet at http://www.oit.doe.gov/bestpractices/motors/

determined that optimizing this system would have a significant impact on overall electric use in the facility.

Figure 2. Energy and Demand Load Balance Estimates



Process Cooling System Description

The manufacturing facility has a total of four process cooling systems sized for 250 to 300 tons each. The systems run continuously during production, about 7,000 annual hours and are off Sundays and Holidays. A typical schematic of each cooling system is shown in Figure 3. The two systems we analyzed have a total of 4 cooling towers, 13 pumps and 3 chillers. The hot and cold sides of each pump tank are hydraulically connected through a gap in the bottom of the baffle separating the two sides. In both chilled water and tower water loops, warm water is bypassed from the hot tank to the cold tank which mixes to maintain the leaving water temperature setpoint of the cold tank, see Figure 4.

During the initial assessment of the system high cooling water flow rates and low temperature differentials appeared to be a good opportunity for efficiency improvement. However we quickly learned that product quality is compromised by low cooling water flow rates and high temperature differentials in the product molds. Another early observation was the pumping energy being wasted because of the open pump tanks. Open pump tanks were needed because of the frequent mold changes that allowed air to enter the chilled water piping. In both cases, discussions with plant personnel revealed operating constraints that effected potential energy efficiency measures. Identifying constraints, like these, early in the project helps focus later efforts.

Figure 3. Existing Process Cooling Schematic – Typical of Each System

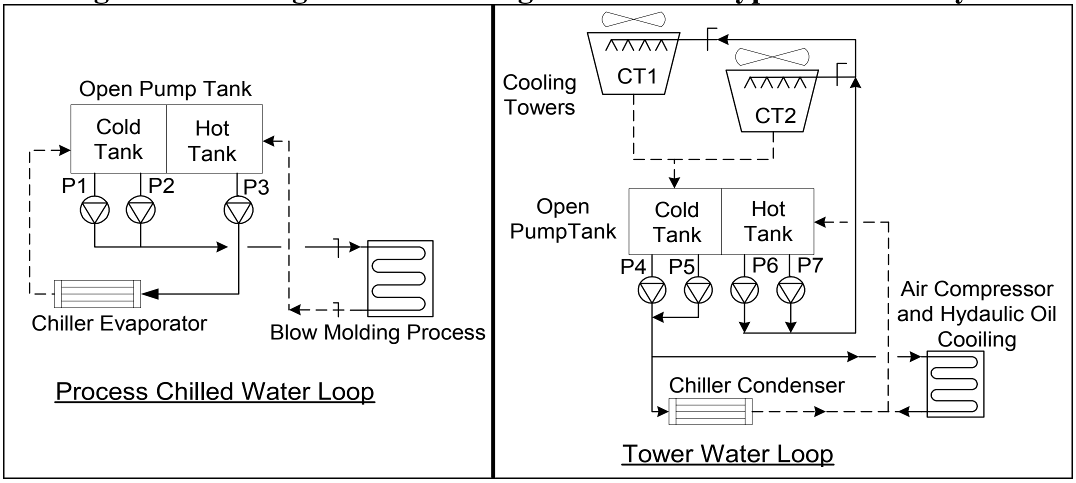
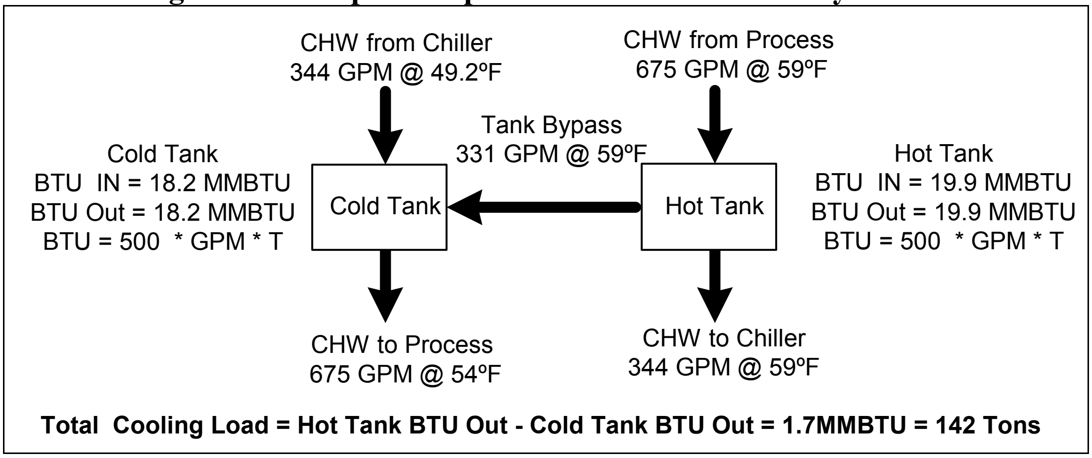


Figure 4. Example Pump Tank Load Balance for System #2



Load Duty Cycle

Before component energy use could be evaluated a load duty cycle was created. The load duty cycle describes the annual production schedule and the cooling loads associated with different levels of production.

Production schedule. Fifteen minute interval demand data was used to identify three distinct production periods; full production, part-load production and no production. Each process cooling system and the manufacturing equipment it serves has a separate interval pulse meter. An annual load profile, shown in Table 1, was created by evaluating the average daily electric consumption (kWh) of each process cooling system.

Table 1. Production Schedule

	System #1		System #2	
	Days	**Hours**	**Days**	**Hours**
Full Load Production	191	4584	206	4944
Part Load Production	91	2184	87	2088
No Production	83	1992	72	1728
Totals	365	8760	365	8760

Process cooling loads. One-time and trended measurements of chiller power, pump power, chilled water temperatures and pumping differential pressure were made to calculate system cooling loads under full load conditions. A load balance of all four pump tanks was used to validate measured water temperatures and calculated water flow rates against measured chiller power and performance. Once validated, flow rates and temperatures were used to determine peak process chilled water loads and process tower water loads, see Table 2.

Table 2. Peak Chilled Water Cooling Loads

	Peak Cooling Load (tons)	System Design Capacity (tons)	Percent Load
System #1	160	270	59.2%
System #2	142	280	50.7%

System Component Performance

Chiller energy. Chiller power was measured in five minute intervals over a two week period and aggregated daily consumption (kWh) totals were compared to the demand interval meter aggregated daily consumption (kWh). Average daily chiller energy consumption (kWh) was calculated for both full load production and part load production. Peak demand was based on the peak daily chiller demand measured during the trending period.

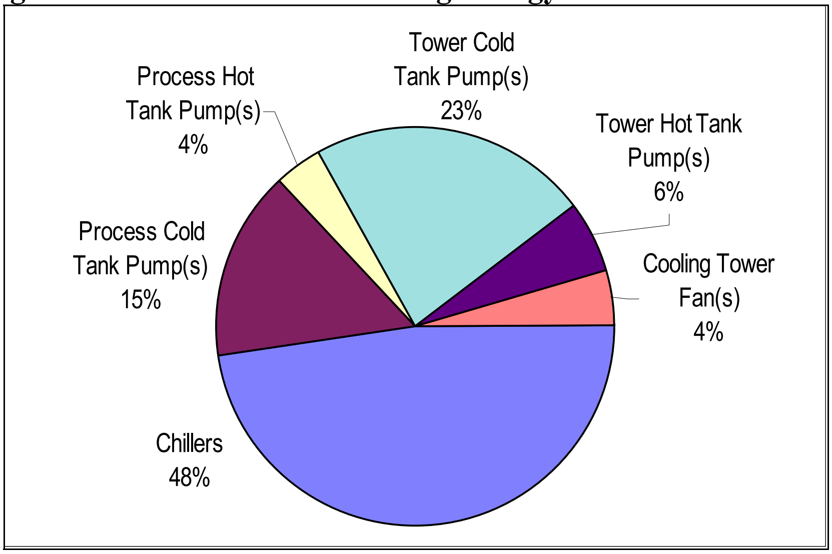
Pump energy. All the pumps studied were centrifugal end suction pumps with standard efficiency motors. Measured pump power and differential pressure were used to estimate water flow rates using published manufacturer curves. Pump power and pressure measurements were generally one-time measurements with the exception of the chilled water process pumps. Power and pump discharge pressure (suction pressure of the open system was assumed constant) was trended to determine the effects on energy consumption of full load versus part load production. There was little fluctuation in motor power as a result of changes in production.

Cooling tower energy. The cooling towers for each process cooling system are induced draft, counterflow towers of fiberglass-reinforced polyester construction. Fan power was measured with single one-time measurements and it was observed that they ran continuously during production periods.

Baseline Energy Use

The load duty cycle and performance data was used to calculate the annual energy consumption of each system component, shown in Figure 5.

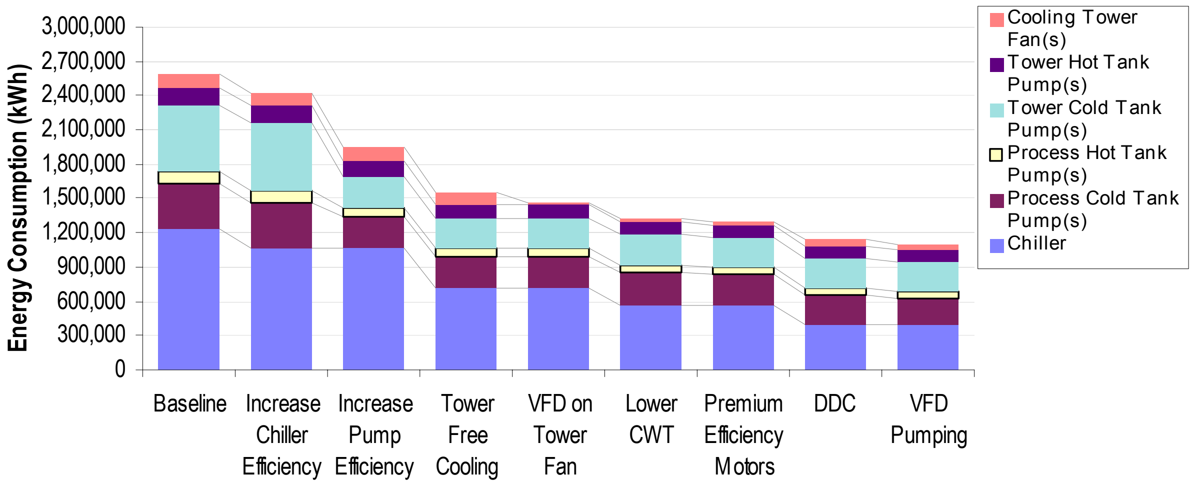
Figure 5. Baseline Process Cooling Energy End-Use Breakdown



Energy Efficiency Measures

Identifying the baseline energy use of each system component revealed numerous opportunities for additional energy efficiency. Many of the opportunities involved equipment that wasn't sized properly and as a result was operating inefficiently. We also determined that energy savings could be further optimized by combining the two cooling systems into a single larger system. Energy savings are shown by system component for each energy efficiency measure in Figure 6.

Figure 6. EEM Energy Comparisons by System Component



Increase chiller efficiency. Combining the two cooling systems required the use of only two chillers instead of three. The most inefficient chiller, which was only 30% loaded, was no longer needed. The efficiency of one of the remaining chillers improved when the load was increased from 63% to 95% of full load capacity.

Improve pumping efficiency. We observed that none of the pumps were properly selected for their operating condition. All of the pumps were oversized for pressure (head) and the cold tank pumps (see Figure 3) were undersized for flow. The cold tank pumps were all operating off the end of their pump curves causing unstable operation and motor overloading. In-situ measurements of these pumps determined that the efficiency ranged from 50-65%. New pumps selected for the correct flow rates and head pressures improved overall pump efficiency and reduced motor failure.

Evaporative cooling (Tower Free Cooling). The low design wetbulb temperature of Utah's arid climate is ideally suited for evaporative cooling applications. A cooling tower was sized for 1,785 gpm with a range of 10°F, an approach of 7°F and a design wetbulb temperature of 45°F to provide evaporative cooling. Evaporative cooling is potentially available for a total of 4,726 hours with the selected cooling tower. However we assumed only 2,388 hours were available because the switch between evaporative cooling and mechanical cooling was to be done manually, twice a year. Additional energy was saved by eliminating the pump tank on the Tower Water Loop and only using a single pump for the chiller condensers, cooling tower and new heat exchanger because air entrainment was not a concern.

VFD control of the cooling tower fan. A variable frequency drive controlling the cooling tower fan speed was the most efficient way to maintain the leaving water temperature setpoint. Because of the size of the new cooling tower, the fan would only need to operate above 30% full load power 11% of the time during evaporative cooling and 4.5% of the time during mechanical cooling. Significant fan energy savings were realized compared to the four existing tower fans running continuously at full load.

Lower chiller condenser water temperature. The new cooling tower was large enough to allow the chillers to use 70°F condenser water during the summer rather than the 80°F water previously being used. This had a significant impact on chiller performance without significantly impacting cooling tower fan energy (because of the tower size).

Install premium efficiency pump motors. All the existing pump and fan motors were standard efficiency, so the replacement of pumps and fans made it an ideal time to invest in premium efficiency motors. The replacement fans and pump motors were all significantly larger than original motors (due to aggregation of 13 motors to 5) which increased the overall available motor efficiency.

Direct digital control of the process cooling system. The process cooling systems were operated manually with minimal automatic control for staging the chillers and control of the cooling tower fans. Digital control of the entire process cooling system, especially automatic switchover between evaporative cooling and mechanical cooling allowed an additional 1,400 hours of evaporative cooling.

Variable speed process chilled water pumping. Evaluation of the cooling requirements of the blow molding process revealed that when process equipment wasn't being used the chilled water system pressure increased due to decreased water flow rates. While not verified as part of this study there was concern that the increased system pressures would affect the consistency of the final blow molded plastic product. A variable speed drive allowed a constant system pressure to be maintained during part load production.

Conclusion

Industry decision makers should be wary of vendor based energy efficiency proposals. In this paper we showed how a vendor overstated cost savings by 132% and energy savings by 80% using rule-of-thumb engineering. One of the largest hurdles to improving the acceptance of energy efficiency as a viable economic alternative is the continued failure of energy projects to meet the stated savings.

We also showed that using a systems approach is an accepted methodology that can reduce the risks associated with energy efficiency projects. A systems approach helps identify exactly how a system works and how it can be optimized. Only by understanding these two things can an energy efficiency project be successful.

In this study six additional energy efficiency measures and significant additional savings were identified that significantly increased energy savings and improved the overall manufacturing process. The two original energy efficiency measures would have only saved 814,700 kwh and 1,270 kW. As a result of the FinAnswer study a project was installed that will save 1,479,500 kWh and 2,495 kW annually, increases of 82% and 96% respectively. Annual energy cost savings increased from $37,800 to $70,500. Based solely on energy savings this project had a return on investment of 17.6%. When the incentive from the electric utility was included the return on investment became 35%.

Anticipating similar savings potential for the remaining two process cooling systems brings expected annual savings close to 3 million kWh and 5MW of demand. This equates to a 58% reduction in total cooling energy use and an 8.7% reduction in total annual energy use. Any industrial facility considering an energy efficiency project should take the time to conduct a detailed energy audit using a systems approach. The increased costs associated with this type of energy audit are rewarded with a project that has reduced risk, greater savings and the potential to improve overall product quality.

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