Lawrence Berkeley National Laboratory
Environmental Energy Technologies Division

Cleanroom
Energy Efficiency Workshop

Proceedings

Berkeley, California
March 15, 1999

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

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Applied Materials - Carol Asuncion, Applied Materials; Eric Concannon, Supersymmetry

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Genentech - Gary Shoenhouse, Genentech

STMicroeletronics - (Report not available) Peter Rumsey, Supersymmetry

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LBNL research - Dale Sartor, LBNL Applications Team

Lighting technologies - Dr. Michael Siminovitch, LBNL

Low Flow Fume Hood - Geoffery Bell , LBNL

ATMI Agreement – Mark Holst, ATMI/ Ecosys

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SECTION A

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Summary of Workshop

Introduction

On March 15, 1999, Lawrence Berkeley National Laboratory hosted a workshop focused on energy efficiency in Cleanroom facilities. The workshop was held as part of a multi-year effort sponsored by the California Institute for Energy Efficiency, and the California Energy Commission. It is part of a project that concentrates on improving energy efficiency in Laboratory type facilities including cleanrooms. The project targets the broad market of laboratory and cleanroom facilities, and thus cross-cuts many different industries and institutions. This workshop was intended to raise awareness by sharing case study success stories, providing a forum for industry networking on energy issues, contributing LBNL expertise in research to date, determining barriers to implementation and possible solutions, and soliciting input for further research.

Case Studies

The case studies that were presented represented a wide range of energy efficiency improvements in several industries. They ranged from implementation of single measures to a whole systems approach to energy savings. Opportunities for energy savings were demonstrated for small firms as well as some of the industry's leading firms. Each of the case studies demonstrated short-term payback in terms of avoided energy usage. Typical payback periods ranged from 0.5-2.3 years. One of the case studies involved a significant utility rebate due to the energy improvements that were implemented.

Attendees

Workshop attendance included a cross-section of professionals active in various aspects of cleanroom design, operation, and energy efficiency improvement. In attendance were leading firms doing business in California representing the semiconductor, biotechnology, national laboratories, semiconductor equipment manufacturers, engineering firms, research organizations, and sponsoring organizations. Special recognition of the presenters is due for their excellent work in preparing and presenting material which heightened awareness of the opportunities for improvement. The following individuals contributed greatly to the success of the workshop:

> Rick Diamond, LBNL – for facilitating the proceedings.
>
> Chris Robertson, Chris Robertson & Associates – for a discussion on the current activities in cleanroom energy efficiency initiatives, including the activities of the Northwest Energy Efficiency Alliance.
>
> Ken Martin, Pacific Mechanical & Engineering, Inc. – for presentation of the Hine Design VFD Case Study.

Carol Asuncion, Applied Materials – for presentation of the Applied Materials chiller retrofit Case Study

Eric Concannon, Supersymmetry – for presentation of the Applied Materials chiller retrofit Case Study

Dave Barr, Black & Veatch Corp. – for presentation of the Motorola class 10,000 conversion Case Study

Gary Shoenhouse, Genentech Corp. – for presentation of the Vacaville facility Case Study

Peter Rumsey, Supersymmetry – for presentation of the STMicroelectronics Case Study

Fred Gerbig, Gerbig Engineering Corp. – for a discussion of energy efficiency measures and considerations in cleanrooms

Dale Sartor, LBNL – for a presentation describing prior LBNL research activities and results.

Mark Holst, ATMI/Ecosys – for describing the ATMI/ LBNL research and commercialization agreement.

Dr. Michael Siminovitch, LBNL – for presentation of lighting technology concepts.

Geoffery Bell, LBNL – for a demonstration of the ultra low flow fume hood.

Research

LBNL presented the activities in prior research for laboratory type facilities. Of note were the development of a design guide for laboratories, a design intent tool, a low air-flow fume hood, airflow distribution design tools, and lighting concepts. Participants viewed demonstrations of "light tube" and fiber optic lighting concepts or a demonstration of the patented low flow fume hood developed at the laboratory. An agreement with ATMI was announced to develop additional applications of the fume hood technology for semiconductor manufacturing applications.

Conclusions

Important initiatives are in progress through the Northwest Energy Efficiency Alliance, EPRI/Sematech, Lawrence Berkeley National Laboratory, and many firms operating cleanrooms. Cleanroom operators are beginning to benchmark and explore energy saving opportunities. Cleanrooms are utilized in a number of different industries and institutions yet the potential for significant energy reduction is cross-cutting for all applications. The economic benefits from energy efficiency improvements typically provide very short term return on investment, however the non-economic benefits such as worker safety or environmental improvement often have more far reaching benefit.

The case studies presented highlighted several issues. There were consistently short payback periods for the implemented measures. Return on investment typically occurred in less than two and one half years and the ongoing benefits will accrue for the life of the facility. Energy efficiency improvements can be implemented as stand-alone improvements, part of a larger retrofit project, or implemented in the initial design. Several larger firms are participating in benchmarking activities to determine their performance and are beginning to implement changes. Organizations such as EPRI/Sematech have limited energy research programs underway. Most smaller firms and some larger ones, are less likely to have the resources to undertake significant energy efficiency studies and could benefit from public goods programs to learn about best practices and new technologies. Electric Utility rebate programs can offer an incentive to examine the potential areas of saving and other market transformation programs can overcome other barriers identified. Facilities that implemented a whole systems approach realized approximately $500,000 per year savings. Following the workshop, STMicroelectronics decided that the case study for their facility could not be published. Consequently no information for this case study is included. An additional case study is being prepared and will be made available to the participants.

The attendees identified the typical barriers to implementing energy efficiency improvements. The entire group then voted on the top four barriers. The complete listing of barriers is included in this package. While many barriers to implementing energy efficiency measures were discussed, the most prevalent issues were selected and the group brainstormed possible solutions. The list of solutions is included in this package and the group discussion is summarized below:

1. Insufficient design and construction time, and budget:

   Work with all owner decision makers to convince them of the potential benefits of energy efficiency and include requirements in requests for proposal. Provide early planning for energy efficiency including clearer design goals, consider third party energy efficiency analysis, develop financial incentives for designers and constructors, and develop better tools for designers' use.

2. Capital budget approval:

   Similar items to 1. above, plus emphasis on life cycle cost rather than first (Capital) cost. Show energy cost as a line item in budget requests, include energy efficiency upgrades with other upgrades, share improvements with the rest of the industry, and highlight other non-energy advantages such as environmental benefits. Provide a fund for energy efficiency improvements or utilize performance contracting.

3. Emphasis on first cost rather than life cycle cost:

   Energy efficiency can result in lower first cost and ongoing savings. Many financing options are available including rebates, shared savings, guaranteed savings, and outsourcing the upgrades/energy supply. Facilities aren't always operated as designed. A data base of building operating parameters would be helpful. An integrated systems approach to energy efficiency is needed.

4. Uncertainty on room end use/process tool requirements:

   Owners and suppliers need earlier decisions on building use. Design should provide flexibility for future growth. Chiller and other long lead time equipment frequently drive early overly conservative selection. Work with manufacturers to reduce delivery times.

The attendees also provided input on their three top priorities for further research and development. The ideas included in this report represent a wide range of research or technology transfer activities. Some of the ideas related to overcoming the barriers previously identified while others addressed new opportunities for energy efficiency.

The research ideas can be categorized as follows:

Measurements and standards

The participants would like to see standard energy metrics based upon real data. These metrics would be useful in benchmarking facilities and devising operational improvements. Existing "standards" should be evaluated and revised if there is scientific basis to do so. Arbitrary cleanroom airflow velocity of 90 ft./min., for example, should be re-examined.

Other benefits

Strategies should be developed to maximize benefits of energy efficiency improvements along with non-energy benefits. Financial and non-financial considerations for presentation to decision-makers should be developed. Federal and State incentives in the form of rebates or other programs should be pursued.

Process considerations

For semiconductor facilities, tools used to process wafers account for a significant portion of the overall energy consumption. Participants were interested in accurate measurement of tool energy usage, leading to right sizing of facility systems and encouraging tool mfgs to improve energy efficiency of their tools. Strategies or technologies for reduction of process exhaust flow are needed.

Utilities

Standardization of parameters for commonly used utility systems is desirable. Sematech has proposed a task in its 1999 agenda to study the feasibility and benefits of standardizing delivery pressures and temperatures for process cooling water to process tools. There is a need for a full facility model of utilities.

HVAC Systems

Cleanroom laminar effects, air velocity relationship to cleanliness, reducing deposits of organics, and exhaust reduction were all identified as priorities for research.

Owner/Operator/Designer issues

Guidelines and training tools for designers and facility operators were identified. A "tool kit" for energy issues was suggested.

Copies of presentation materials and handouts follows.

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SECTION B

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WORKSHOP ON
ENERGY SAVING OPPORTUNITIES IN CLEANROOMS
MARCH 15, 1999

8:30-8:45	**WELCOME / WORKSHOP GOALS**
8:45-9:15	**INTRODUCTIONS/ LOGISTICS**
9:15-9:45	**ENERGY EFFICIENCY OPPORTUNITY/ BENCHMARKING**
9:45-10:00	**BREAK**
10:00-11:40	**CASE STUDIES**
11:40-1:00	**LUNCH**
1:00-1:50	**CASE STUDIES**
1:50-2:45	**BARRIORS TO IMPLEMENTING IMPROVEMENTS**
2:45-3:00	**BREAK**
3:00-3:45	**RESEARCH/MARKET TRANSFORMATION NEEDS**
3:45-4:00	**LBNL RESEARCH**
4:00-5:00	**LAB DEMONSTRATIONS (OPTIONAL)** **Tour A - Low flow fume hood/ Wet bench technology** **Tour B - Cleanroom lighting concepts**

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SECTION C

ERNEST ORLANDO LAWRENCE
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SECTION F

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Hine Design: Variable Speed Drive Control of Recirculation Fans for Class 100 Cleanroom

Project Benefits Summary

Annual Energy Savings	372 MWh/y
Annual Energy Cost Savings	$36,000/y
Actual Project Cost	$55,000
Project Payback	1.5 years

Facility Description

Hine Design, a subsidiary of Asyst Technologies, operates a robotics manufacturing facility in Sunnyvale, California. The 45,000-ft^2 building includes 4,000-ft^2 of class 100 cleanroom space, 6,000-ft^2 of combined clean air return chases and class 10,000 assembly areas, with the remaining building space serving as their operations and engineering offices. The facility operates from 8am to 5pm, Monday through Friday, and is closed on weekends and holidays.

All of the clean air provided to both the class 100 and class 10,000 spaces is filtered by 99.99% efficient HEPA (high efficiency particulate air) filters installed in fan powered HEPA units (FPHs). The class

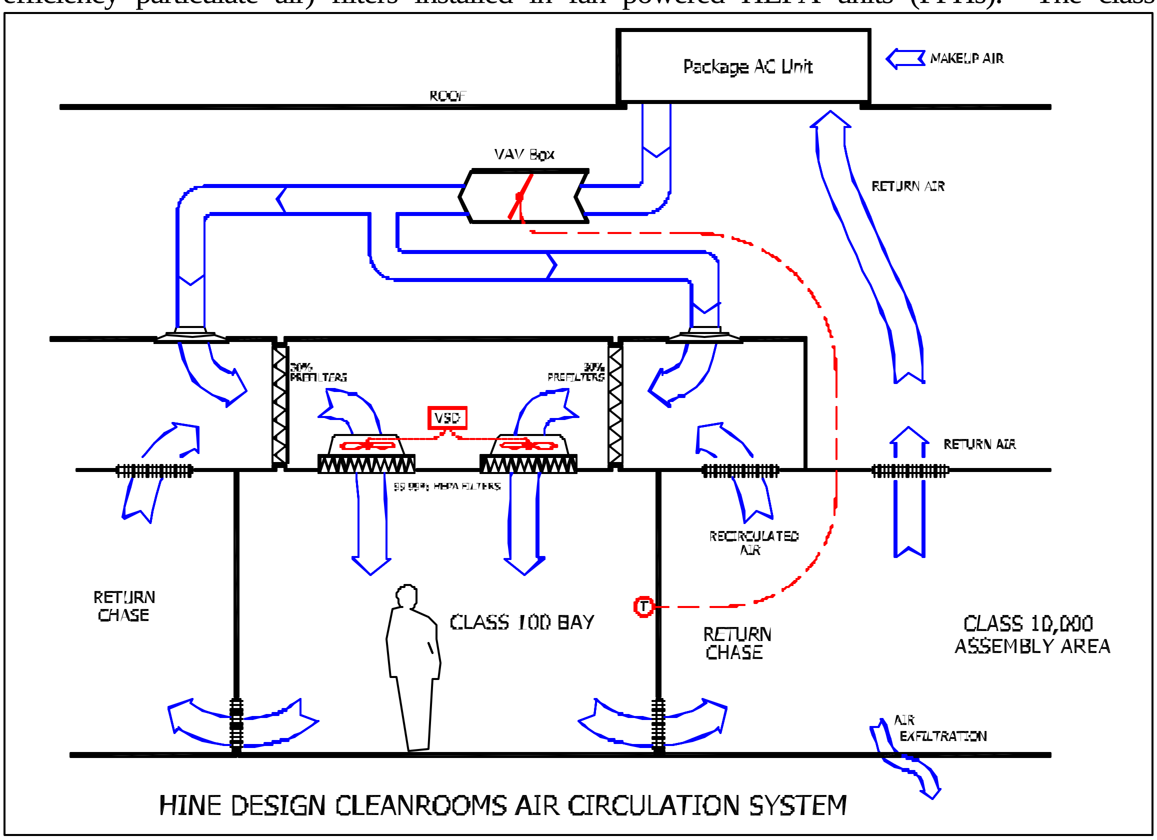


Figure 1

100 space is comprised of 6 individual bays surrounded by return chases and with the large class 10,000 assembly area at the north side of the bays. As shown in Figure 1, air is supplied to the bays by dedicated FPHs and exits through low sidewall returns into the return chases. The FPHs recirculate the air from the chases into mixing plenums where conditioned air is also supplied from two package units located on the roof. The mixed air in the plenum then passes through 30% filters into the ceiling plenum above the FPHs. There is no process exhaust from the bays, but exfiltration from the chases into the office areas requires a small amount of makeup air to keep the cleanroom positively pressurized. Therefore, the rooftop package units primarily condition return air from the class 10,000 assembly area and intake only a small amount of makeup air. Due to the nature of the manufacturing process and the naturally mild Sunnyvale climate, there is no provision for humidity control in the package units.

Project Description

In order to reduce energy use in their cleanrooms, Hine Design hired Northern Pacific Mechanical to design and implement new control logic. Two specific controls were retrofitted onto the system serving the class 100 bays to provide the energy saving benefits:

- Variable speed drives (VSDs) on the FPHs serving the class 100 bays (shown in Figure 1)
- A custom control system that schedules the speed of the VSDs based upon occupancy patterns

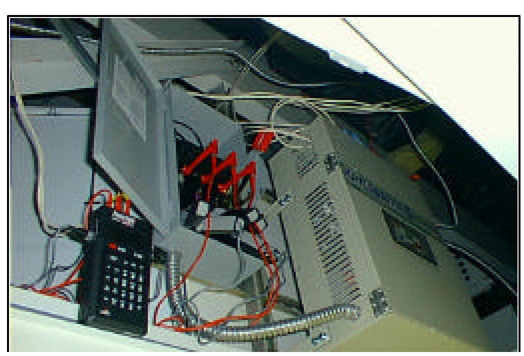
On normal operating days (M-F), the control system operates the VSDs in the occupied mode from 5am to 5pm, and on weekend days, it operates the VSDs in occupied mode from 6am to 10am. Based upon particle measurements within the bays, it was determined that 60% fan speed is appropriate to maintain cleanliness during operation. At all other times, the control resets the VSDs to 15% speed to maintain positive flow through the HEPA filters and the rooftop package units are shut down. As will be discussed later, when 15% speed is commanded by the control system, the VSDs actually run at 0 Hz (they turn the fans off).

The theory supporting the energy savings associated with this type of system is the "cube law" for fans. This law states that the power required by a fan changes as the cube of the flow induced by it (i.e. power $\propto$ flow^3). This indicates that as the flow through a fan is reduced or increased by a known factor, the power required by the fan is reduced or increased by the same factor cubed. Our measurements confirm savings proportional to the cube law (see the calculations in Appendix A): at 60% speed, fan power is predicted by the cube law to drop by 86%; our measurements show an 82% reduction in fan power.

The energy analysis for this project, including formulas, can be found in Appendix A. The energy cost savings, based upon our measurements, is approximately $36,000 per year. The incremental cost of installing the VSDs and the control system was $55,000, so the simple payback for this project works out to 1.5 years.

Analysis Methodology

To determine the energy savings associated with the VSD control, power measurements were taken in cleanroom bay 6. In order to



measure both modes of operation, the system operated over a period of one day. Implied in this measurement is the assumption that the percentage of power saved in this bay is equivalent to the power that is saved in all the bays. A PowerSight true RMS power meter (shown at right measuring VSD power) collected the data at one minute intervals for just over 24 hours. As shown in Figure 2, the power demand during each time interval is essentially constant. Therefore, measurements were taken for only one day, assuming that this data represented the power demand during each mode of operation throughout the year. In order to determine the savings associated with this system, we also measured power demand with the VSD running at full speed for a 15 minute period (the spike at the far right on the Figure 2 shows our measurements at full speed). Without the VSDs and controls, all of the FPHs would run at full speed 24 hours a day, even at night to maintain positive flow through the HEPA filters. These measurements were then used to calculate the annual energy cost savings based upon actual average utility rates for Hine (see Appendix A).

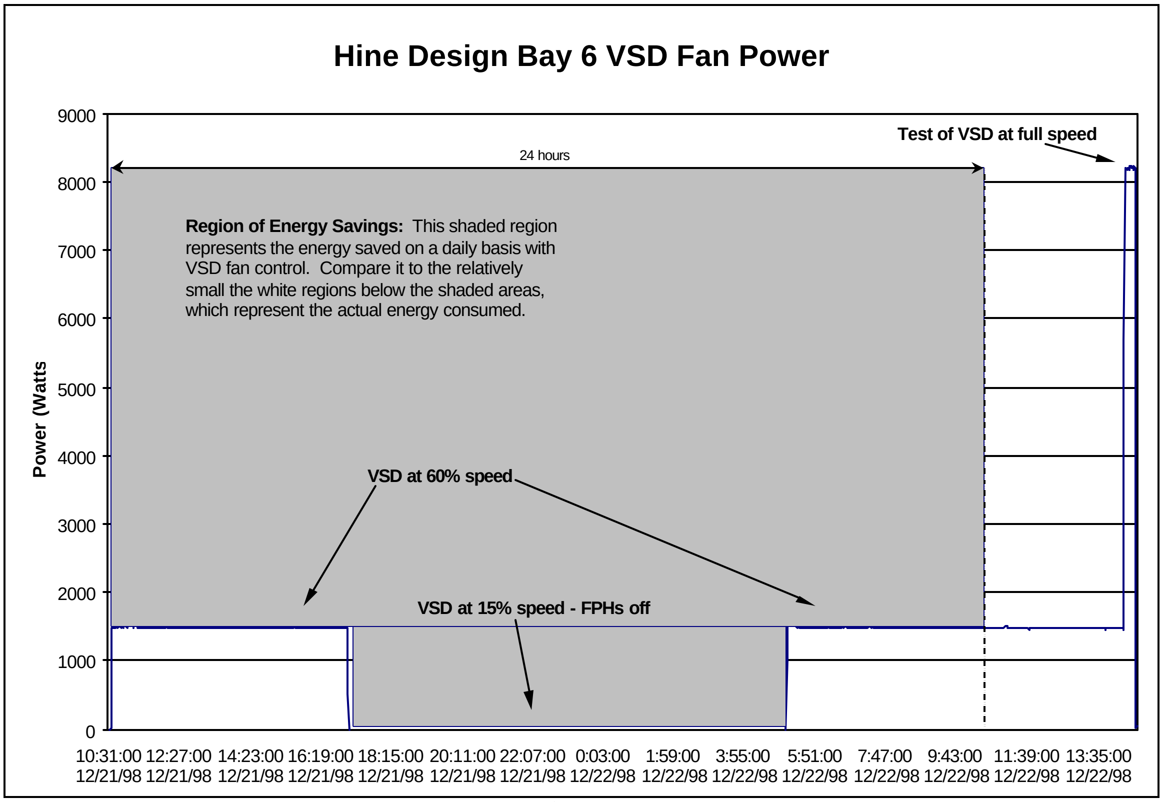


Figure 2

Discussion

The measurements illustrated above show that the fans draw no power at 15% speed. Therefore, the assumption that 15% speed maintains positive flow through the HEPA filters was incorrect. It is likely that the VSDs have been setup with a minimum operating frequency, typically 20 Hz (33% speed), below which they will shut their output to zero power. Our investigation of the VSDs with the manufacturer found that the drives have a low limit parameter that can be set to any frequency (for 15% speed, this minimum needs to be 9 Hz). This discovery will lead to very slightly increased energy use as Hine resets the minimum VSD speed to allow operation at 15% speed and achieve their goal: positive flow through the HEPA filters to prevent particle release. Extrapolating the measured results for the system, we have determined that increasing the fans to 15% speed will increase annual energy use by 1,540 kWh/year [$(0.15)^{2.66}$ x 45.9 kW x 5,214 h/y]. The net annual energy savings would then be reduced from just over 372 MWh/y to about 371 MWh/y – a truly insignificant reduction of 0.4%! The cost impact of this "fix" would be about a $150 increase in annual energy bills.

Furthermore, if Hine does modify the VSDs to actually maintain positive flow through the HEPA filters at all times, they may find that their particle counts drop during normal operating conditions. Based upon this information, the existing normal operating speed of 60% may no longer be necessary to maintain their class 100 rating, at which point they can further reduce their energy use by slowing the fans down even more. This feedback effect should at least offset the meager energy use increase, however it requires that Hine test their particle levels to determine an appropriate fan speed under the potentially cleaner conditions.

One other discovery during our study of the facility was that the 99.99% HEPA filters installed in the FPUs were *used* when they were installed; i.e. they were already at least partly loaded (dirty). This actually improves the efficiency of the filter because, during use, the particles fill the pores in the filter media making it even harder for other particles to pass through. However, loading of the filters also makes it more difficult for the air to pass through them (higher filter pressure drop), increasing the amount of energy needed by the fans to recirculate the air. Another consequence of filter age is that they begin to degrade (common problems are sagging, tears, loose framing, etc.) and release particles from stress points. It may be worth investigating the opportunity to replace the filters with new filters to see how particle counts and fan energy are influenced. We suspect that fan energy and particle levels will be reduced, allowing further reductions in fan speed and related energy use. The flexibility of VSD controls makes all of these options possible.

Many cleanroom operators, including projects we evaluated at Applied Materials, Conductus, Exar, and Lam Research, have installed energy saving controls on their recirculation fan systems that are similar to the Hine system. Some have installed VSDs that run at constant speed without scheduling, allowing them to minimize airflow based upon particle counts, but without the need for independent fan control logic. This type of system works especially well for facilities that operate around the clock, where scheduling is not necessary. Still other facilities, like Applied Materials, are taking the Hine scheduling idea to another level by installing occupancy sensors that control VSD speed based upon the activity in the individual clean areas. Rather than fixed scheduling of fan speed, the occupancy sensors detect whether the space is in use and modulate the fans up and down accordingly. In this way, the fans can be reduced any time the cleanrooms are unoccupied, including during normally occupied times. Another innovation for fan speed control that also expands on the Hine system concept is that of real-time particle counting and control of the fans. This system counts particle levels continually and modulates fan speed to maintain whatever cleanliness level is required for the space supplied by each fan. This idea has the potential of tapping into energy savings that few facilities have achieved[1].

[1] For more about this, see "Energy Savings in Cleanrooms from Demand-Controled Ventilation" by David Faulkner, et. al. in the *Journal of the Institute of Environmental Sciences; Nov/Dec 1996, pages 21-27.*

Figure 3: Hine Design Case Study Data Analysis

Hine Design: Variable Speed Drive Control of Recirculation Fans for Class 100 Cleanroom

	Descriptions	*Values*	*Formulas*	*Notes*
A	Total Rated Recirculation Fan Power	140 *hp*		*Design data*
B	Bay 6 Rated Recirculation Fan Power	25 *hp*	-	*Design data*
C	Bay 6 VSD Average Power at Full Speed	8.2 *kW*	-	*Measured*
D	Total Recirculation Fan Power at Full Speed	45.9 *kW*	*A x C / B*	*Assuming all fan motors would operate at the same percentage of their rated power as the motors in Bay 6*
E	Annual Hours of Operation at Full Speed without VSD Control	8,760 *h/y*	-	*Fans must run at all times to maintain positive flow through the HEPA filters*
F	Total Annual Recirculation Fan Energy Use without VSD Control	402,259 *kWh/y*	*D x E*	
G	Bay 6 VSD Average Power at 60% Speed (31.5 Hz)	1.5 *kW*	-	*Measured - normal operating fan speed to maintain particle counts*
H	Predicted Fan Power Reduction at 60% Speed (31.5 Hz)	86%	*1 - [(31.5 Hz) / (60 Hz)]^3*	*Based on the cubic relationship between fan speed (or flow) and power*
I	Actual Fan Power Reduction at 60% Speed (31.5 Hz)	82%	*1 - (G / C)*	*This result indicates a power 2.66 rather than the power 3.0 (cubic) relationship predicted by the theory*
J	Total Recirculation Fan Power at 60% Speed	8.4 *kW*	*A x G / B*	
K	Annual Hours of Operation at 60% Speed with VSD Control	3,546 *h/y*	*(68 h/w) x (52.14 w/y)*	*Fans scheduled to run from 5am-5pm M-F and 6am-10am S-S, every week; i.e 68 hrs/wk*
L	Total Annual Recirculation Fan Energy Use at 60% Speed	29,782 *kWh/y*	*J x K*	
M	Bay 6 VSD Average Power at 15% Speed (0.0 Hz)	0 *kW*	-	*Measured - night and weekend fan speed intended to maintain positive flow through HEPA filters*
N	Total Annual Recirculation Fan Energy Use with VSD Control	29,782 *kWh/y*	*L*	
O	Annual Energy Savings	372,477 *kWh/y*	*F - N*	
P	Average Cost of Electricity	$0.098 *per kWh*	-	*From Hine Design (PG&E billing data)*
Q	Total Electricity Cost Reduction	$36,435 *per y*	*O x P*	
R	Incremental Cost of VSDs and Control System	$55,000	-	*From Hine Design*
S	Project Payback	1.5 *y*	*R / Q*	

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.

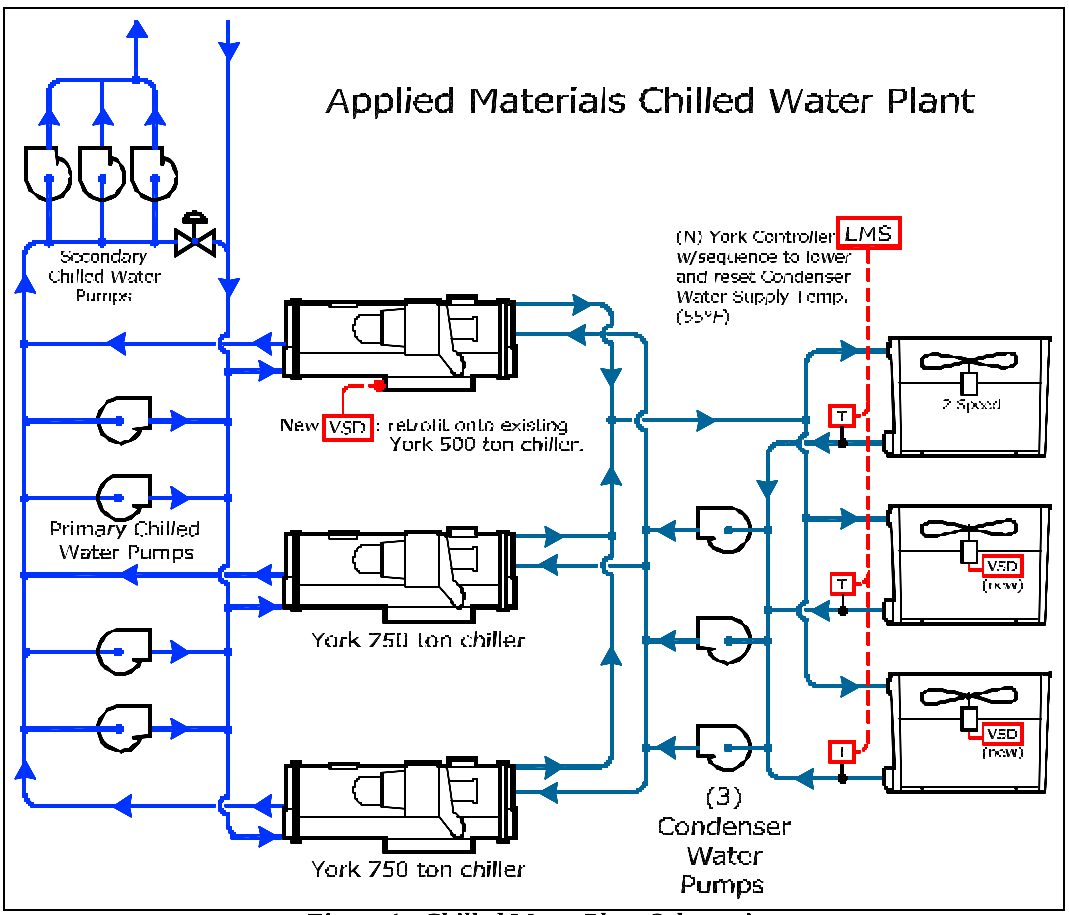


Figure 1: Chilled Water Plant Schematic

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.

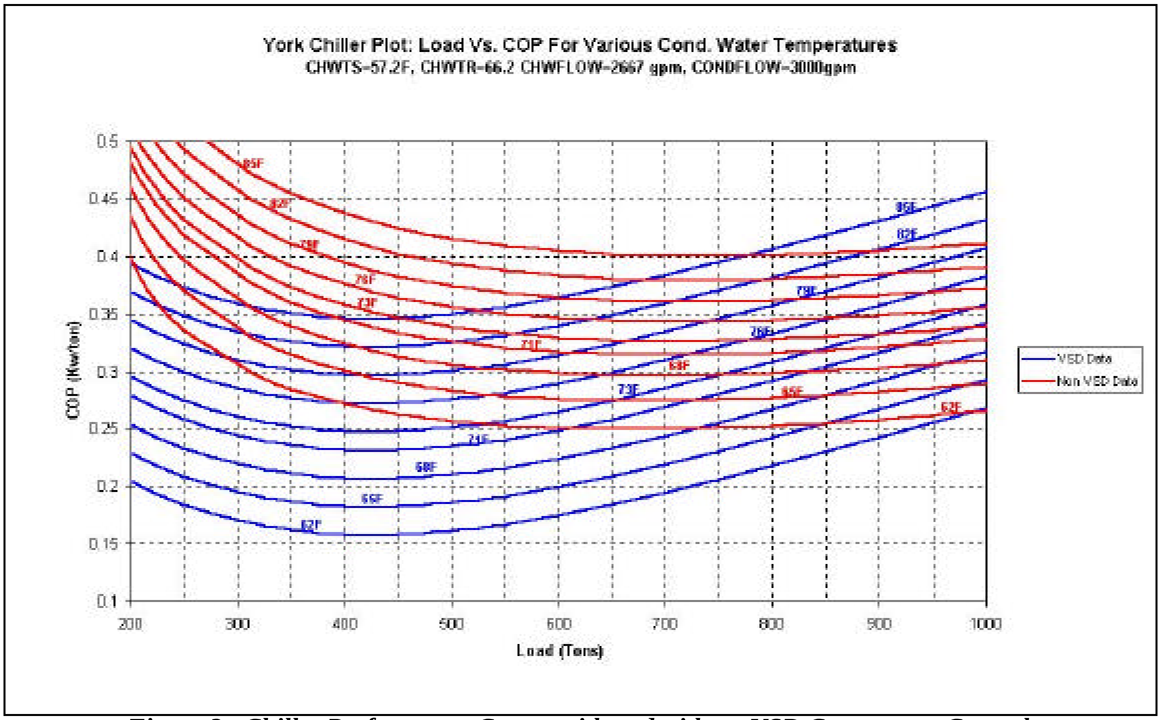


Figure 2: Chiller Performance Curves with and without VSD Compressor Control

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.

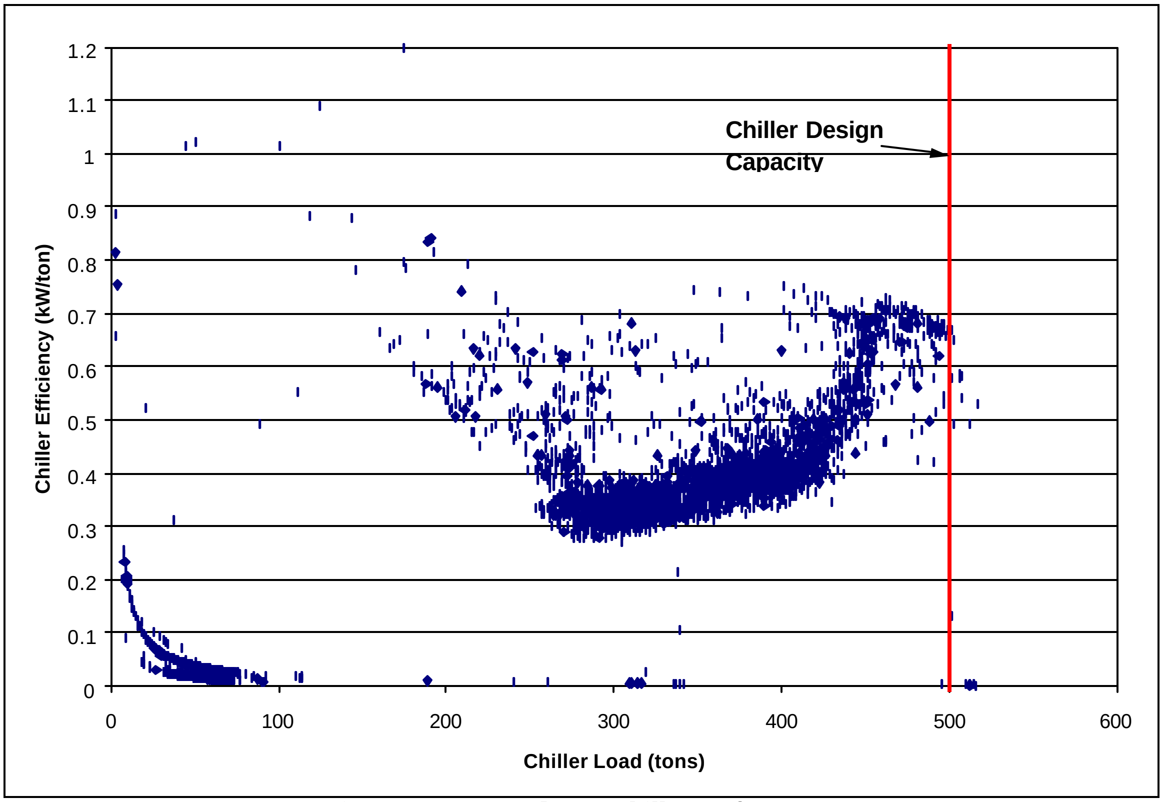


Figure 3: Measured VSD Chiller Performance

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.

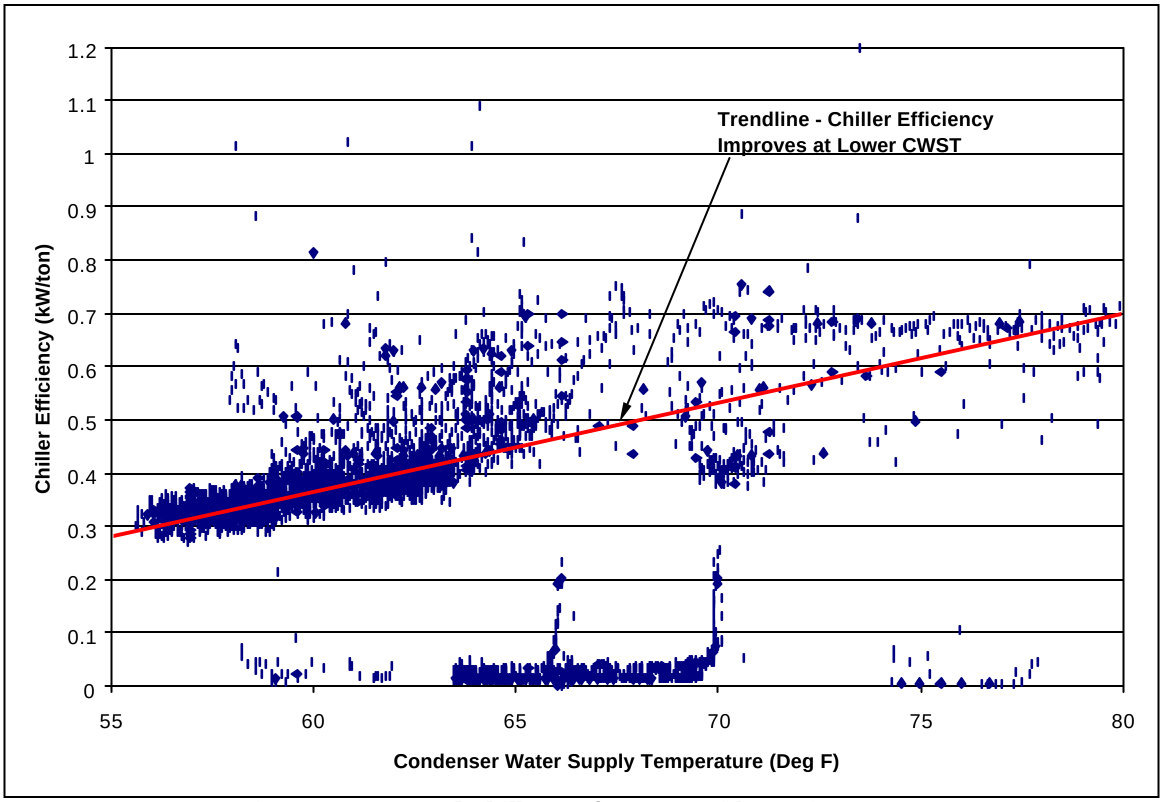


Figure 4: Measured Chiller Performance with Varying CWST

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.

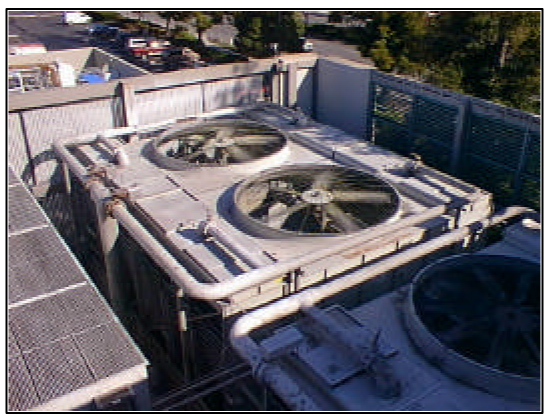


Figure 5

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

Applied Materials: Chilled Water Plant Efficiency Upgrade

	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*	

Motorola: Cleanroom Declassification from Class 10,000 to Class 100,000[2]

Project Benefits Summary

Estimated Annual Energy Cost Savings	***$154,940***
Actual Project Cost	***$89,700***
Project Payback	***7 months***

Facility Description

The Motorola AIEG facility in Northbrook, Illinois is part of the Motorola Automotive and Industrial Electronics Group. The facility includes a 6,700-ft^2 class 10,000 cleanroom used for test and assembly of automotive electronics controllers. The building also contains office space and another production area. A single air handler serves the cleanroom and includes two parallel supply fans and two parallel return fans that supply the cleanroom through ceiling mounted HEPA filters. Each of the fans has adjustable pitch fan blades. Twelve steam humidifiers and thirteen duct-mounted electric reheat coils humidify and reheat the supply air to each room to maintain the 70°F ±2°F dry bulb and 45% ±5% relative humidity setpoints for the cleanroom.

Project Description

The purpose of this project was to reduce operational costs and energy use by reducing the cleanroom classification from class 10,000 to class 100,000. To accomplish this airflow was reduced but the ceiling grid and number of HEPA filters remained the same to allow for future flexibility in the cleanrooms. The facility currently operates at class 100,000 or better. Measures were also implemented to improve temperature and humidity control to reduce unnecessary dehumidifying when the outside air is already below the cleanroom humidity setpoint.

The air handling unit supply volume (return air and outside air) was reduced from 67,000 cfm to approximately 30,000 cfm (10 cfm/ft^2 to 5 cfm/ft^2) by shutting down one each of the supply and return fans. The pitch of the blades on the existing fans were modified to further reduce the airflow and decrease energy use. The supply air temperature setpoint had to be decreased from 67°F to 63.7°F with the reduction in supply airflow because the heat load in the room remained the same. Since dehumidification demand requires the cooling coil to cool the air to 48°F, much less energy is needed to reheat the air to meet the lower supply temperature setpoint. As a result of this improvement, the peak load for reheating the supply air is expected to drop from 412 kW to 150 kW. The actual savings are still being measured but the estimated energy use impacts are shown in table 1.

Table 1 - Estimated Energy Savings

Operation	*Previous (kWh/y)*	*Current (kWh/y)*	*Savings (kWh/y)*
Fan Operation	825,700	130,700	695,000
Reheat During Cooling	1,795,100	549,000	1,246,100
Cooling	615,800	301,600	314,200
Heating	557,700	314,000	243,700

There are huge energy savings due to the reduction in fan power and and reheating of the supply air. Obviously, turning fans off saves energy, but adjusting the pitch of the fan blades also contributes to the energy savings. When the pitch of the blades is modified, the fan will only be able to supply the amount of air required and motor energy can be minimized. Adjusting blade pitch also results in a change in fan efficiency (up or down, depending upon the original blade position), however this impact is small relative to the overall reduction in motor power required to deliver less air.

[2] Based on “Motorola AIEG, Northbrook, Illinois, Cleanroom Conversion Study.” Prepared by Black &Veatch ATD; April 29, 1999.

More precise control of cooling coil dehumidification was achieved by installing a dewpoint sensor after the cooling coil. When the outdoor air dewpoint is below 45°F (the room setpoints require a dewpoint of about 48°F) during cool, dry seasons like spring and fall, the air does not need to be dehumidified. Adjustment of control of the cooling coil to only cool the air down (if cooling is needed) to meet the required 70°F dry bulb temperature setpoint then saves by reducing the energy needed to cool the air all the way down to 48°F and reducing the energy needed to reheat the air back up. This control also prevents unnecessary dehumidification by the cooling coil that, in turn, requires more steam to raise the relative humidity of the air to the required 45% setpoint.

Applicability to the Cleanroom Industry

Significant energy was saved on this project because all of the recirculated and outside air is dehumidified and reheated. Therefore, a 50% reduction in airflow not only reduces fan energy but also greatly decreases the amount of energy needed to condition the smaller quantity of air. The energy use benefits of changing cleanliness classification are vividly demonstrated by the work at Motorlola. However, very few facilities are capable of changing cleanliness classification. It is worth considering primarily for facilities that have modified operations to include less sensitive processes or in facilities where the original classification has proven far cleaner than is actually required for the manufacturing process that was implemented. The Motorola facility is quite small and this type of conversion is likely to be much more costly for a large facility, however, the energy use benefits are so large, that it is likely to be a worthwhile investment with a very short payback even in the largest facilities.

Typically, cleanroom HVAC systems use separate makeup air and recirculation units and only the makeup air from outside needs to be conditioned. This method is much more efficient because only the makeup air is dehumidified and reheated to meet the appropriate temperature and humidity setpoints when mixed with the recirculation air. Since the recirculation air is already close to the room setpoints (typically slightly warmer), it can provide a large portion of the heating needed for the makeup air when the air mixes and the amount of reheat required for the makeup air can be further reduced.

Genentech: New Energy Efficient Pharmaceutical Manufacturing Cleanroom Facility[3]

Project Benefits Summary

Estimated Annual Energy Cost Savings	$552,800/y
Actual Incremental Project Cost	$1,783,360
Utility Incentive	$842,400
Project Payback (after incentive)	1.7 years

Facility Description

The Genentech Vacaville facility is made up of six buildings in Vacaville California. This is the second site for Genentech, the first site is located in South San Francisco, CA. Genentech is a leading biotechnology company that discovers, develops, manufactures and markets human pharmaceuticals for significant unmet medical needs.

The site's six buildings include:

1. 180,000-ft^2 Bulk Manufacturing Building with class 10K and 100K cleanroom areas and 10 air handling units (approx. 400,000 cfm)
2. 18,000-ft^2 Central Utility Plant with 3,400 tons of chilled water, 3,000 scfm of compressed air, 14,000 gpm of tower water (process and HVAC), and 70,000 lb/hr of high pressure steam
3. 40,000-ft^2 Lab/Administration Building
4. 30,000-ft^2 Warehouse
5. 20,000-ft^2 Facilities Service Building
6. A "spine" connecting all of the buildings together

Figure 1 – Bulk Manufacturing Building

The energy saving measures for the site were aimed at the entire facility. However, this study focuses only on measures that affect the cleanroom areas. In addition to internal production requirements, these areas are required to comply with Food and Drug Administration (FDA) regulations for cleanliness because the facility is intended for the production of pharmaceuticals.

Project Description

A total of twenty-two separate energy efficiency measures were performed at the Vacaville site. These measures are summarized below with a mention of estimated energy savings. The estimated savings were calculated by Genentech's energy consultant, Southern Exposure Engineering based upon baseline and enhanced energy consumption models. No measured data is currently available for these measures.

Key aspects of the energy efficiency project

DISCHARGE AIR TEMPERATURE RESET (MAKEUP AIR HANDLERS)
Control logic was implemented to reset the discharge air temperature up from 55°F to 60°F when the demand for cooling decreases. This leads to a reduction in energy use because the makeup air is not cooled all the way down to 55°F. All of the cleanrooms are regulated by the FDA, which requires that they be

[3] Based on "Recommendations Report, Volume 1 of 2, Genentech, Inc., New Facility, Vacaville, CA." Prepared by Southern Exposure Engineering and Pacific Gas and Electric Company; November 21, 1997.

supplied with a constant volume of makeup air. This temperature reduction prevents overcooling and subsequent unnecessary reheating of the supply air to the space, thereby saving chilled water and steam plant energy. This measure is expected to have annual energy cost savings of about $155,000/y and a reduction in peak electrical load of about 19 kW.

VARIABLE SPEED DRIVES FOR THE VARIABLE VOLUME AIR HANDLERS

Instead of inlet vanes for the supply and return fans, variable speed drives (VSDs) were installed on the six variable volume air handlers throughout the building including one serving the cleanroom. The VSDs reduce the horsepower of the fans to reduce flow, whereas inlet vanes reduce the flow by increasing pressure drop while the fans are still running full speed. VSD operation reduces fan motor energy use more than vanes do at low flow conditions. The annual energy cost savings are expected to be about $23,000/y with a reduction in peak load of about 40 kW.

HIGH EFFICIENCY BOILERS AND BOILER ECONOMIZERS

High efficiency boilers were installed as well as boiler economizers. The boiler stack economizers recover waste heat out of the flue gas, allowing more steam generation using the same amount of fuel. Together these measures are expected to have annual energy cost savings of about $48,700/y.

TOWER WATER FOR PROCESS COOLING

Water from the cooling towers is being used for high temperature processes that do not need the low temperatures provided by the comparatively less efficient chillers, which operate at 0.5 kW/ton efficiency, at best. The cooling towers are able to provide cooling at about 0.04 kW/ton (an order of magnitude improvement in efficiency). The cooling towers provide 75°F water for processes that do not require 40°F chilled water such as pasteurizing and cooling for the water for injection (WFI). This measure is expected to save about $62,700 annually and reduce peak load by about 455 kW.

PROCESS CHILLER WITH A SURGE TANK

A dedicated process chiller was installed in manufacturing building to provide the low temperature processes with 40°F water instead of using the chilled water from the central utility plant. A surge tank was also installed for chilled water storage to reduce the peak electric demand. The surge tank holds 15,000 gallons and provides approximately 600 ton-hours of thermal storage. Large energy savings also come from this separation of low temperature loads from the higher temperature loads. This allows the central plant to operate at 44°F, instead of 40°F, resulting in a significant improvement in its efficiency. The low temperature chiller and surge tank are expected to save about 152,000 kWh annually and reduce peak loads by about 560 kW, results in cost savings of about $36,000/y.

Figure 2 – Surge Tank

HIGH EFFICIENCY EQUIPMENT AND UNEQUAL CHILLER SIZING

A high efficiency process chiller and high efficiency central plant chillers, vacuum pumps, and motors were installed. In an effort to operate the chillers as close to full load as possible, where they are most efficient, a 600 ton chiller and two 1,400 ton chillers were selected instead of three 1,134 ton chillers. This unequal sizing method saves energy by allowing the chillers to stage up in smaller steps and operate much closer to full load. The two large chillers are run at full load while the smaller one can be run to supply any additional cooling that is needed. By selecting high efficiency equipment and unequal sized chillers, about $113,250 will be saved annually with a reduction in peak load of 296 kW.

LOW APPROACH COOLING TOWERS

Large cooling towers were installed to reduce the approach from 14°F to 8°F above the design wet bulb temperature of 71°F. In addition, the spray nozzles were reconfigured to spread the condenser water more evenly over the fill while allowing the flow to better match the required flow for the chillers. This modification of the nozzles allowed the approach to drop even further down to 4°F. There was an increase in cooling tower fan power from 102 kW to 167 kW, however, much more energy was saved by providing the chillers with cooler condenser water, which improves the ability of the chiller to reject heat. This reduction in condenser water temperature in expected to improved the efficiency of the large chillers from 0.62 kW/ton to 0.49 kW/ton (0.013 kW/ton per °F decrease in condenser water supply temperature). This measure is expected to save about $24,000 annually with a decrease in peak load of 70 kW.

Figure 3 - Cooling Towers

PUMP VARIABLE SPEED DRIVES

VSDs were installed on the condenser water pumps, primary chilled water pumps, secondary chilled water pumps, tertiary chilled water pumps, and heating water pumps. The VSDs save energy by precisely matching the flow and the pressure requirements of the system to minimize pump energy. These drives will save approximately $36,900 annually and will reduce the peak demand by 140 kW.

Applicability to the Cleanroom Industry

These efficiency measures have not inhibited Genentech from complying with strict FDA regulations for pharmaceutical plants. The plant it is expected to operate and more reliably with these modifications and, because the project had an excellent payback of 1.7 years, after the utility incentive, it will be more profitable to operate in the long run. One example of improved reliability is the surge tanks, which guarantee that process chilled water will be available when needed in case of a shutdown.

Part of the reason that this project was so successful was that the measures could be implemented in the development phases of the plant before any equipment was purchased or installed. Energy efficiency measures implemented in a new building can achieve greater and more cost-effective savings than retrofit measures implemented in existing buildings.

Project Challenges

Genentech encountered a number of challenges while trying to implement energy saving measures for this project. In a concerted effort to maintain the goal of efficient operation, Genentech worked through solutions to most problems they encountered. Some of these problems are common in the cleanroom industry and their solutions should be instructive for other facility operators and planners. The first problem was that no review period was scheduled for analysis of the energy saving alternatives. These reviews were to be included in the overall design review period, where they would probably fall through the cracks. To solve this problem, the energy consultant was integrated with the design team to provide quick feedback on ideas and recommendations to improve energy use during the design process. Secondly, no defined budget was allocated for development of energy saving ideas at the beginning of the project. However, money for actual projects was included in the overall project budget. The solution was to obtain utility funding for idea development and analysis and with utility incentives for ideas that resulted in a payback of greater than two years. A third challenge to successfully capturing the savings from energy efficiency measures lies with the building operations staff. This is being addressed through education, training and awareness of the original design intent.

Lawrence Berkeley National Laboratory
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Proceedings

SECTION G

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

BARRIERS TO IMPLEMENTATION OF ENERGY EFFICIENCY MEASURES

In this exercise, participants were given a list of barriers previously identified through LBNL's participation with industry, research organizations, and Universities. Many of these barriers were previously identified in LBNL's report "Energy Efficiency in California Laboratory type facilities". The participants were asked to brainstorm and add any additional issues that they felt hindered implementation of energy efficient measures. The following lists represent the groups understanding of the barriers. These have been grouped into economic, regulatory, "inertia", and practical considerations. Once agreement on the barriers was obtained, the group then voted on the most significant barriers. This identified the following issues as the most significant:

Insufficient time and/or fee – The group felt that most projects are under very tight schedule and capital budget constraints. This often precludes studying options to improve energy efficiency.

Capital Budget Approval - The participants felt that obtaining capital budget for energy efficiency improvements was a barrier.

First vs. Operational Cost - The group discussed issues relating to capital cost versus operating (expense) cost. Issues of first cost emphasis rather than life cycle cost were identified.

Uncertain Room Use - The participants identified a frequent problem in both semiconductor and biotechnology cleanrooms in that the room use and corresponding loads for sizing equipment are often unknown when a project begins. They are not identified until after key sizing decisions need to be made to support schedules.

The Group then brainstormed possible solutions to these barriers. The resulting group input is attached as "Solutions to the Most Significant Barriers."

Economic Issues:

E1 Obtaining Capital Budget approval

E2 Accounting for Capital Cost versus Operating Cost

E3 Short payback required (2 years or less)

E4 Energy cost a small % of total production value

E5 Emphasis on first cost versus on-going operating cost

E6 Design and construction fees and financing structure emphasizes short term

E7 Uncertainty of changing economics for base business

E8 Way Energy is accounted for

Regulatory Issues:

R1 Mandated flow rates: e.g. 100 ft./min. exhaust; 4 cfm/sq. ft. , etc.

R2 Insurance Company requirements: bonus for increased exhaust, redundancies, etc.

R3 Government interpretation of current Good Manufacturing Practices (cGMP) will not allow changes.

R4 Fear of regulation limits sharing of data

R5 Prescriptive Standards versus performance standards

R6 Uncertainty

R7 Use of wrong metric

R8 Environmental Regulation works in reverse

R9 R3 – industry perception

<u>"Inertia" Issues:</u>

I1 That's the way we always do it

I2 Insufficient time and/or fee to consider alternatives

I3 Decisions made early in design and no time or too costly to change

I4 Out of date design standards or available vendor options

I5 Replication of existing buildings/ designs

I6 Lack of education for Designers

I7 Lack of education for Operators

<u>Practical Issues</u>

P1 Availability of equipment/components

P2 Incremental buildout

P3 Future use uncertainty/flexibility

P4 Standardize spare parts/ equipment

P5 Proprietary issues – inability to share best practices

P6 Lack of technical basis for fine tuning

P7 Cleanroom Protocol limits trade off opportunities

P8 Uncertain room use / tool set

Solutions to Most Significant Barriers

Inertia Issue – Insufficient Time and/or Fee

-Planning early

-Convincing owners

-All players on board

-Complete decision chain

-Fee for performance ±

-Third party energy efficiency analysis

-Define energy efficiency requirements in the RFP

-Better, faster, cheaper analysis tools

-Clearer design goals

-Experience & knowledge of design firms

Economic Issue – Capital Budget Approval

-See previous pages

-"Capital Savings"

-Show energy cost as a line item

-Roll energy efficiency upgrades into other upgrades

-Capture multiple benefits of energy and non-energy

-Provide industry-wide information

–Energy efficient fund for design services, or equipment

Solutions to Most Significant Barriers

Economic Issue – First vs. Operational Cost

-Tax laws regarding depreciation and expensing

-Systems approach for energy efficiency

-Energy Efficiency can result in lower first cost

-Creative financing

  -Rebates

  -Shared Savings

  -Guaranteed /

  -Outsourcing

-Metrics $/ft^2 as designed Vs. $/ft^2 as operated

-Focus on Non-energy benefits - reliability

-Capitalize operation up front

-Focus on operations

-Database of building operating parameters

-Learning from previous plants – provide feedback to designers

Practical issue – Room Use/Tool Set Uncertainties

-Design for flexible or questionable use

-Get owners and suppliers to decide earlier

-Reduce penalty for oversizing

-Reduce chiller delivery time, to match actual design load

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SECTION H

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

PARTICIPANTS PRIORITY RANKING FOR
Research and Development

Participant: ***1***

- **Issue 1:** Documenting (measuring) non-energy benefits.
- **Issue 2:** Decision-making research – how and why are energy projects approved or disapproved.
- **Issue 3:** Diffusion of innovation – how new energy projects/products are transferred within companies and across companies. Replicability?
- **Issue 4:** Operator training and certification.

Participant: ***2***

- **Issue 1:** Cleanroom/H-6 air monitoring for hazardous/contaminating chemicals/vapors as method of control of minimum exhaust rates, to allow for reduction in continuous makeup air requirements.
- **Issue 2:** Bigger emphasis on the importance of design and research/evaluation of alternatives.
- **Issue 3:** Accurate data for tool heat loss for better sizing of equipment.

Participant: ***3***

- **Issue 1:** Parametric data on utility consump tion for various microelectronics products (processors, dram, etc). Emphasis on electrical power.
- **Issue 2:** The level of acceptance of mini-environment technology within the microelectronics industry. Evaluation of first cost of mini's versus the energy savings and corresponding reduction in first cost of the air management system.
- **Issue 3:** Minimization of exhaust.

Participant: ***4***

- **Issue 1:** Research on what considerations other than financial ($$ savings) may sway decision makers to implement energy efficiency – how do you sell it?
- **Issue 2:** Quantify social benefits of energy efficiency – why should they do it?
- **Issue 3:** Case studies of min/max airflow rates for various designs and actual cleanliness achieved – what others have done.

Participant: ***5***

- **Issue 1:** Real air change rates for clean room design

- **Issue 2:** What will it take to transform the industry away from cost driven savings/opportunities?

- **Issue 3:** Chiller plant optimization studies

Participant: 6

- **Issue 1:** Identification of standard metrics for tools and types of facilities.

- **Issue 2:** Ways of reducing wasted energy by reusing it in other parts of the process plant.

- **Issue 3:** Education for designers and owners of clean rooms.

- **Issue 4:** How to market energy savings versus capital costs.

Participant: 7

- **Issue 1:** Process Energy Model – this model would provide a generalized perspective on things like: Energy/Process step by type, Heat rejection to (by area), etc.

- **Issue 2:** Low energy, high volume abatement emissions research for VOC's, HAP's and maybe PFC's.

- **Issue 3:** Fab scale energy model

Participant: 8

- **Issue 1:** Non-energy benefits – Identify the NEB's from energy projects. Quantify their impacts. Develop case study materials. Recruit suitable allies to help communicate results, e.g. insurance carriers (build on E. Mills work).

- **Issue 2:** Energy efficiency performance measurement, metrics. Expand IMPS work to define appropriate measurement system, quantify costs and benefits. Find early adapter to work with.

- **Issue 3:** Lots of great research ideas!

Participant: 9

- **Issue 1:** Federal and state financial incentives for energy.

- **Issue 2:** Better tool electrical load – operational cycle and heat rejection load.

- **Issue 3:** Establish a credible set of metrics – develop financial incentive package to "motivate" compliance and upgrades – federal and/or state funded.

Participant: 10

- **Issue 1:** Identification of non-energy productivity or environmental improvements that carry energy efficiency benefits.

- **Issue 2:** Operational data to support convincing arguments for energy efficient technology and operating practice investments, through first-principal simulation, demonstrations, baseline/benchmarking studies, etc.

- **Issue 3:** Mapping and evaluation of relative worth of issues versus technologies and applicability to various plant configurations and operations.

- **Issue 4:** Map decision process for technology adoption and pinpoint the steps with the greatest opportunity for encouraging adoption and how.

Participant: 11

- **Issue 1:** Cleanroom tools – vendor standards heat gain to space and how it is removed lower exhaust air required and safety level for workers to discharge levels of %HPM.

- **Issue 2:** Cleanroom air flow rates – number of air changes versus particle count pollution abatement levels mini-environments for C1-10 and lower.

- **Issue 3:** Cleanroom lighting levels – heat gain to space.

Participant: 12

- **Issue 1:** Fab energy pareto diagram without interruption of manufacturing.

- **Issue 2:** Optimization of cleanroom temperature, humidity and pressurization control.

- **Issue 3:** Non-intrusive analysis of manufacturer tool energy pareto diagrams of "real" tools.

- **Issue 4:** Risk and/or reliability analysis tools to help quantify benefits of energy efficient projects.

Participant: 13

- **Issue 1:** Metrics – Create a small set of metrics and gather as much data as possible and share kw/ton, cfm/kw, cfm/kw, gpm/kw

- **Issue 2:** Targeted project for small cleanrooms

- **Issue 3:** Research on the need for primary/secondary pumping systems and /or low face velocity design – create fundamental design philosophy change.

- **Issue 4:** Technology adoption

Participant: 14

- **Issue 1:** How do we create incentives for equipment (and tool) manufacturers to create and/or promote use of smaller, more efficient equipment, e.g. chiller manufacturers would rather sell you a big (over-sized) chiller.

- **Issue 2:** Need to know more about actual operating costs of facilities.

- **Issue 3:** Desperately need to give emphasis to small cleanroom operators – they make up at least a factor of 10 more of the companies who operate cleanrooms.

Participant: ***15***

- **Issue 1:** Move the line between design and construction to allow significantly more effort, at the earliest possible stage, in energy efficient design. Frustrated by numerous projects wither because design has moved past the stage where energy efficiency can be implemented in design and/or where resources are no longer available to perform design development and analysis.

- **Issue 2:** Heat recovery from exhausts – heat pipes, thermal wheels, run-around systems. Potential for energy savings are significant. Resistant to changes in design concepts.

- **Issue 3:** Air flow rate reductions based on instrumental controls. Blind reliance on standard rates. Measure particles – change standards, educate insurers.

Participant: ***16***

- **Issue 1:** How-to incentive-ize energy-efficient design and operation

- **Issue 2:** Better integration of process and facility design for resource efficiency.

Participant: ***17***

- **Issue 1:** More efficient cleanroom process tool energy use (electrical energy and exhaust air/make-up air needs).

- **Issue 2:** Cleanroom class versus product yield. Is it possible to reduce class or reduce clean room support areas class and not greatly effect yield versus gowning and personnel tool cleaning protocols. Yield versus airflow velocity Hepa coverage, Hepa type, etc. (also mini-environments).

- **Issue 3:** Cleanroom performance metrics.

Participant: ***18***

- **Issue 1:** Intuitive, easy-to-use, power research stations with expandability and expansive installed applications programs.

- **Issue 2:** Semi-conductor tool power research to become a mature science, not only to increase efficiency but to strengthen tool sets.

- **Issue 3:** Tight specifications all tool and infrastructure.

Participant: ***19***

- **Issue 1:** Modeling fab.

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