Applied Materials: Chilled Water Plant Efficiency Upgrade

Project Benefits Summary

Measured Annual Energy Savings	1,058,000 kWh/y
Measured Annual Energy Cost Savings	$74,000/y
Estimated Annual Energy Cost Savings	$87,000/y
Actual Project Cost	$201,000
Actual Project Payback	2.7 years

Facility Description

Applied Materials (Applied) occupies their corporate headquarters, including more than 30 buildings, in Santa Clara, California. The primary purpose for this site is to research, develop, and manufacture wafer processing tools for the semiconductor industry.

The focus of our study is building 2, which includes a large cleanroom research facility on the lower level and offices on the upper level (the space between the levels is used to provide facilities services to the cleanrooms). The building originally included a chilled water plant with one 500 ton York chiller. In 1994, two new 750 ton York chillers were installed to accommodate expansion of cleanroom operations on the first floor of the building. Current plant operation reserves one of the 750 ton chillers as a backup and the other is used along with the 500 ton chiller to supply 40°F chilled water to meet the cooling and dehumidification loads for the building. The chilled water plant also includes three open loop cooling towers (each sized to match the three chillers) with a common sump.

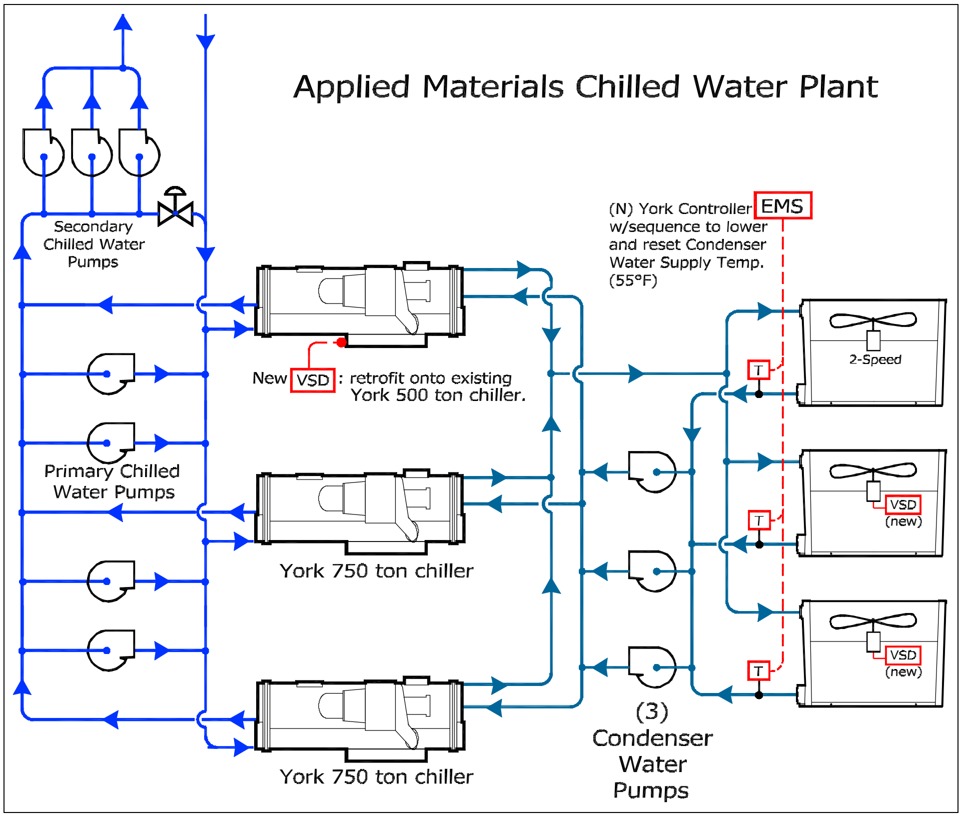

Figure 1: Chilled Water Plant Schematic

Project Description

Since the build out of the building shell and plant in the mid-1990's, a few measures have been implemented to improve control of and reduce energy use by the chillers. These include installation of a variable speed drive (VSD) on the 500 ton chiller and condenser water supply temperature optimization.

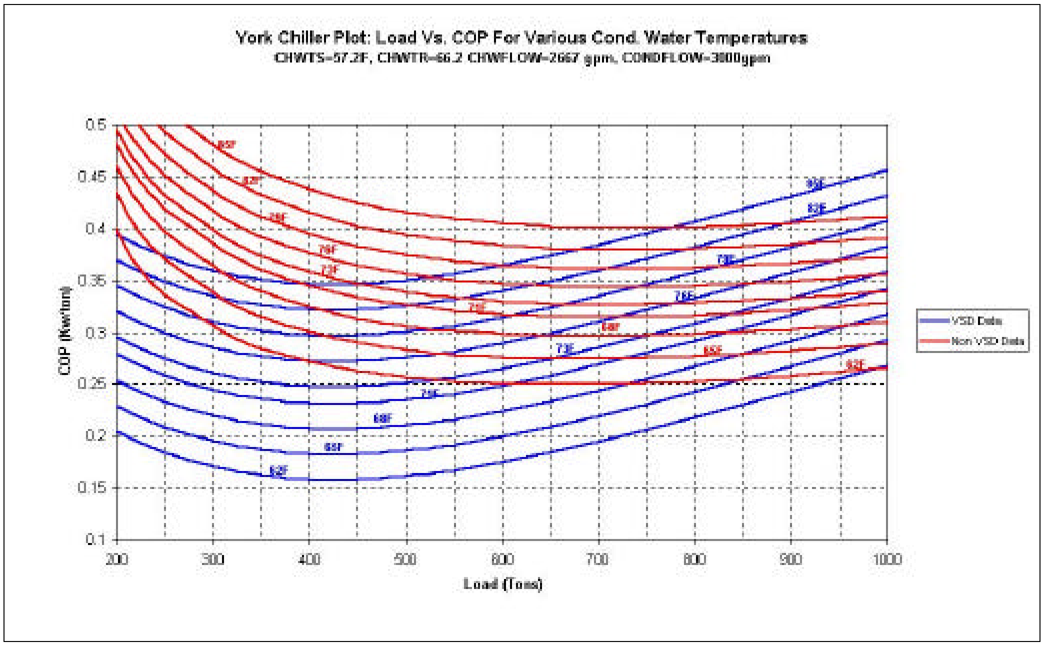

Figure 2: Chiller Performance Curves with and without VSD Compressor Control

The VSD on the 500 ton chiller is beneficial in that the chiller actually performs better at part loads (25% to 75%), where chillers operate much of the time, than at full load. Figure 2 shows manufacturer's data for the same 1,000 ton chiller with and without a VSD. At any condenser water supply temperature (CWST; the numbers shown above each line) the VSD chiller efficiency (kW/ton) improves, or goes down, as load begins to drop, but the non-VSD chiller efficiency steadily gets poorer with decreasing load. As is shown in the figure, this is equally true at any CWST. It is also important to recognize that this type of graph can be developed for any size centrifugal chiller from any manufacturer.

Measured data for the VSD chiller (see figure 3), illustrates that this chiller is in fact performing as predicted: chiller efficiency improves from about 0.65 kW/ton at full load down to about 0.33 kW/ton at low load (building load never dropped below 250 tons during chiller operation). The solid cloud of points represents over 95% of the measurements during operation; all other data is either due to transients at startup or was measured when the chiller was not operating. It is also important to note that this data is for a varying CWST, so some portion of the efficiency improvement at low load is likely due to improved CWST (see figure 5 and discussion below).

The physical explanation for this efficiency improvement is that the VSD allows chiller capacity to be reduced by reducing compressor speed rather than by closing inlet guide vanes, which throttle back on the refrigerant flow by increasing pressure drop. Inlet guide vanes do reduce the total energy required by the compressor, but at a rate slower than the rate of reduction in cooling output, hence the decline in efficiency at lower loads. Note that, because the VSD consumes a small amount of power, the full load efficiency for the VSD chiller is slightly poorer than for the non-VSD chiller.

The operational effect is that the VSD chiller allows more efficient operation at almost all loads. Prior to installation of the VSD, if cooling loads in building 2 reached, for example, 1,000 tons, one 750 ton and the

500 ton chiller were required to operate, with at least one of them operating at part load (poor efficiency). With the VSD, plant operation is much more efficient because the 750 ton chiller can be run at full load (best efficiency) while the 500 ton chiller is used to cover the remaining load very efficiently due to the VSD. Likewise, if the total cooling load is low, the 500 ton chiller can cover the load alone with much better performance than it would without the VSD.

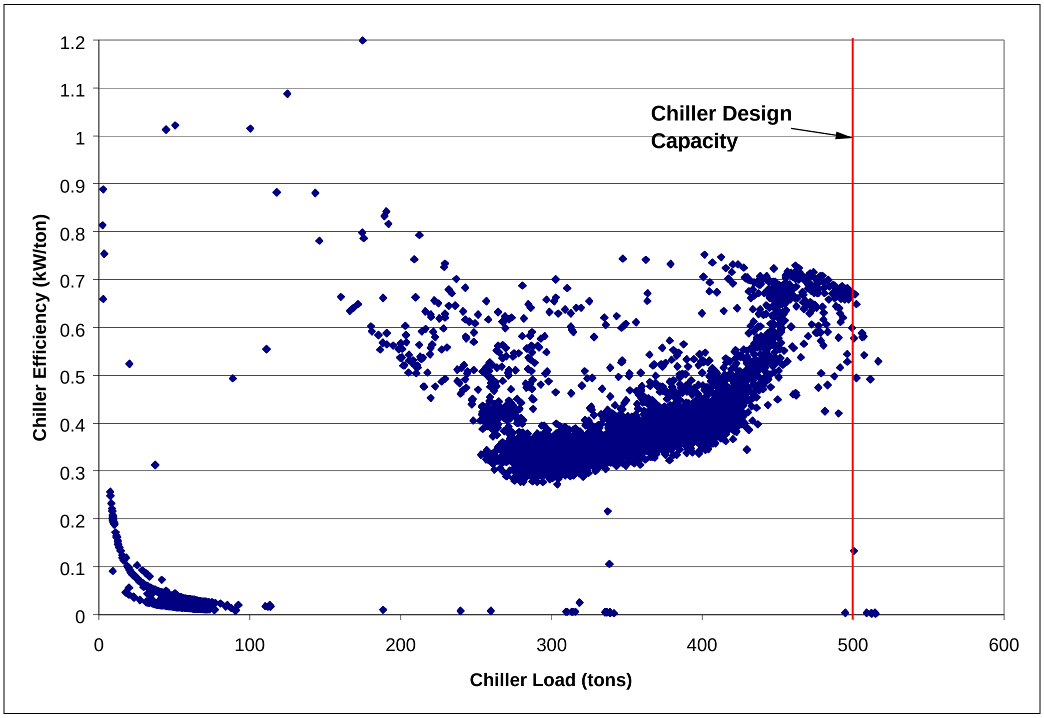

Figure 3: Measured VSD Chiller Performance

Condenser water reset is one of the most cost-effective ways to improve chilled water plant performance because it typically only requires modification of the control logic (at relatively low cost) and can improve chiller performance dramatically. Figure 2 also illustrates the chiller performance gains possible by reducing the CWST with a constant chilled water supply temperature (CHWST). This improvement can be explained simply by recognizing that compressor power is proportional to pressure developed by the compressor, which is in turn directly dependent upon the desired refrigerant temperatures at the inlet and exit of the compressor. These two temperatures are typically combined into a number known as the refrigerant lift. The lower of these temperatures is determined by the CHWST and the higher temperature is dependent upon the CWST. Therefore, if the CWST is reduced for a constant CHWST, the refrigerant lift, pressure developed by the compressor, and compressor power are all reduced.

Again, the measured data for chiller efficiency (see figure 4) confirms the theory: as CWST decreased, the chiller efficiency improved. It is important to note that the improvement shown by the data is also partly due to the operation of the VSD. Comparison of the data in figures 3 and 4 clearly indicates that the best chiller efficiency is achieved at the lowest CWST and at the lowest load.

The normal method for reducing CWST is to increase cooling tower capacity by either running additional tower fans, or speeding up tower fans with VSDs (if installed). The only limits to the CWST setpoint are the capacity of the cooling towers and the lower temperature limit that can be safely handled by the chiller (very cold condenser water can affect the oil used to lubricate the compressor and can cause rubber seals to leak – both resulting in maintenance problems). Most chilled water plants tend to be installed with excess cooling tower capacity, especially plants for cleanroom facilities, which typically have backup chillers installed with dedicated cooling towers. Proper piping and control logic easily allow the excess tower capacity to be accessed even when the backup chiller is not in use.

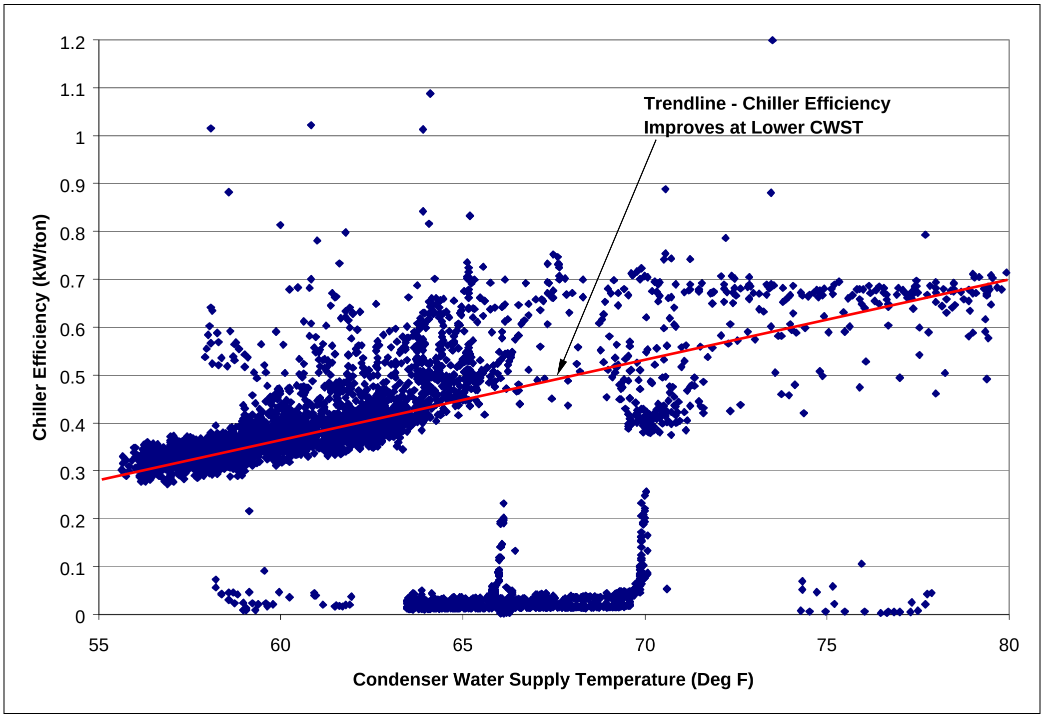

Figure 4: Measured Chiller Performance with Varying CWST

The York chillers operating at Applied are explicitly designed to allow condenser water temperatures down to 55°F, or lower, and Applied has implemented controls to maintain 55°F at all loads. This required some control programming to stage the three cooling towers (shown in figure 5) in order to maintain the new setpoint. The data in figure 4 confirms that the control reaching 55°F, but shwos that it is not able to maintain this. Both inadequate tower capacity for this low CWST and prevailing weather may be significant factors in this difficulty. Clearly it benefits Applied to keep the CWST as low as possible.

Figure 5

Another control that Applied implemented to optimize the cooling towers was to allow water to run over the fill in all three towers regardless of the tower fans being on or off. This allows for a small, but useful, amount of evaporative cooling within the towers without using any fan energy.

A new DDC control system was installed to allow optimization of staging for the both the chillers and the cooling towers. Data provided by York at the time of installation estimated that these two measures would cost about $201,000 and have an annual cost savings of about $87,000/y. Measurements confirm that this savings estimate was about right: extrapolation of the measured data indicates savings of about $74,000/y, resulting in a payback of about 2.7 years (see figure 6).

Applicability to the Cleanroom Industry

The chiller VSD contributes a large potion of the energy savings mentioned above. However, not all existing chillers can be retrofitted with VSDs. It is worthwhile to note, however, that most chiller manufacturers are willing to provide an estimate of the cost to install a VSD, if possible, given the chiller type, operating conditions, and capacity. Keep in mind that most cleanroom facilities operate plants with multiple chillers and need only one VSD on the smallest chiller to realize the full benefits. All other chillers would be used as “base load” machines running at full load. Another point about chiller VSDs is that a control system must exist or be installed that can control the staging of the chillers in order to optimize plant efficiency at all loads. Given the simplified nature (plant shutdown is not needed, very little equipment must be altered or replaced, etc.) of these measures, they can be cost effective for virtually all cleanroom plants.

Other Energy Efficiency Projects Underway at Applied

Applied has undertaken a number of other measures to improve energy use at building 2. Data for these measures is quite sparse, but they ar still worth a mentioning.

- All process cooling is done using dedicated indirect (closed loop) cooling towers. When loads are extreme, the excess cooling is handled by a small heat exchanger using chilled water. This non-compressor based cooling method likely saves Applied thousands of dollars per year. Many facilities use 40°F chilled water with plate heat exchangers to remove heat from their process cooling system, requiring about ten times the energy of a non-compressor system.
- A project is underway to install motion sensors and particle counters in the cleanroom bays, which will control recirculation fan VSD speed based upon demand. If the space in unoccupied, the fans will slow to minimum speed. When occupied, the fans will operate to maintain the desired particle levels based upon the real-time particle measurements. This control has the potential to cut annual fan energy use by up to 75%.
- Two of the chilled water plant cooling tower fans have been retrofitted with VSDs to allow more precise control of the CWST and to take advantage of the fan energy savings possible with parallel fan operation.

Figure 6: Applied Materials Case Study Data Analysis

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	Descriptions	*Values*	*Formulas*	*Notes*
A	VSD Chiller Efficiency at Full Load	0.70 *kW/ton*	-	*Measured data*
B	Annual Average VSD Chiller Load	425 *tons*	-	*Estimated based upon measurements and discussions with building staff*
C	VSD Chiller Efficiency at Average Load	0.42 *kW/ton*	-	*Measured data - includes impacts of VSD operation and CWST reset*
D	Annual Average Hours of VSD Chiller Operation	6,500 *h/y*	-	*Estimated - chiller runs exclusively in winter and every night during other seasons*
E	Total Annual VSD Chiller Energy Savings with VSD and CWST Reset	773,500 *kWh/y*	*B x (A - C) x D*	*Assuming this chiller would operate at its full load efficiency on average when operating without the VSD*
F	Non-VSD Chiller Efficiency at 70 Deg F CWST (typical CWST setpoint)	0.65 *kW/ton*	-	*Estimated based upon measured data for VSD chiller, which is a smaller version of this chiller*
G	Non-VSD Chiller Efficiency at 60 Deg F CWST (measured average with reset)	0.52 *kW/ton*	*F x [1 - (2% x [(70 Deg F) - (60 Deg F)])]*	*Assuming a 2% efficiency improvement for each degree F reduction in CWST - the data for the VSD chiller indicates an improvement of over 5%, but also includes the affects of the VSD*
H	Annual Average Non-VSD Chiller Load	625 *tons*	-	*Estimated based upon measurements, observations, and discussions with building staff*
I	Annual Average Hours of Non-VSD Chiller Operation	3,500 *h/y*	-	*Estimated - chiller runs daily in summer and on warm days during other seasons*
J	Total Annual Non-VSD Chiller Energy Savings with CWST Reset	284,375 *kWh/y*	*(F - G) x H x I*	
K	Total Annual Chiller Energy Savings	1,057,875 *kWh/y*	*E + J*	
L	Average Cost of Electricity	$0.070 *per kWh*	-	*Assumed based upon prevailing Santa Clara utility rates*
M	Total Electricity Cost Reduction	$74,051 *per y*	*K x L*	
N	Actual Cost of VSD Retrofit and Cooling Tower Control Programing	$201,000	-	*From Applied Materials*
O	Project Payback	2.7 *y*	*N / M*	