Title

Cleanroom Energy Efficiency Workshop

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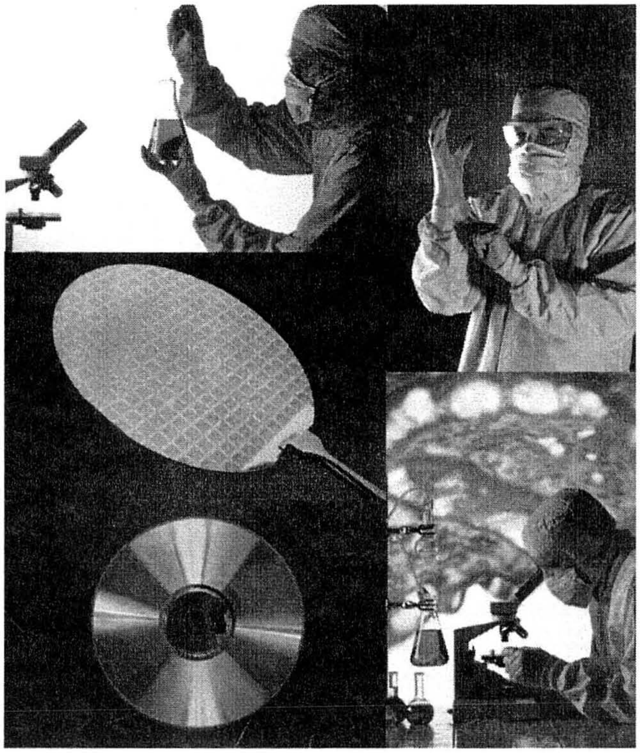
Environmental Energy Technologies Division

Cleanroom
Energy Efficiency Workshop



Proceedings

Berkeley, California
March 15, 1999

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

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Contents

Lawrence Berkeley National Laboratory
Environmental Energy Technologies Division

Cleanroom
Energy Efficiency Workshop

Proceedings

SECTION A

ERNEST ORLANDO LAWRENCE
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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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Cleanroom
Energy Efficiency Workshop

Proceedings

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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Environmental Energy Technologies Division

Cleanroom
Energy Efficiency Workshop

Proceedings

SECTION C

ERNEST ORLANDO LAWRENCE
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March 15,1999

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Environmental Energy Technologies Division

Cleanroom
Energy Efficiency Workshop

Proceedings

SECTION D

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Welcome to
Lawrence Berkeley National Laboratory

Workshop on Energy Saving Opportunities in Cleanrooms

March 15, 1999

Environmental Energy Technologies Division

A Word About Attendees

- Research
- Semiconductor
- Biotechnology
- National Laboratories
- Tool Manufacturers
- Design Firms
- Energy Analysis Firms
- Utilities
- Sponsors

A Word About Our Sponsors

- California Institute for Energy Efficiency
- California Energy Commission

Purpose of Today's Workshop

- Increase Awareness of Energy Efficiency Opportunities
- Share Information
- Help Develop Research/Market Transformation Agenda
- Identify and Eliminate Barriers
- Add Value to Industry's Energy Reduction Efforts

Goals for the Workshop

- Open Exchange of Information
- Stimulate Further Action
- Expand Network for Energy Efficiency
- Recognize Successful Case Studies
- New Ideas for Advancements
- Establish Collaboration Partners

Today's Agenda

8:00-8:30	Arrive at parking garage/ Shuttle to lab
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	Barriers 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

FIGURE XIII-2b: SUMMARY of TOTAL SPACE IN USE for 2000 - UNITED STATES (sq. ft. x 1000)

Category	Class 1–10	Class 100	Class 1,000	Class 10,000	Class 100,000	Total
Aerospace	46.35	139.05	92.70	185.40	463.50	927.00
Automotive & General Applications	66.06	154.14	220.20	440.40	1,321.20	2,202.00
BioClean	0.00	77.40	51.60	51.60	77.40	258.00
Disk Drives	66.15	66.15	132.30	88.20	88.20	441.00
Flat Panels	227.10	227.10	333.08	302.80	423.92	1,514.00
Food	0.00	75.35	226.05	452.10	753.50	1,507.00
Hospitals	0.00	592.00	148.00	296.00	444.00	1,480.00
Medical Devices	0.00	294.75	196.50	294.75	1,179.00	1,965.00
Other Electronics	0.00	68.15	204.45	408.90	681.50	1,363.00
Pharmaceuticals	0.00	930.60	620.40	620.40	930.60	3,102.00
Semiconductor Suppliers	281.33	23.35	70.33	46.98	46.98	468.97
Semiconductors	5,626.50	467.00	1,406.63	939.63	939.63	9,379.38
TOTAL	6,313.49	3,115.04	3,702.24	4,127.16	7,349.43	24,607.34

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Environmental Energy Technologies Division

Cleanroom
Energy Efficiency Workshop

Proceedings

SECTION E

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Workshop on

Cleanroom Energy Efficiency

Sponsored by

Lawrence Berkeley National Laboratory

15 March 1999

"Energy Efficiency and Benchmarking Overview"

Chris Robertson

Chris Robertson & Associates

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This work supported in part by the Northwest Energy Efficiency Alliance

Northwest Energy Efficiency Alliance

- Non-profit corporation focused on energy efficiency market transformation -- "The Alliance"
- Idaho, Montana, Washington, Oregon electric utilities, state, environmental and energy industry business interests
- 18 directors, $60+ million budget, > 45 projects
- Semiconductor and electronics industry focus of several projects

More information about the Alliance:
Jeff Harris or Blair Collins 503-827-8416
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Objectives

- Alliance interests in energy efficiency performance measurement system, related metrics, data visualization; and collaborative project funding
- Overview recent industry history of energy efficiency performance measurement, analysis and benchmarking
- One company's clean room energy efficiency opportunities and why important to senior management
- Suggest energy efficiency performance measurement as a requirement for successfully capturing the efficiency resource and also a useful research issue
- Comment on organizational and institutional issues

Alliance's Interests -- Clean Room Energy Efficiency

- Commitment to help facilitate growth of advanced resource efficiency through "market transformation" strategies, primarily in electronics industry
- Co-funding for a small number of strategic projects with companies with shared interests (N = 6-10)
- Interests focused on projects w/ PNW leverage
- Project development aimed at energy efficiency performance measurement, facilities systems integration, improved operations and design, high reliability power supply
- Tool and process load improvements

Recent Semiconductor Industry Energy Efficiency Activity

- NWPPC Workshops with Lee Eng Lock, SUSA, 1995-96
- Western Digital (SUSA) clean room AEE Energy Project of the Year, '96
- SEMATECH International Energy Project, 1997 - 1999
- LBNL/CIEE California market research and lab design guide 1987
- Tool vendors requested to provide accurate measured data, 1997-98
- Alliance Microelectronics Energy Efficiency Project, 3/98-3/00
- STM revisions to Environmental Decalogue goals, 3-12/98
- Nikei Microdevice Seminar -- M Duffin on Green Tools, 5/98
- APEC Forum "Cleaner Production in Electronics Mfctr" 5/98
- World Semiconductor Council Executive ESH Summit, 7/98
- CEBSM "Negawatts for Fabs" AB Lovins, 8/98
- SEMI Call for Papers -- Env. Improvements in Tools, 7/99
- Alliance workshop on energy performance metrics & measurement, 1/99

STM AMK Project Summary
(Investment and savings in K US$)

	Investment	Savings	Payback
Total Projects	$2,071	$2,190	.95
Largest	$1,044	$790	1.32
Smallest	$0	$0.3	--
Fastest	$1.0	$30.0	.03
Slowest	$104	$34.5	3.01

1991 - 97 cumulative savings
$30.2 million
370,000 tons carbon dioxide
(@ $5/ton CO2 emission deal pays for the efficiency investment)

STM -- Beyond AMK

1998 -- Technical analysis and evaluation at 6 sites vintage -- new to 40 years old

- Found 20-30 projects per fab
- 1/3 payback < 1 year
- 1/3 in 1-2 yr.
- 1/3 in 2-4 yr.
- Average 18 month

System wide expect US $50 million/yr savings

STM's estimated financial value of advanced energy efficiency strategy

- US $50 million/yr to bottom line
- About 30 cents/share or
- ~ 10% bump in current EPS
- Equal to increased sales of US$ 500 million/yr at present 10% profit margin

STM Strategic Energy and Environmental Goals

- **Reduce CO_2 per chip in next generation plants by 75 percent** (J Romm, Cool Companies, Island Press, '99)
- **Improve efficiency in each plant**
- **Move rapidly toward "carbon-neutral" using energy efficiency and green power**
- **Vision 2000 Initiative -- "To be 'best-in-class' in environmental protection"** - Pasquale Pistorio, CEO
- **"Benchmark against perfection"**
  (Womack and Jones, Lean Thinking, Simon and Schuster, 1996)

Energy Efficiency Opportunities

- **Ubiquitous -- every factory & system should be assumed to have significant opportunity**
- **Some opportunities large, some small**
- **Often interactive, synergistic ... systems perspective and sequence matters**
- **Collectively large in each factory we've examined**
- **Valuable**
- **If not well measured, value left on the table**

Energy Efficiency Performance Measurement

- **"What gets measured gets managed." foundation for continuous improvement**
- **supports company learning curve as personnel change**
- **key to achieving deep and lasting savings**
- **FMCS (designed to maintain temperature and humidity specs) usually inadequate to measure energy efficiency**

Energy Efficiency Performance Measurement System Qualities

- **Reliable and stable over time**
- **Accuracy commensurate with value of information**
  (mag flow meters for cube law loads;
  thermistors for small delta T)
- **Cost-effectiveness from systems perspective**
- **Provide data to support continuous improvement**
- **Document energy performance**
  baseline versus improvements
  data archive

Measurement to Provide Feedback, Comparisons

- to facility managers to optimize plant operations
- to plant operators to diagnose out of spec condition
- to the firm's facility management group, via intranet, to compare strategies from fab to fab
- to CFO to evaluate economic performance of efficiency investments, cost control, capital budgeting
- to designers and specifiers to optimize next plant design (require, design, build, *measure, analyze, improve,* repeat)
- to groups of companies, via internet, to benchmark and compare fab-fab, company-company

Benefits of Energy Efficiency Performance Measurement System

Improves ...	Reduces ...
Operator effectiveness	Operating costs
Maintainability	Maintenance costs
Plant reliability	Unplanned outages
Equipment life	Capital additions
Next plant design	Capital cost for next plant
Environmental compliance	Post-Kyoto exposure

Non-energy benefits likely greater than energy bill savings

Profit from Kyoto Protocol

- Add economic value to efficiency improvements by sale of CO_2 offset credits
- Deals available now at US $5 to $7 per ton CO_2
- Translates to ~ 1/2 cent per conserved kWh
- Deals with better documentation (measurement!) have greater value than those supported by estimated savings
- Is your wasted energy for sale?

Cultural and institutional change issues are more difficult than engineering issues

Price Waterhouse -- about complex technical issues
70% institutional; 30% technical

Strategic benefits cross-cut the organization

How to turn facilities function into profit center?
(50% fab electricity can be converted to profit at >30%/y ROI; Ron Perkins)

How to structure strategic improvement projects with energy use reduction benefits?

How to maintain and grow institutional learning curve?

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Environmental Energy Technologies Division

Cleanroom
Energy Efficiency Workshop

Proceedings

SECTION F

ERNEST ORLANDO LAWRENCE
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northern Pacific
Mechanical & Engineering, Inc.

3/15/99

Enclosed is a package containing copies of today's presentation as well as a copy of the Case Study of the clean room systems at Hine Design and a copy of an article from ASHRAE (American Society of Heating Refrigeration and Air Conditioning Engineer) about application of VFDs to motors.

NPME takes great pride in its engineering accomplishments and we hope that you may find interest in the application of VFDs to your clean room.

Sincerely,

Ken Martin, PE
president

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Drives

- Variable Frequency Drives control 3 phase motor speed
- Variable Frequency Drives save fan energy
- Variable Frequency Drives increase control
- Variable Frequency Drives are 95% to 98% efficient
- Variable Frequency Drives need consideration

Goals of System Design

- Maintain good system performance
- Provide best system efficiency
- Allow for interface by User

Fans use much less energy at lower speeds

- Because clean rooms use air paths that are fixed in dimension and shape, the fan power reduction is clearly know for reductions in system flow rate.

Air flow may not need to be so high

- Many clean rooms use flow rates that are much higher than needed.
- Many air handling designers over design system
- Design values generated by ASHRAE and DOD are often conservative.
- Power usage by clean room fans is often double what is necessary

Why take a chance! Enjoy both worlds with high fan power, lower energy usage and upgraded control

- VFD application can allow for full air flow
- VFD application can allow for controlled air flow above or below design.

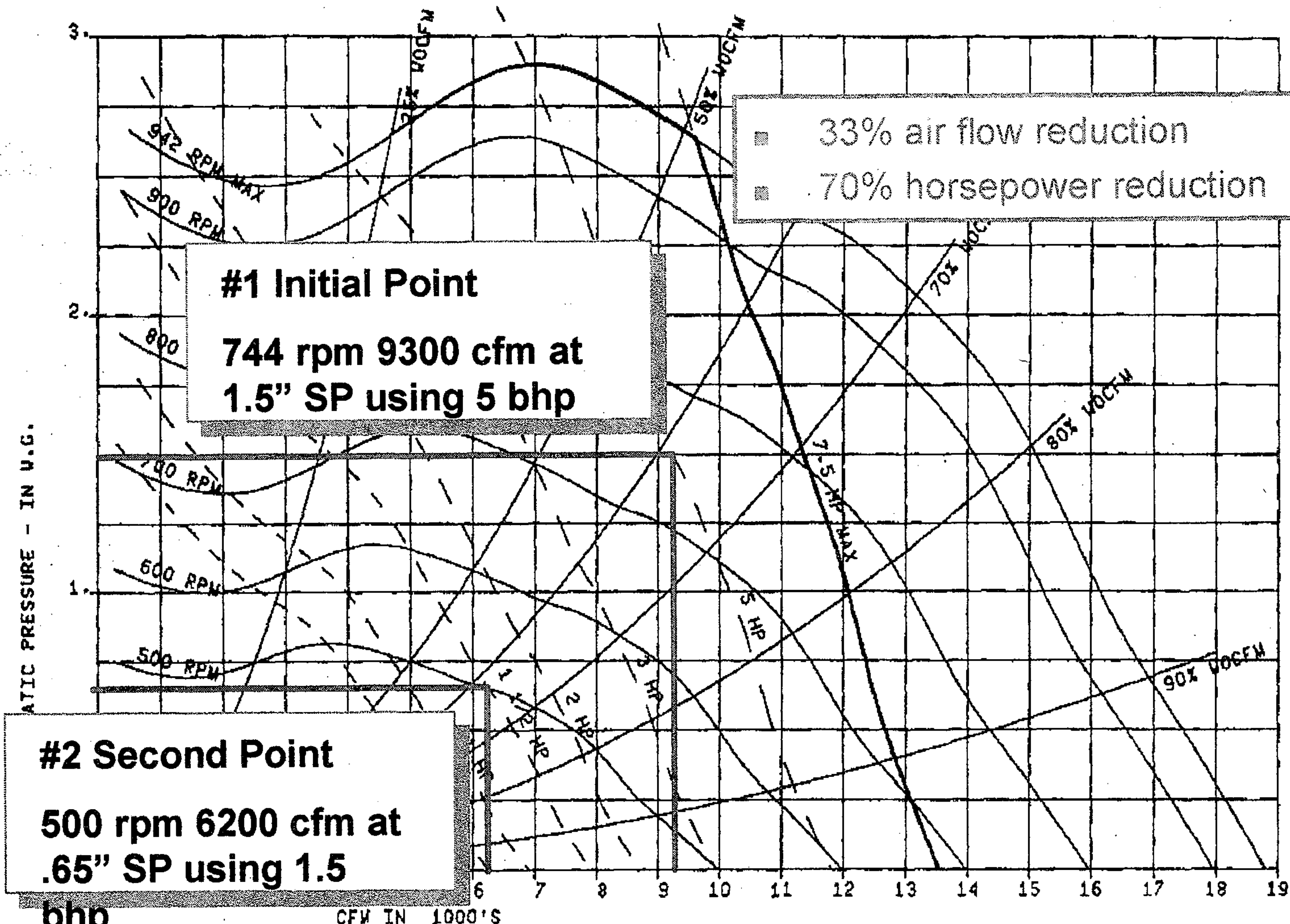
So, what's the problem?

- All power provided by Utility Companies is 60.0Hz only. Therefore, induction motors go one speed.
- Since the speed of an induction motor is a function of the frequency of the power, only changes in frequency change motor speed.
- Only changes in power frequency will efficiently reduce fan speeds.

- #1- Full air flow
- #2- 70% air flow

Fan Speed Vs Fan HP

- 33% air flow reduction
- 70% horsepower reduction



#1 Initial Point

744 rpm 9300 cfm at 1.5" SP using 5 bhp

#2 Second Point

500 rpm 6200 cfm at .65" SP using 1.5 bhp

The Hard Numbers

Derivation of Air Horsepower Equation

Equation 1
For a fan connected to a fixed system, the flow rate is proportional to the RPM

$CFM := K_1 \cdot RPM$

Equation 2
For a fixed dimensional system the flow rate of air is proportional to the velocity of the air

$CFM := K_2 \cdot V$

Equation 3
For a fixed dimensional system the pressure drop of the air is proportional to the Square of the Velocity as well as the CFM and RPM

$\Delta P := K_3 \cdot V^2$

therfore

$\Delta P := K_4 \cdot CFM^2$

therfore

$$\Delta P := K_5 \cdot RPM^2$$

Equation 4
Air horse power is the product of the flow rate and the change in pressure.

$AHP := K_6 \cdot CFM \cdot \Delta P$

Equation 5
Substituting equation 1 & 3 for CFM & ΔP in equation 4 we have the simple relationship between fan rpm and fan horsepower.

$$AHP := K_7 \cdot RPM^3$$

Concerns

- VFDs can damage motors if not applied correctly. Harmonic oscillation and high voltage spikes can occur. Read the ASHRAE report included.
- Lowering of flow rates can affect laminarity if it exists. Non-laminar rooms are not affected.
- Minimum flow rates may be required for cooling, dehumidification and exhaust
- Dynamic room pressure controls are recommended

NPME thanks you for your time

- NPME takes great pride in energy savings that are REAL.
- NPME has a full engineering staff to assist you and produce a functional design
- NPME has a full crew to install your system

CASE B – 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

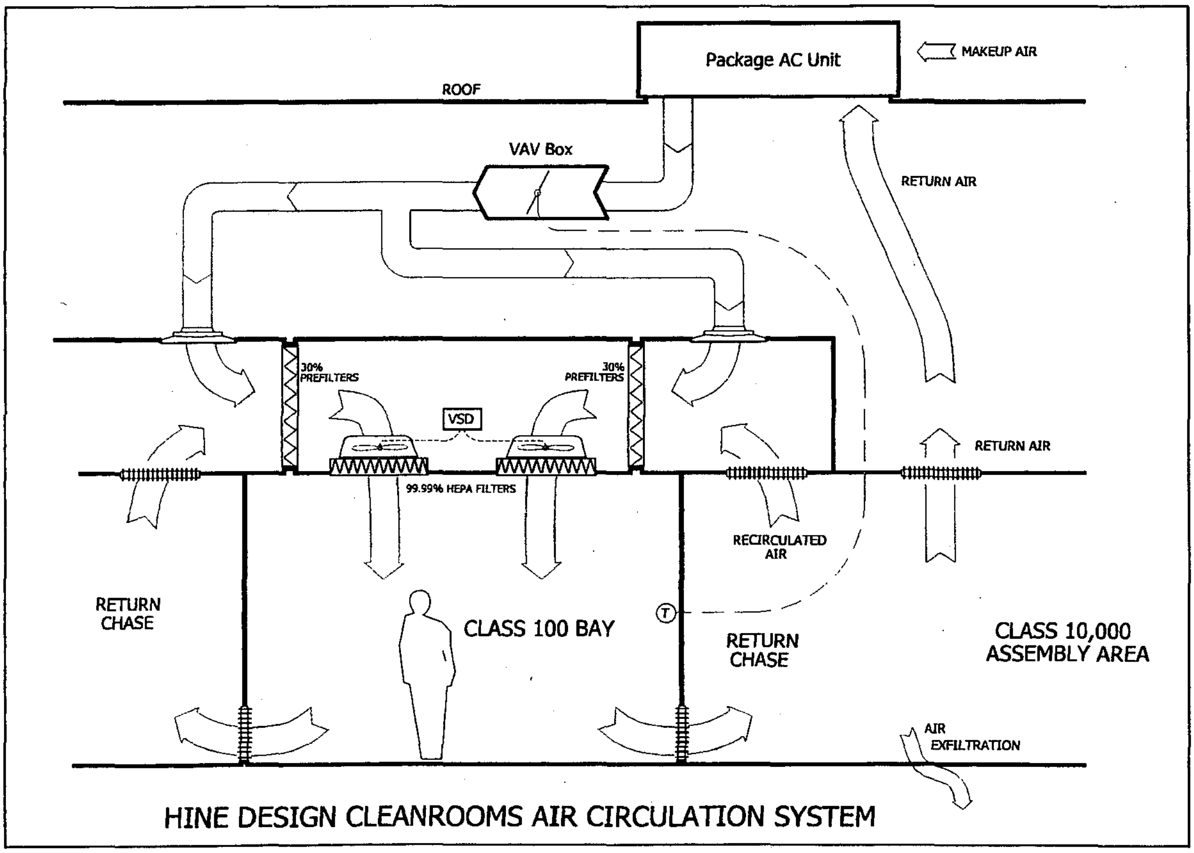


Figure 1

(FPHs). The class 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:

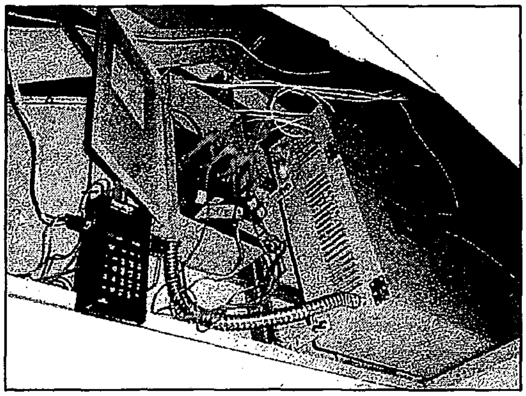
- Variable speed drives (VSDs) on the FPHs serving the class 100 bays (shown in Figure 1)
- A custom control system that schedules the speed of the VSDs based upon occupancy patterns

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).

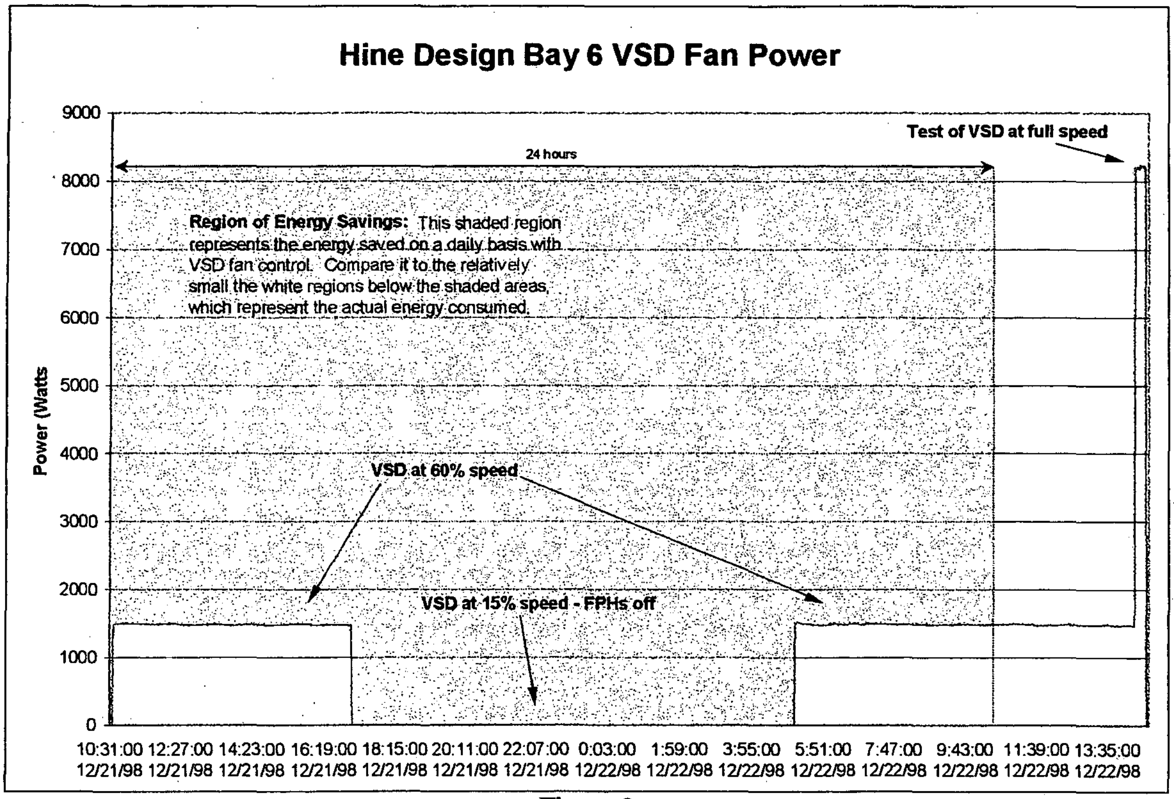


Figure 2

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 $[(0.15)^{2.66} \times 45.9 \text{ kW} \times 5,214 \text{ h/y}]$. 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

CASE B – 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 B / C*	*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*
K	Total Recirculation Fan Power at 60% Speed	8.4 *kW*	*A x B / C*	
J	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*	*D x E*	
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 / S*	

ASHRAE JOURNAL

Design Considerations for Motors And Variable Speed Drives

By Thomas F. Lowery
Member ASHRAE

Insulated Gate BiPolar Junction Transistors (IGBTs) have been applied in variable speed drives since the early 1990s. These devices changed the characteristics of wave forms applied to the motors due to the speeds at which they cycle on and off. Variable speed drives have used a technique known as Pulse Width Modulation (PWM) for nearly 30 years for controlling power transistors. However, as the switching speeds increased to allow higher carrier frequencies from 1 or 2 kHz to 8, 15 or as high as 20 kHz, new concerns arose over phenomena previously seen only in wave transmission devices like antennae and broadcast signal equipment. The basic reliable motor control did not change in theory, but faster transistor switching time changed the application variables such as drive to motor lead length.

Lead lengths should not exceed manufacturer's recommendations. If possible, design the system by placing the drive as close to the motor as possible. This should be the primary goal of the engineer because this method usually is the most cost effective. However, certain applications may not permit short leads and other methods must be considered. Engineers now must consider these factors when applying newer IGBT-based variable speed drives.

Switching Times and dv/dt

Control algorithms for PWM drives must accurately output a specific voltage at a given fundamental motor frequency. This ratio, known as the V/Hz pattern, keeps motor current and torque characteristics stable while operating at varying speeds. Additionally, when controlling IGBT transistors, the drive design engineer must maintain a transistor's on-time to off time ratio for motor stability. In doing so at higher carrier frequencies, the transition-time from off to on and then on to back off again must be maintained as a small percentage of the overall PWM cycle.

Figure 1 shows the switching of a Bipolar Junction Transistor (BJT) versus an IGBT as an example of how the increased switching speeds effect the turn-on and turn-off times as a ratio of the overall cycle. Note that the BJTs are switching at a frequency of 2 kHz and the IGBTs are switching at a frequency of 8 kHz, or four times faster.

The high rate of change in voltage over relatively short periods of time is know as the dv/dt of the voltage pulse. The dv/dt is quantified in units of volts per microsecond. As the number of pulses increase, so must the dv/dt. Note that this voltage waveform is a function of the drive design and is not a user settable parameter.

The maximum design carrier frequency sets the limits on how fast a transistor must cycle on and off. If the waveform shown at the output of the drive was identical at the motor terminals, this high dv/dt would not be a concern, but as this wave propagates through the conductor, the characteristics can change and be vastly different at each end of the cable.

This article describes the relation of dv/dt in the IGBT to that of the older BJT. An important concept here is that when design engineers use IGBTs, they must set ratios of on-time to off time versus the turn-on and turn-off times to maintain stability in the motor. Essentially the turn-on and turn-off times (which sets the dv/dt) must be a small percentage of the overall pulse cycle. If a design engineer wants to establish the maximum carrier frequency of the drive to be 8kHz for example, the turn-on, turn-off, and dv/dt are set for this frequency in hardware. The dv/dt is not a programmable function.

If a user runs the drive at a lower carrier frequency, 2 kHz for example, the dv/dt is still set for the 8kHz running condition. Comparing IGBT to BJT from a dv/dt standpoint must account for these operating characteristics. IGBT drives could be set at a maximum of 2 kHz carrier frequency and the dv/dt would be identical to that of an older BJT, but in application this is never done. All commercially available IGBT-based drives switch at these

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About the Author

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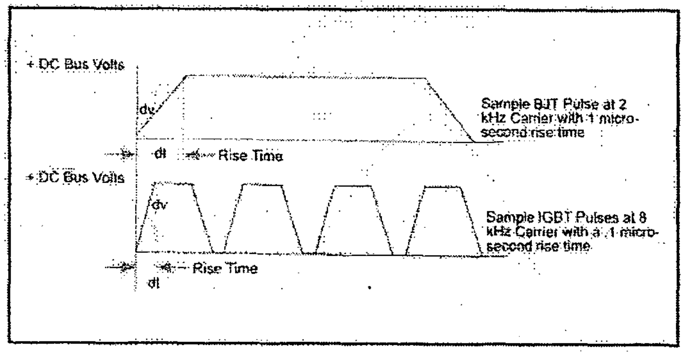

Figure 1: BiPolar vs. IGBT PWM switching.

higher carrier frequencies so the comparison between the two devices is accurate.

Drive to Motor Conductors

There are several conductor characteristics that affect the voltage pulse wave form and specific dv/dt effects at both the drive and motor terminals. Impedance or electrical resistance in AC circuits has an impact on the voltage pulse as it travels from the drive to the motor. The motor impedance and the relationship to the cable impedance is important when analyzing the pulse wave transmission. When the cable impedance closely matches the motor impedance, the voltage pulse is evenly distributed across the system. However, when the motor impedance is much larger than the cable impedance, the pulse will reflect at the motor terminals, causing standing waves.[1]

A filter and/or reactors can be placed between the drive and motor. There are a number of commercially available devices that are designed to eliminate the standing waves. If pursuing this method of attenuation, an engineer or user should follow the recommendations set by the manufacturer in applying these devices. Cost is also a factor when selecting filtering devices. MTE, TCI and EMS are companies that have published a great deal of information on the subject.

Figure 2 shows the surge impedance of both the motor and the cable for different horsepowers. Note that relatively small motors, less than 2 hp, have very high impedance with respect to typical cable. Larger motors, greater than 100 hp, closely match cable impedance values.

Damaging reflected waves are more likely to occur in smaller motors because of the mismatch in surge impedance values.[2,3] If multiple small motors are run from a single drive, the potential for reflected waves is high. Special considerations must be given to designing such a system.

Riding the Reflected Wave

Reflected waves damage motors because transmitted pulses and reflected pulses added together can cause very high voltage levels. Since these voltage pulses are transmitted through the conductor over specific distances, the cable length is a key variable when examining the potential for damaging voltages. *Figure 3* shows the relationship between cable distance, switching times, and voltage levels of pulses at motor terminals.[4]

The voltage level at which motor damage begins is determined by the materials used in the insulation system.[5] When

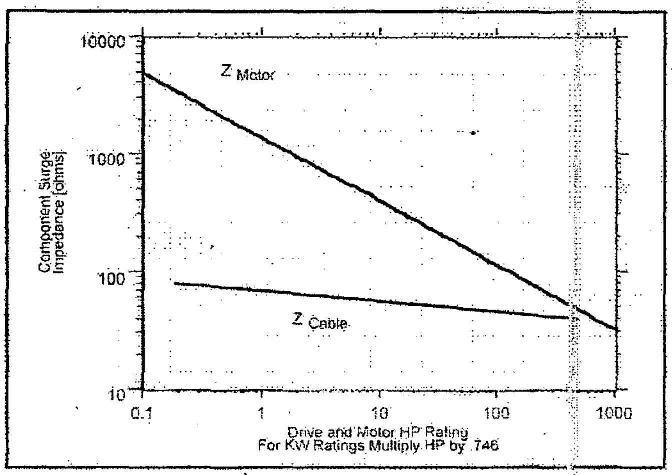

Figure 2: Motor/drive relative impedance.

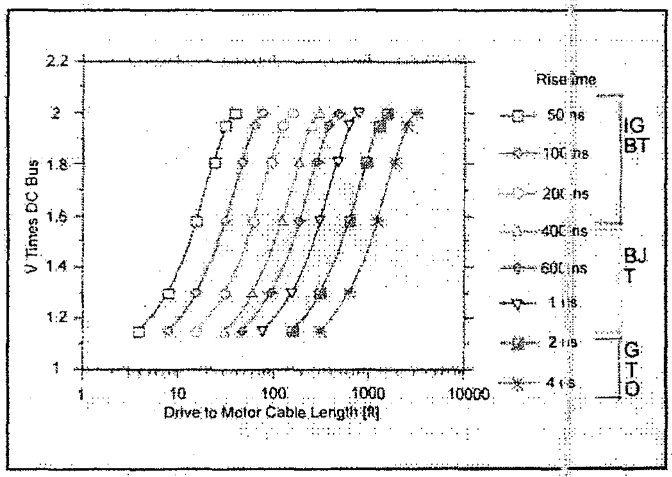

Figure 3: Switching times, cable distance and pulse peak voltages.

specifying motors for operation on variable speed PWM drives, engineers should specify the voltage withstand level based on the dv/dt of the drive and the known cable distance.

There are no simple calculations to show how peak voltage relates to lead lengths. The problem here is that there are many variables that go into these calculations. The best thing to do would be to work with your drive and motor supplier to determine appropriate lead lengths for each application. Standing wave and reflected wave mathematical equations are very complex, and even by making several assumptions by fixing some of the variables this analysis is difficult. Manufacturers should determine the allowable lead length with their drive and state it to the application engineers. This is less of a concern with 208/230 volt applications, since the motor insulation material is always higher rated than low voltage drives can generate.

Because motor manufacturers do not use lower rated materials specifically for these lower voltages, the insulation systems are identical to that of a 460 or higher rated motor. Theoretically, voltage peaks generated by drives on a 208/230 volt system can never reach these rated values and therefore there is no concern for damage due to over-voltage at any lead length at any carrier frequency.

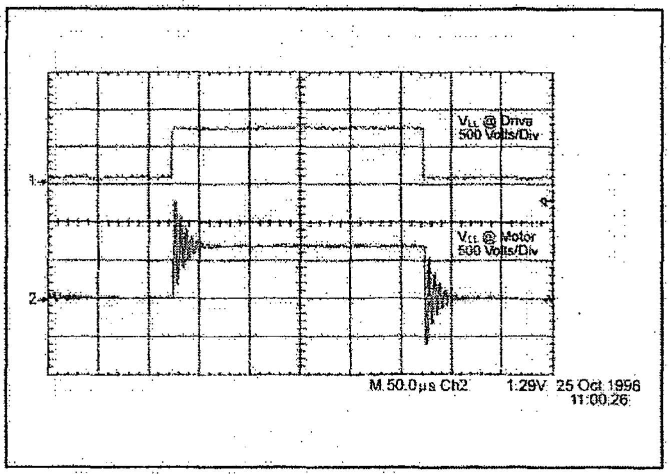

Figure 4: Reflected wave voltage levels at drive and motor.

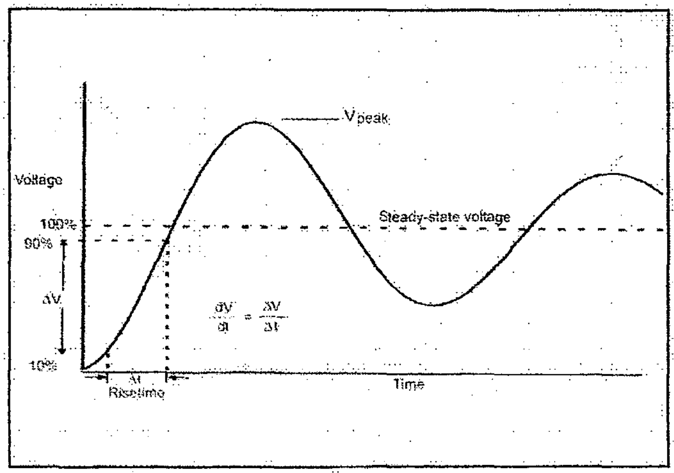

Figure 5: Motor voltage peak and dv/dt limits. NEMA MG1-1993, Part 30, Figure 30-5.

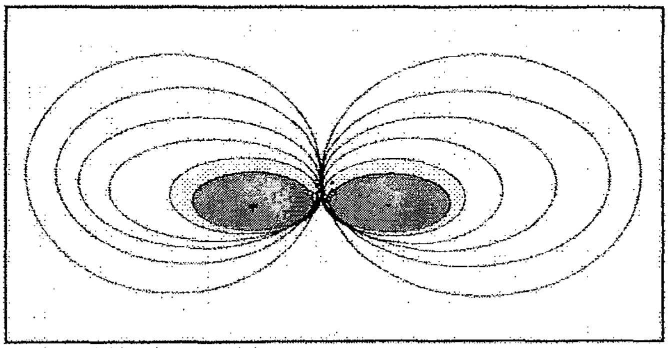

Figure 6: The ionization of a gas or partial discharge from excessive voltage peaks and high dv/dt in motor conductors.

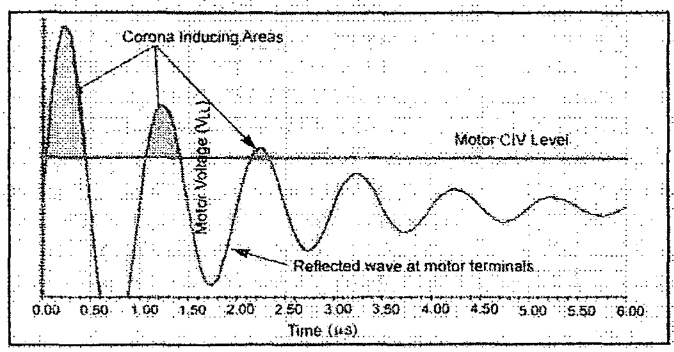

Figure 7: Damaging reflected waves above motor CIV levels.

To describe the reflected wave phenomena, oscilloscope measurements were taken at each end of the drive to motor conductor. These traces, shown in *Figure 4*, demonstrate the effect of transmitted and reflected pulses adding together forming damaging voltage potentials. The induction motor must be designed to withstand these voltage levels or insulation breakdown will occur.[6]

Motor Ratings and NEMA Standards

A 460-volt induction motor is constructed to withstand voltage levels higher than the nameplate might suggest.[7] The specific maximum voltage withstand value should be obtained from the manufacturer, but typical values for 208V and 460V motors range from 1,000 volts up to 1,800 volts. Higher voltages such as motors fed from 575V power systems may be rated up to 2,000V peak.

This rating is determined by the design and materials used to insulate the induction motor. NEMA, the National Electrical Manufacturers Association, has established a standard to assist motor specifying engineers as part of the MG1 standard. NEMA MG1-1993, Part 31.40.4.2[8] states the established PWM drive fed motor limits and is shown in *Figure 5*.

This standard establishes a V peak of 1,600 volts and a minimum rise time (dt) of 0.1 microseconds for motors rated less than 600 Volts. Specifying motors applied on drives that meet or exceed these limits assures the design engineer that insulation breakdown will not occur in the motor from excessive voltage peaks or fast IGBT switching times.

Motor Insulation Break Down

Damage to the motor can occur only if the peak voltage or minimum rise time is exceeded. If reflected waves generate voltage levels higher than the allowable peak, insulation begins to break down. This phenomenon is known as Partial Discharge (PD) or corona. *Figure 6* shows how intense electrical fields around motor conductors can ionize surrounding gases causing damaging corona effects.

When two phases or two turns in the motor pass next to each other high voltage peaks can cause a spark plug effect, damaging the insulation. The voltage at which this begins is referred to as the Corona Inception Voltage or CIV rating of the motor[6] (*Figure 7*). Again, NEMA specifies this level at 1,600 Volts in MG1.

Eventually, air gaps inside the varnish material ionize due to the high voltage gradients causing phase-to-phase or turn-to-turn short circuits. These circuits are microscopic insulation breakdowns and are usually detected by the drive current sensors resulting in over-current trips. Under this short circuit condition, a motor may operate properly when run across the line or in bypass mode but consistently trip when run from drive power.

Motor factory testing may be required to confirm this failure mode. *Figure 8* shows how air gaps in the varnish material ionize, causing these microscopic short circuits across two conductors.

Special motor insulation systems can be added to accommodate even the highest of generated peak voltages. These systems usually use special high voltage die-electric withstand material that does not break down inside the motor. Usually this cost is prohibitive in most cases, but it is still a possible solution to a difficult problem.

Conclusions

Variable speed drive technology changes with advancements in power semiconductor designs. As IGBT designs allow drive design engineers to increase the switching frequency utilized in PWM drives, quieter motor operation is achieved by removing objectionable audible motor lamination vibrations in the human hearing spectrum. This drive advancement helps design engineers use drives in critical noise applications that previously relied on mechanical VAV systems. The higher switching frequency also forces system design engineers to consider new application criteria such as drive-to-motor lead length and motor insulation systems when selecting the equipment.

NEMA has adopted a standard for motors applied on variable speed drives that should be used by the engineer to ensure a proper system. Drive and motor manufacturers now publish information on dv/dt, lead lengths, and motor CIV levels to assist in the design process. This information must be used to determine the application variables of the variable speed drive system to insure reliable operation. By considering all these drive and motor variables and using published data, VAV system designers can take advantage of all the energy saving and system benefits from drives without sacrificing any of the reliability of the system.

Drive/Motor Characteristic	High Carrier Frequency	Low Carrier Frequency	Recommendations
Motor Audible Noise	Lower	Higher	Use higher carrier frequency where audible noise critical
Lead Length	Shorter	Longer	Follow manufacturer's recommendations
System Efficiency	Lower	Higher	Higher carrier results in more heat generated by drive
Drive Output Amp Rating	Lower	Higher	Running at higher carrier frequency requires larger drive heat sink
Potential for Motor CIV Damage	Higher	Lower	Specify motors per NEMA standards

Table 1: Drive carrier frequency engineering application considerations.

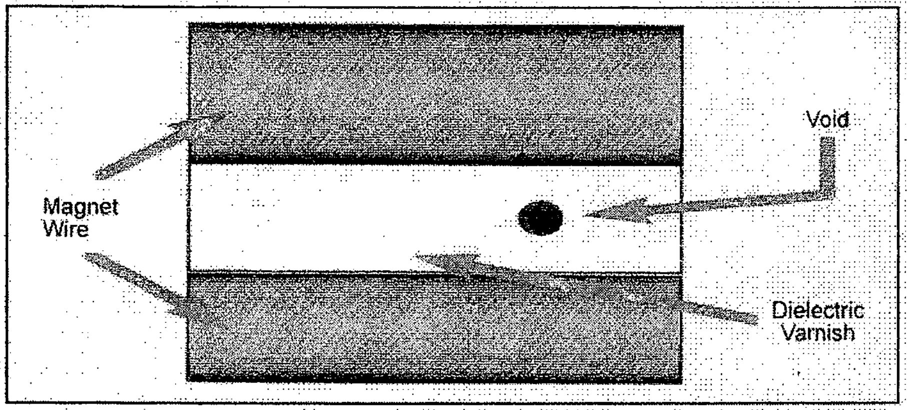

Figure 8: Ionization of insulation air gaps.

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Case Study:

Applied Materials
Chilled Water Plant Efficiency Upgrade

Prepared by:
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Applied Materials

- Carol Asuncion - Facility Manager
- Santa Clara based semiconductor wafer processing tool manufacturer
- Building 2 - Research and development center
- 1st floor: 27,000 sf of cleanroom space
- Consists of 61 process tools
- 2nd floor: 46,000 sf of office space

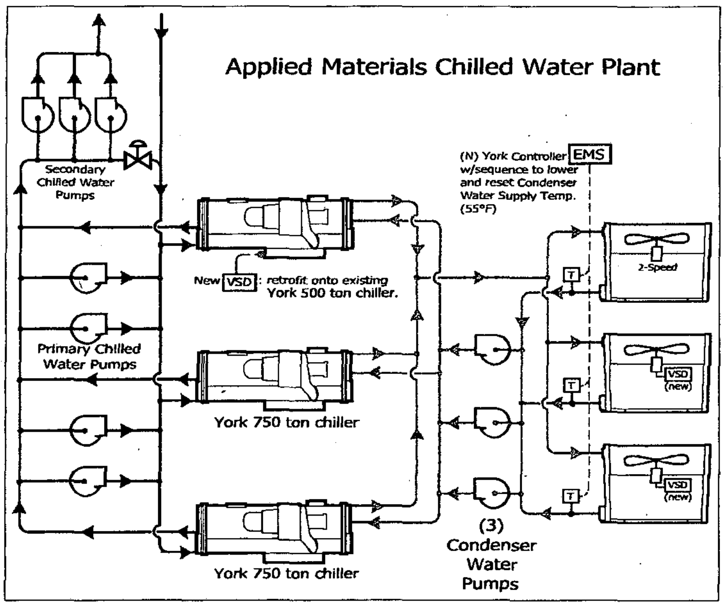
Chilled Water Plant

Before

- 2 - 750 ton chillers (1 backup) and 1 - 500 ton chiller
- 40°F CHWST
- Lead-lag loading
- Two-speed tower fan controls (3 towers)
- 65-70°F CWST

After

- VSD retrofitted onto 500 ton chiller
- New chilled water plant controls
- Optimized loading with VSD chiller
- 55°F CWST

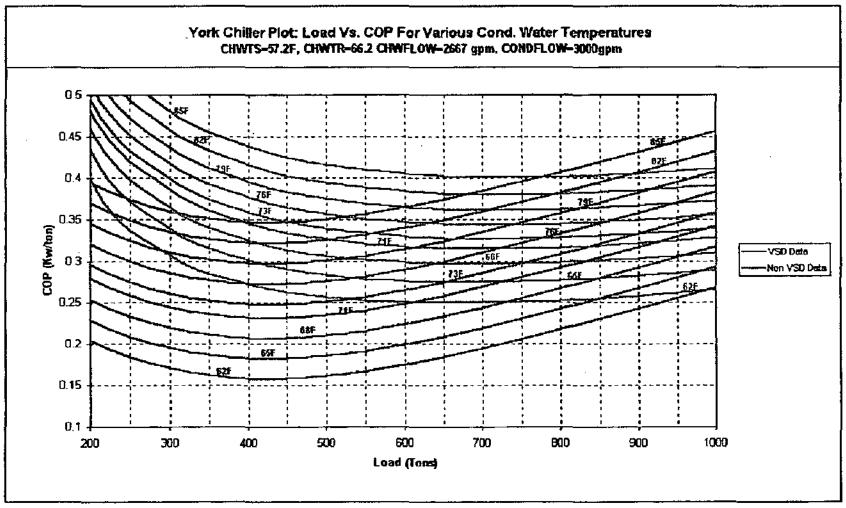


1. 500 ton Chiller VSD

- Retrofitted onto existing chiller by York
- Chiller control center installed to optimize staging
- Efficient operation at all loads

How does the VSD save?

- Normally, inlet vanes throttle back on refrigerant flow, increasing pressure, to reduce load
- With a VSD, compressor speed is reduced
- Chiller power is proportional to *both* pressure and to speed, however . . .
- Therefore, the VSD chiller is much more efficient at part loads
- The VSD consumes some power, so at full load it is not as efficient - rarely operate at full load



2. Condenser Water Reset

- Tower staging controls installed
- Each tower was installed to be dedicated to one chiller but with a common header
- Fans are operated as needed to maintain 55°F CWST
- Water pours over all three towers, even with the fans off

How does lower CWST save?

- Lowering CWST reduces the "lift" required by the chiller (raising CHWST also reduces lift)
- Lift is the refrigerant temperature difference across the evaporator and condenser
- Chiller power is proportional to refrigerant pressure, which is proportional to chiller lift

Energy Savings Summary

- The total cost of the two project components was about $200,000
- Savings is estimated to be about $87,000 per year
- Payback: 2.3 years
- Annual savings will continue for years afterward

Other Efficiency Efforts at B2

- VSDs for two of three cooling tower fans
- Fab process cooling provided by dedicated cooling towers
- Real time particle counting and occupancy sensors to control recirculation fan VSDs (also planned for Building 3)

CASE A – Applied Materials: Chilled Water Plant Efficiency Upgrade

Project Benefits Summary

Annual Energy Cost Savings	$87,000/y
Actual Project Cost	$201,000
Project Payback	2.3 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.

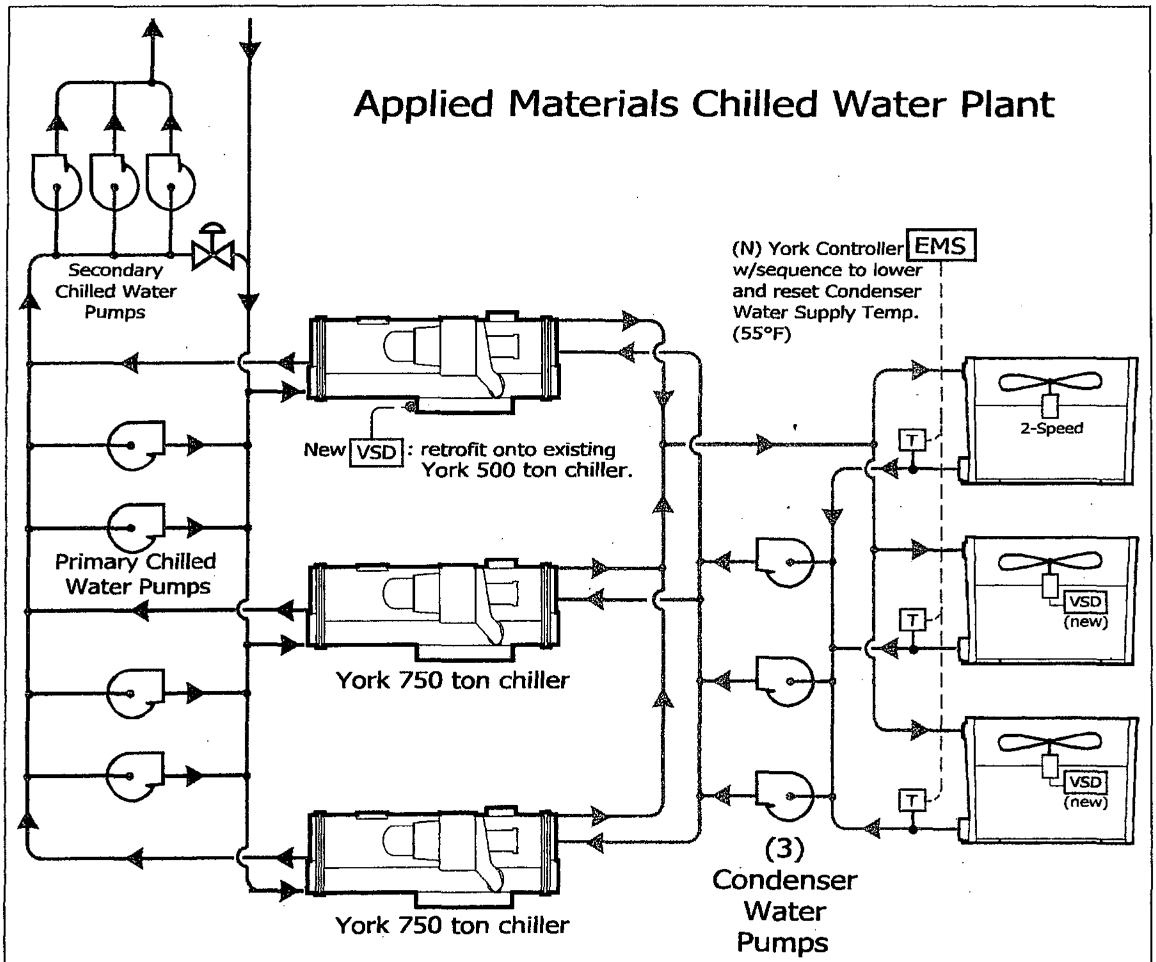


Figure 1: Chilled Water Plant Schematic

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.

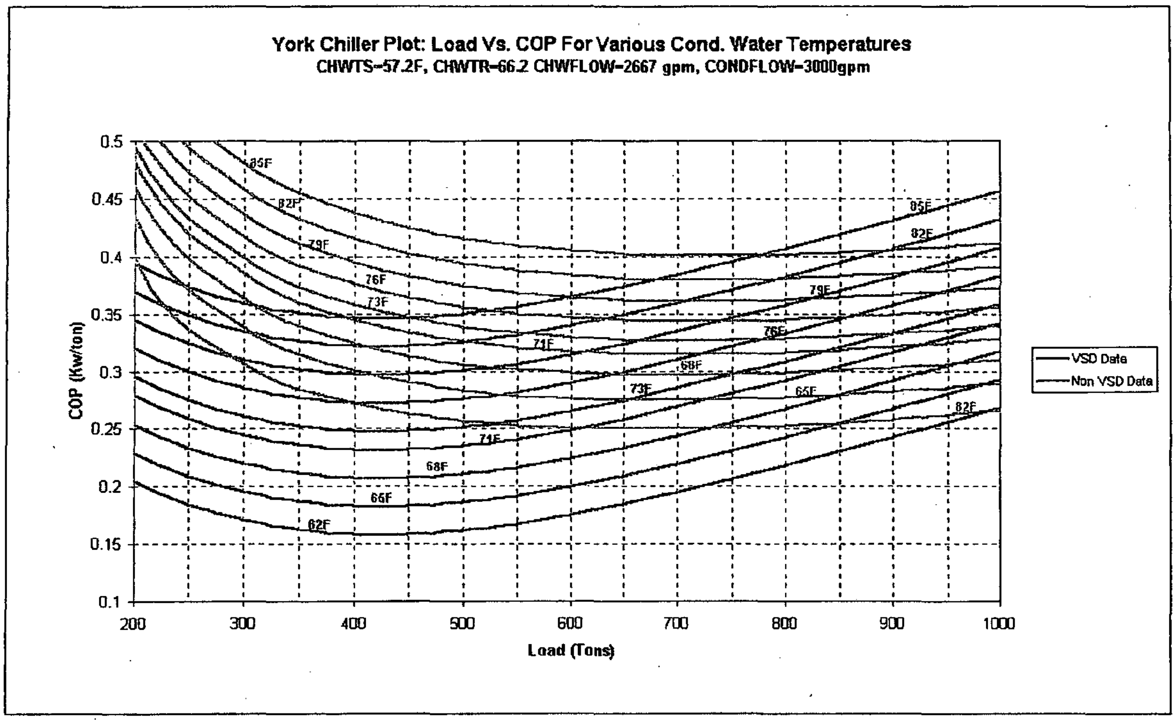


Figure 2: Chiller Performance Curves with and without VSD Compressor Control

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. 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 very low, the 500 ton chiller can cover the load alone with much better performance than it would without the VSD.

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.

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.

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 3) in order to maintain the new setpoint. 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.

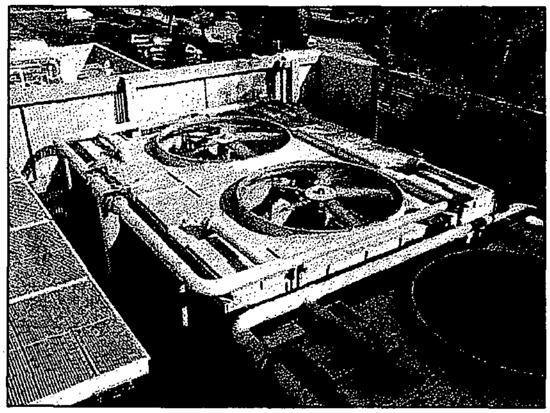


Figure 3

A new DDC control system was installed to allow optimization of staging for the both the chillers and the cooling towers. Data provided by Applied indicates that these two measures have an annual cost savings of about $87,000 and that their overall cost was about $201,000, resulting in a payback of about 2.3 years.

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.

WORKSHOP ON ENERGY SAVING
OPPORTUNITIES IN CLEANROOMS

MOTOROLA AIEG
CLASS 10K CLEANROOM CONVERSION

David A. Barr, P.E.
Black & Veatch ATD

1.0 INTRODUCTION

The purpose of this project was to reduce operational costs by reducing the cleanroom space classification from Class 10,000 to Class 100,000.

2.0 EXISTING CONDITIONS

- One air handling unit operating at approximately 67,000 cfm
- Mixed return air/outdoor air conditioned for humidity control
- Entire airflow cooled and dehumidified to 45F by CHW, humidified with steam, reheated with electric coils
- Significant energy cost to operate fans, cool (by chillers) and reheat air

3.0 REDUCE AIRFLOW

- Reduce airflow from 10 cfm/sf to 5 cfm/sf, or approximately 30,000 cfm
- Outdoor air rate remains the same
- Space humidity setpoint remains the same
- Cool and reheat approximately 45% of existing airflow
- Lower discharge temperature to maintain space temperature (reduce reheat)
- Reduce fan operating horsepower

4.0 ENERGY SAVINGS

- Operating cost reduced by an estimated 60%
- Significant CHW savings due to reduced dehumidification or recirculated air
- Significant electric reheat savings due to reduced reheat of recirculated air and reduced discharge temperature
- Minor savings due to reduced motor horsepower
- Construction cost payback of 7 months

5.0 CONCLUSION

- Initially expected savings from reduced motor horsepower only
- Existing HVAC system non-typical for a cleanroom
- Typical cleanroom HVAC has dedicated makeup units for humidity control and recirculation air handlers for temperature control
- Provided opportunity for energy savings even though outdoor air rate and space heat gain remained the same

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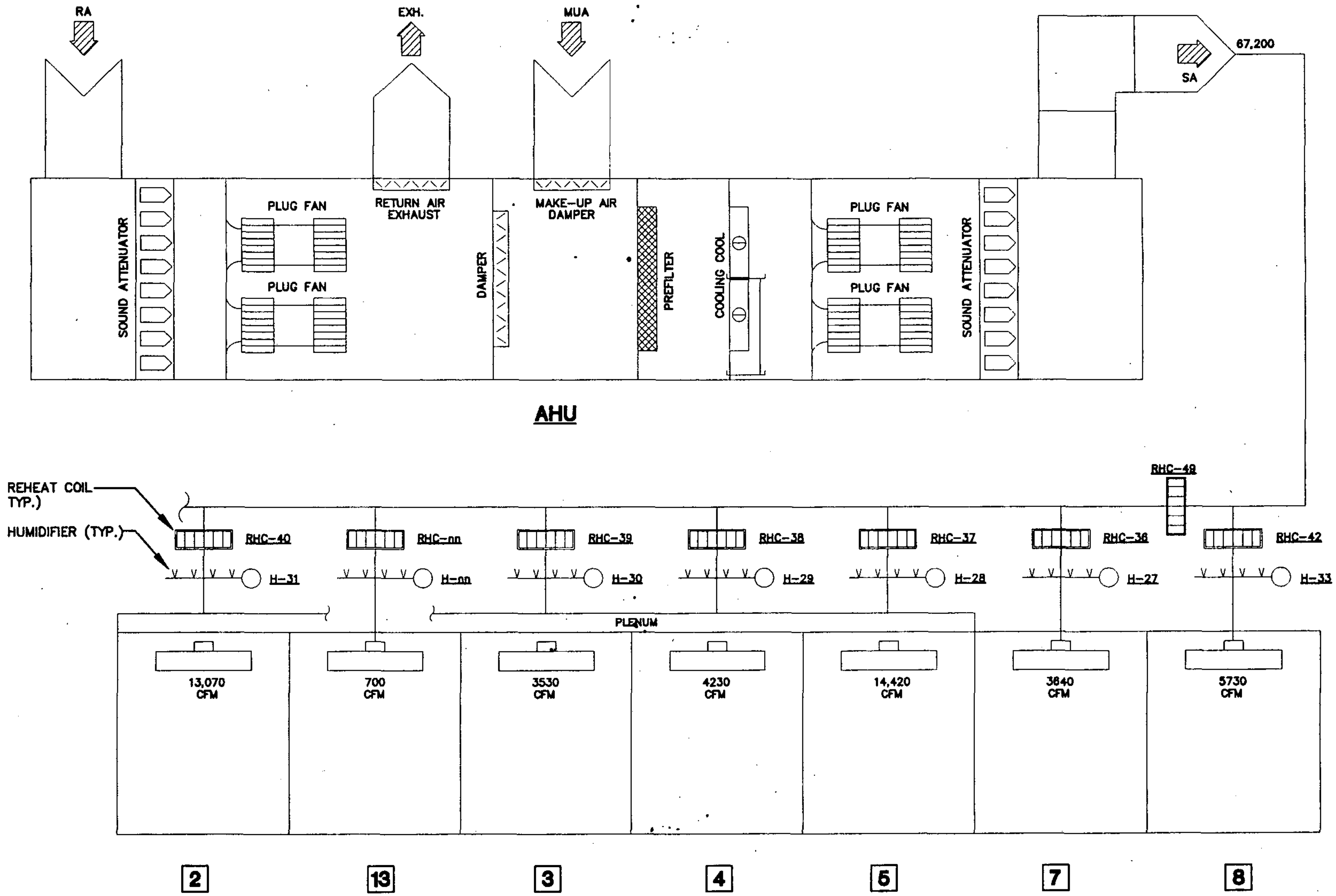

BLACK & VEATCH
PROGRESS BY DESIGN
PROJECT

DATE

TABLE 2.2 -- EXISTING AIR HANDLING UNIT DESIGN CONDITIONS

Assumes 20% OA and space design temperature of 70F at 40% RH.
Assumes OA conditions of 105Fdb/79Fwb summer, -8F winter.
Assumes summer discharge temperature of 48F (LAT of 45F to allow for fan heat).

MOTOROLA AIEG
Northbrook, Illinois
Class 10,000 Cleanroom Conversion

Air Handling Unit **Existing** Assume density of air @ 0.075 pcf for all conditions

SECTION	AIRFLOW CFM	EAT Fdb	EAT Fwb	Ent W lbw/lba	Ent h btu/lba	LAT Fdb	LAT Fwb	Lvng W lbw/lba	Lvng h btu/lba	delta h btu/lba	q btuh	EWT F	LWT F	FLOW gpm	FLUID
Summer															
Return Air	53,760	70.00	55.80	0.0063	23.70										
Outside Air	13,440	105.00	79.00	0.0154	42.60										
Mixed Air	67,200	77.00	61.30	0.0081	27.40										
Cool/Dehumidify	67,200	77.00	61.30	0.0081	27.40	45.00	44.00	0.0059	17.30	10.10	3,054,240	38.0	48.0	610.8	chw
Fan Heat/Disch.	67,200	45.00	44.00	0.0059	17.30	48.00	45.50	0.0059	17.90						
Reheat	67,200	48.00	45.50	0.0059	17.90	67.00	53.90	0.0059	22.60	4.70	1,404,480			411.5	kW
Humidifier	67,200	67.00	53.90	0.0059	22.60									OFF	
Winter															
Return Air	53,760	70.00	55.80	0.0063	23.70										
Outside Air	13,440	-8.00		0.0000											
Mixed Air	67,200	54.40	46.80	0.0050	18.60										
Cool/Dehumidify	67,200	54.40	46.80	0.0050	18.60	54.40	46.80	0.0050	18.60	0.00	0	38.0	48.0	0.0	chw
Fan Heat/Disch.	67,200	54.40	46.80	0.0050	18.60	54.40	46.80	0.0050	18.60						
Reheat	67,200	54.40	46.80	0.0050	18.60	67.00	52.80	0.0050	21.90	3.30	931,392			272.9	kW
Humidifier	67,200	67.00	52.80	0.0050	21.90	67.00	55.00	0.0063	23.20	1.30	393,120			380.16	lb/hr

Summer peak cooling load of 611 gpm (255 tons)
Summer constant reheat load of 412 kW
Winter peak heating load of 273 kW
Winter peak humidification load of 380lb/hr

Process Report

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Process Report

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	W	dW	t	dt	rh	drh	v	dv
	grains/lbm		grains/lbm		F	F	%	%
1	56*		77*		40.9		13.69	
2	41.2*	-14.8	45*	-32	93.8	52.9	12.83	-0.8599
3	41.2*	0	67*	22	42.3	-51.5	13.39	0.5596
4	44*	2.8	70*	3	40.7	-1.56	13.47	0.08489

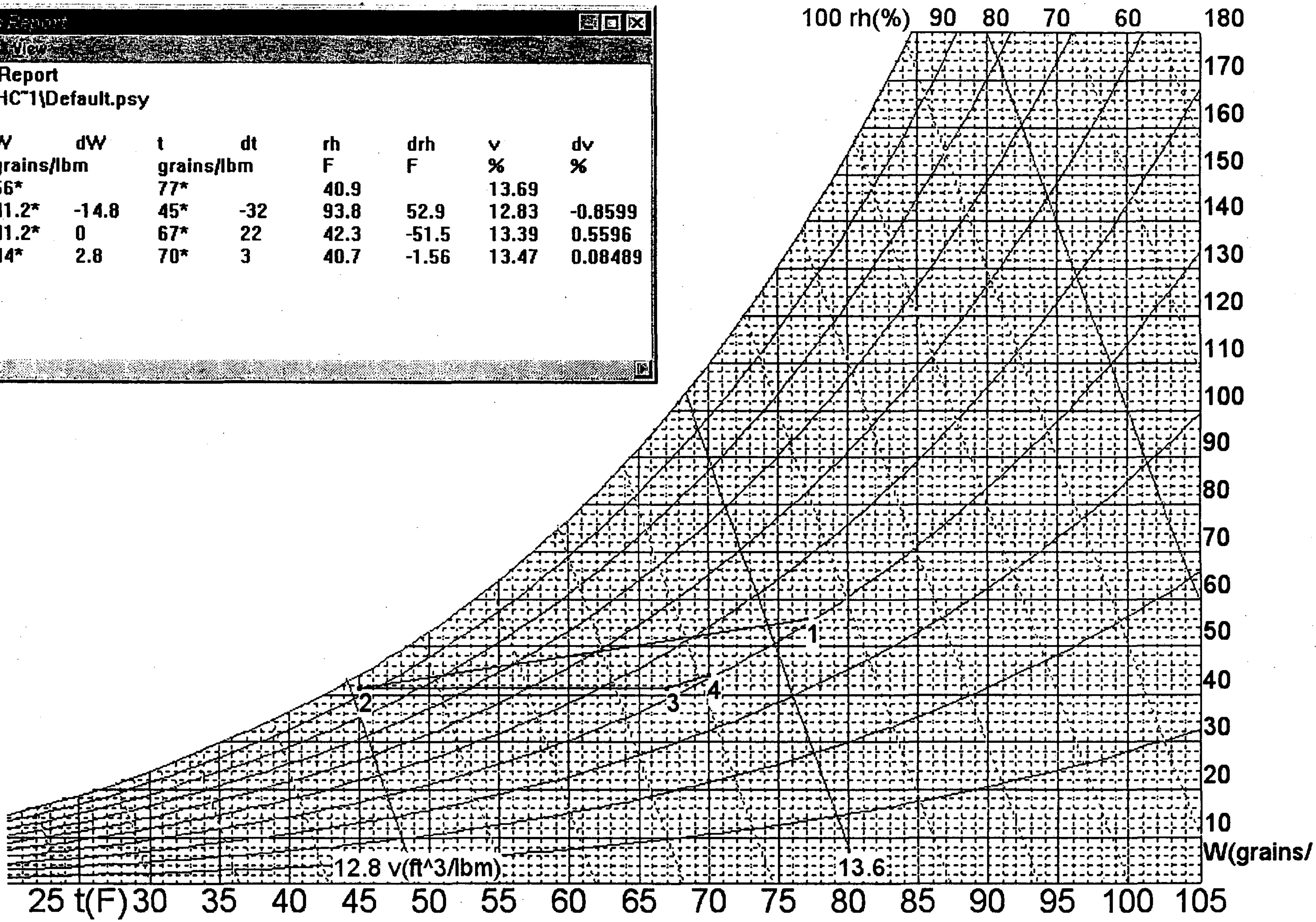

TABLE 2.3 – ANNUAL COOLING AND HEATING LOADS

Existing Conditions, assuming 20% outside air, internal space temperature of 70F, 40% RH.
Assume cooling to 48F discharge when OA is greater than 52F.
Assume free cooling to 62F and reheat to 67F when OA is between 30F and 52F.
Assume heating to 67F with minimum OA when OA is less than 30F.

PEAK COOLING LOAD	3,054,240 Btuh		PEAK REHEAT KW	412 kW
DESIGN AIRFLOW	67,200 CFM		PEAK HEATING KW	273 kW

						OA	RA	RA	Cooling	Annual		Heating	
DRY BULB	WET BULB	HOURS	OA h	Disch. h	OA Cfm	BTUH	h	BTUH	BTU	Hours	Heat kW	kW-h	
								constant					

DRY BULB	WET BULB	HOURS	OA h	Disch. h	OA Cfm	OA BTUH	RA h	RA BTUH constant	Cooling BTU	Annual Hours	Heat kW	Heating kW-h	
105.0	79.0	0	42.8	17.2	13,440	1,536,192	23.7	1,572,480	0				
102.0	77.0	0	40.8	17.2	13,440	1,415,232	23.7	1,572,480	0				
97.0	76.0	6	39.8	17.2	13,440	1,354,752	23.7	1,572,480	17,563,392				
92.0	74.0	50	37.7	17.2	13,440	1,239,840	23.7	1,572,480	140,616,000				
87.0	72.0	165	35.9	17.2	13,440	1,130,976	23.7	1,572,480	446,070,240				
82.0	70.0	324	34.1	17.2	13,440	1,022,112	23.7	1,572,480	840,647,808				
77.0	67.0	487	31.6	17.2	13,440	870,912	23.7	1,572,480	1,189,931,904				
72.0	64.0	681	28.3	17.2	13,440	731,808	23.7	1,572,480	1,569,220,128				
67.0	61.0	759	27.2	17.2	13,440	604,800	23.7	1,572,480	1,652,555,520				
62.0	57.0	700	24.5	17.2	13,440	441,504	23.7	1,572,480	1,409,788,800				
57.0	52.0	604	21.4	17.2	13,440	254,016	23.7	1,572,480	1,103,203,584				
52.0	47.0	581	19.2	17.2	13,440	120,960	23.7	1,572,480	983,888,640	4357			
47.0	43.0	565	16.7	21.5	13,440	-290,304	23.7				108	61,186	
42.0	38.0	572	14.3	21.5	13,440	-435,456	23.7				108	61,943	
37.0	34.0	725	12.6	21.5	13,440	-538,272	23.7				108	78,512	
32.0	30.0	869	10.9	21.5	13,440	-641,088	23.7				108	94,106	
27.0	25.0	589	8.9	21.5	13,440	-762,048	23.7				121	71,498	
22.0	21.0	971	7.8	21.5	13,440	-828,576	23.7				149	53,033	
17.0	16.0	231	6.0	21.5	13,440	-937,440	23.7				165	38,023	
12.0	11.0	164	5.0	21.5	13,440	-997,920	23.7				186	30,547	
7.0	6.0	115	3.0	21.5	13,440	-1,118,880	23.7				208	23,911	
2.0	1.0	89	1.0	21.5	13,440	-1,239,840	23.7				230	20,433	
-3.0	-3.0	63	0.0	21.5	13,440	-1,300,320	23.7				251	13,316	
-8.0	-8.0	27	0.0	21.5	13,440	-1,300,320	23.7				273	7,368	
-13.0	-13.0	11	0.0	21.5	13,440	-1,300,320	23.7				295	3,240	
-18.0	-17.0	2	0.0	21.5	13,440	-1,300,320	23.7				316	632	
-23.0	-21.0	0	0.0	21.5	13,440	-1,300,320	23.7			4983	338	0	
TOTAL	-	8740							9,353,466,016	Btu/yr		557,686	kW-h/yr
									779,457	Tons/yr			

Annual Energy Consumption														
FAN OPERATION				REHEAT DURING COOLING				COOLING				HEATING		TOTAL ANNUAL COST
Fan HP	126.4	bhp		Reheat	412	kW		CHW Cons.	779,457	Tons/yr		557,686	kW-h/yr	
Oper. Hrs	8760	hrs/yr		Oper. Hrs.	4357	hrs/yr		Efficiency	0.79	kW/ton				3,794,228 kWh
Annual kW	825,687	kWh/yr		Annual	1,795,084	kWh/yr		Annual kW	615,771	kWh/yr				

3,794,228

TABLE 3.2 -- REDUCED AIR HANDLING UNIT DESIGN CONDITIONS

Assumes 13,440 CFM of OA and space design temperature of 70F at 40% RH.
Assumes OA conditions of 105Fdb/79Fwb summer, -8F winter.
Assumes summer discharge temperature of 48F (LAT of 45F to allow for fan heat).

MOTOROLA AIEG
Northbrook, Illinois
Class 10,000 Cleanroom Conversion

Air Handling Unit **Reduced Airflow** Assume density of air @ 0.075 pcf for all conditions

SECTION	AIRFLOW CFM	EAT Fdb	EAT Fwb	Ent W lbw/lba	Ent h btu/lba	LAT Fdb	LAT Fwb	Lvng W lbw/lba	Lvng h btu/lba	delta h btu/lba	q btuh	EWT F	LWT F	FLOW gpm	FLUID
Summer															
Return Air	16,310	70.00	55.80	0.0063	23.70										
Outside Air	13,440	105.00	79.00	0.0154	42.60										
Mixed Air	29,750	85.81	68.00	0.0104	32.40										
Cool/Dehumidify	29,750	85.81	68.00	0.0104	32.40	45.00	44.00	0.0059	17.30	15.10	2,021,513	38.0	48.0	[illegible]	chW
Fan Heat/Disch.	29,750	45.00	44.00	0.0059	17.30	48.00	45.50	0.0059	17.90						
Reheat	29,750	48.00	45.50	0.0059	17.90	63.70	52.50	0.0059	21.70	3.80	513,783			150.5	kW
Humidifier	29,750	63.70	52.50	0.0059	21.70									OFF	
Winter															
Return Air	16,310	70.00	55.80	0.0063	23.70										
Outside Air	13,440	-8.00		0.0000											
Mixed Air	29,750	34.76	32.30	0.0034	11.80										
Cool/Dehumidify	29,750	34.76	32.30	0.0034	11.80	34.76	32.30	0.0034	11.90	0.00	0	38.0	48.0	0.0	chW
Fan Heat/Disch.	29,750	34.76	32.30	0.0034	11.90	34.76	32.30	0.0034	11.90						
Reheat	29,750	34.76	32.30	0.0034	11.90	63.70	47.50	0.0034	19.00	7.10	946,985			277.5	kW
Humidifier	29,750	63.70	47.50	0.0034	19.00	63.70	53.10	0.0063	22.20	3.20	428,400			380.16	lb/hr

Summer peak cooling load of 404 gpm (168 tons)
Summer constant reheat load of 150 kW
Winter peak heating load of 278 kW
Winter peak humidification load of 380 lb/hr

TABLE 3.3 -- REDUCED ANNUAL COOLING AND HEATING LOADS

Existing Conditions, assuming 13,440 CFM of outside air, internal space temperature of 70F, 40% RH.
Assume cooling to 50F discharge when OA is greater than 52F.
Assume free cooling to 62F and reheat to 63.7F when OA is between 30F and 52F.
Assume heating to 63.7F with minimum OA when OA is less than 30F.

PEAK COOLING LOAD 2,021,513 Btuh
DESIGN AIRFLOW 29,750 CFM

PEAK REHEAT KW 150 kW
PEAK HEATING KW 278 kW

DRY BULB	WET BULB	HOURS	OA h	Disch. h	OA Cfm	OA BTUH	RA h	RA BTUH constant	Cooling BTU	Annual Hours	Heat kW	Heating kW-h	
105.0	79.0	0	42.6	17.2	13,440	1,536,192	23.7	477,068	0				
102.0	77.0	0	40.6	17.2	13,440	1,415,232	23.7	477,068	0				
97.0	76.0	6	39.6	17.2	13,440	1,354,752	23.7	477,068	10,990,917				
92.0	74.0	50	37.7	17.2	13,440	1,239,840	23.7	477,068	85,845,975				
87.0	72.0	165	35.9	17.2	13,440	1,130,976	23.7	477,068	285,327,178				
82.0	70.0	324	34.1	17.2	13,440	1,022,112	23.7	477,068	485,734,158				
77.0	67.0	487	31.6	17.2	13,440	870,912	23.7	477,068	656,466,017				
72.0	64.0	681	29.3	17.2	13,440	731,808	23.7	477,068	823,244,216				
67.0	61.0	759	27.2	17.2	13,440	604,800	23.7	477,068	821,137,433				
62.0	57.0	700	24.5	17.2	13,440	441,504	23.7	477,068	643,000,050				
57.0	52.0	604	21.4	17.2	13,440	254,016	23.7	477,068	441,574,434				
52.0	47.0	581	19.2	17.2	13,440	120,960	23.7	477,068	347,453,978	4357			
47.0	43.0	565	16.7	21.5	13,440	-290,304	23.7				16	9,210	
42.0	38.0	572	14.3	21.6	13,440	-435,456	23.7				16	9,324	
37.0	34.0	725	12.6	21.5	13,440	-538,272	23.7				16	11,818	
32.0	30.0	869	10.9	21.5	13,440	-641,088	23.7				16	14,166	
27.0	25.0	589	8.9	21.5	13,440	-762,048	23.7				126	74,129	
22.0	21.0	371	7.8	21.5	13,440	-828,576	23.7				148	54,728	
17.0	16.0	231	6.0	21.5	13,440	-937,440	23.7				169	39,079	
12.0	11.0	164	5.0	21.5	13,440	-997,920	23.7				191	31,296	
7.0	6.0	115	3.0	21.5	13,440	-1,118,880	23.7				212	24,436	
2.0	1.0	89	1.0	21.5	13,440	-1,239,840	23.7				234	20,839	
-3.0	-3.0	53	0.0	21.5	13,440	-1,300,320	23.7				256	13,558	
-8.0	-8.0	27	0.0	21.5	13,440	-1,300,320	23.7				277	7,492	
-13.0	-13.0	11	0.0	21.5	13,440	-1,300,320	23.7				299	3,290	
-18.0	-17.0	2	0.0	21.5	13,440	-1,300,320	23.7				321	642	
-23.0	-21.0	0	0.0	21.5	13,440	-1,300,320	23.7			4383	342	0	
TOTAL		8740							4,580,773,754	Btu/yr		314,004	kW-h/yr
									381,791	Tons/yr			

Annual Energy Consumption

FAN OPERATION				REHEAT DURING COOLING				COOLING				HEATING		TOTAL ANNUAL COST
Fan HP	20	bhp		Reheat	126	kW		CHW Cons.	381,731	Tons/yr		314,004	kW-h/yr	
Oper. Hrs	8760	hrs/yr		Oper. Hrs.	4357	hrs/yr		Efficiency	0.79	kW/ton				1,295,200 kW-h
Annual kW	130,647	kWh/yr		Annual	548,982	kWh/yr		Annual kW	301,568	kWh/yr				

CLEANROOM ENERGY SAVING CONSIDERATIONS

Class 1 Fab

- Overlap in cooling (from ambient to 60°F with CHW) and dehumidification (from 70°F to 43°F with Glycol CHW) coils on makeup air units. This allows for optimization of chiller operation when multiple CHW and Glycol chillers are in use.
- Use indirect air-to-air heat exchangers to preheat or pre-cool outside makeup air with exhaust air (1 cfm/sf for H-6 occupancies) for cleanroom support areas.
- Reduce heat exhaust rate by rejecting non-hazardous or chemical-free from tools to return air stream. This will reduce outside air rate and required humidification and dehumidification.
- Evaporative coolers for humidication of outdoor air in dry climates. Add grains of water without heat or compressed air. Typical applications require pre-cooling, evaporative humidification, trim cooling/dehumidification, and reheat. Pre-cooling discharge temperature control is critical to prevent over-humidification and subsequent dehumidification.
- Heat recovery from RTO discharge for boiler feedwater preheating.

Genentech Inc.
Vacaville Biopharmaceutical Manufacturing Facility

- Energy Rebate and Cost Savings Program

Gary Schoenhouse P.E.
Genentech Inc.
Sr Project Manager

Bruce Douglas
PG&E
Project Manager

Keith Rothenberg
Southern Exposure Engineering
Owner

Agenda

- Brief Project Overview and Milestones
- PG&E Rebate Program
- Energy Analysis and Results
- Project Challenges and Roadblocks
- Q&A

Project Overview and Milestones

- New $250 Million Greenfield Bulk Biopharmaceutical Manufacturing Facility

  - 180,000 Square Foot Bulk Manufacturing
    - Class 10K and 100K Areas
    - 10 Air Handling Units (Approx 400,000 cfm)
    - Process Utilities

  - 18,000 Square Foot Central Utility Plant
    - 3400 Tons Refrigerated Water
    - 3000 SCFM Compressed Air
    - 14000 GPM Tower Water (Process and HVAC)
    - 70,000 LBS/HR High Pressure Steam

  - 40,000 Square Foot Lab/Admin
  - 30,000 Square Foot Warehouse
  - 20,000 Square Foot Facilities Services Building

- Design	1/95 – 10/96
- Construction	8/96 – 5/98
- Start-up / Commissioning	12/97 – 2/99
- Validation	2/98 - ?

- Project Energy Requirements: Title 24

Genentech Vacaville Project
Utility Incentive Program

- Obstacle
  - Capital Cost
  - Information to make decisions
  - Design intent transfer and implementation of energy efficiency measures
- Utility Program Features
  - Incentive to buy down payback of measures to 2 years ($842,400)
  - Paid for most of analysis which quantified energy savings and cost effectiveness
  - Required verification of proper implementation through commissioning

Southern *Exposure Engineering*
(415) 206-9368

Genentech, Inc.
Vacaville Project
Final Summary of the Analysis

Item	Description	Total kW	Total kWh	Total Therms	Annual Savings kW	Annual Savings kWh	Annual Savings Therms	Annual Savings $	Incremental Cost $	Incentive OFFER	Simple Pay Back After Incent (yrs.)
B	Base Case	5,198	19,976,829	1,498,138	-	-	-	$ -		$ -	
1	Lighting Efficiency	5,136	19,848,308	1,498,688	62	128,521	(550)	$ 10,031	$ 21,912	$ 1,849	2.00
2	High Performance Glazing	5,080	19,669,337	1,487,777	56	178,971	10,911	$ 19,282	$ 95,040	$ 56,476	2.00
3	Discharge Air Reset (B-1 AHU's)	5,055	18,914,989	1,288,332	25	754,348	199,445	$151,095	$ 20,000	$ -	0.13
4	ASD's for VAV AHU's	5,024	18,688,510	1,288,332	31	226,479	-	$ 18,118	$ 71,800	$ 35,563	2.00
5	High Efficiency Boilers	5,024	18,687,196	1,211,663	-	1,314	76,669	$ 34,990	$ 117,051	$ 47,072	2.00
6	Boiler Economizers	5,024	18,687,196	1,181,517	-	-	30,146	$ 13,716	$ 87,240	$ 59,807	2.00
7	Tower Water for Process Clg.	4,569	18,393,441	1,181,517	455	293,755	-	$ 62,676	$ 283,876	$158,524	2.00
8	Process Chiller w/ Surge Tank	4,010	18,546,395	1,181,517	559	(152,954)	-	$ 35,894	$ 378,558	$306,771	2.00
9	Process Chiller Efficiency	3,984	18,381,916	1,181,517	26	164,479	-	$ 13,158	$ 24,423	$ -	1.86
10	HVAC Chiller Efficiency	3,847	17,787,589	1,181,517	137	594,327	-	$ 47,546	$ 171,881	$ 76,789	2.00
11	Cooling Tower Approach 8°F	3,826	17,638,936	1,181,517	21	148,653	-	$ 11,892	$ 182,395	$ 99,549	6.97
12	Cooling Tower Approach 4°F	3,777	17,485,999	1,181,517	49	152,937	-	$ 12,235	$ 500	$ -	0.04
13	Tower Control Optimization	3,794	17,386,127	1,181,517	(17)	99,872	-	$ 7,989	$ 5,500	$ -	0.69
14	ASD's for RW Condenser Pumps	3,723	17,154,886	1,181,517	71	231,241	-	$ 18,499	$ 49,737	$ -	2.69
15	ASD's for Primary RW Pumps	3,688	17,034,110	1,181,517	35	120,776	-	$ 9,662	$ 29,063	$ -	3.01
16	ASD's for Secondary RW Pumps	3,654	16,894,226	1,181,517	34	139,884	-	$ 11,191	$ 23,062	$ -	2.06
17	ASD's for Tertiary RW Pumps	3,654	16,787,744	1,181,517	-	106,482	-	$ 8,519	$ 54,291	$ -	6.37
18	ADS's for Heating Water Pumps	3,654	16,705,809	1,181,517	-	81,935	-	$ 6,555	$ 30,515	$ -	4.66
19	RW Evaporator Flow Reset	3,654	16,672,114	1,181,517	-	33,695	-	$ 2,696	$ 4,000	$ -	1.48
20	Environmental Room Floating Head	3,654	16,615,428	1,181,517	-	56,686	-	$ 4,535	$ 6,908	$ -	1.52
21	Vacuum Pump Efficiency	3,652	16,605,292	1,181,517	2	10,136	-	$ 810	$ 7,683	$ -	9.49
22	Motor Efficiency	3,521	15,958,700	1,181,517	131	646,592	-	$ 51,727	$ 117,925	$ -	2.28
	Total Items 1-22	-	-	-	1,677	4,018,129	316,621	$552,818	$1,783,360	$842,400	1.70

03/10/99

Project Challenges and Roadblocks

Finding and Maintaining an Owner Advocate	Genentech Management Buy-in at the Early Stages of the Project Continued Support of Genentech Project Management and Engineers
No Design or Construction Budget Allocated for Energy Saving Alternatives	PG&E Offered to Fund the Majority of the Costs for Idea Development and Analysis PG&E Offered Incentives for Ideas that Exceeded a 2 YR Payback
No Schedule Allocated for Analysis of Energy Saving Alternatives	Integrated Consultant with Design Team and Provided Timely Feedback on Ideas and Recommendations
Design Team Focused on Implementation and Not Evaluation	Separate Group Providing Energy Saving Ideas and Analysis Energy Consultant Must Provide Information in a Timely Basis Not to Impact Design Schedule
Information Flow From Design Team and Equipment Vendors	Analysis Requirements in Equipment Specifications
Ensure that Final Design and Equipment Purchases are Consistent with Energy Saving Options	Include Energy Consultant in Design Package Reviews
Ensure Construction and Commissioning is Consistent with Energy Saving Options	Include Energy Consultant in On-Site Verification and Review of Commssioning Documents Tie Incentives to Commissioned Systems
Ensure Operations Maintains Energy Savings Philosophies	Education and Awareness

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Environmental Energy Technologies Division

Cleanroom
Energy Efficiency Workshop

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."

BARRIERS TO IMPLEMENTATION
OF
ENERGY EFFICIENCY MEASURES

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

BARRIERS TO IMPLEMENTATION
OF
ENERGY EFFICIENCY MEASURES

"Inertia" Issues:

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

Practical Issues

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

BARRIERS TO IMPLEMENTATION
OF
ENERGY EFFICIENCY MEASURES

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

BARRIERS TO IMPLEMENTATION
OF
ENERGY EFFICIENCY MEASURES

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 consumption 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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SECTION I

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Energy Efficiency in High Technology Industry Buildings

March 15, 1999

Dale Sartor, P.E.
Geoffrey Bell, P.E.
Bill Tschudi , P.E.
John Busch, Ph.D.
Ashok Gadgil. Ph.D.

Lawrence Berkeley National Laboratory
Environmental Energy Technologies Division
Applications Team

Research Staff

+

In-House Energy Management

=

ATeam
Energy Efficient Design Applications

Opportunities are Real

- 41% reduction in energy use per square foot from 1985 baseline
- $4.4 million/year more research based on 1985 energy prices
- Pollution reduction
  - 14,174 tons CO_2
  - 12,885 tons SO_2
  - 9,449 tons Nox
- Improved worker productivity
- Safer environment
- Improved reliability

Project Focus: Energy Efficient High Tech Buildings

- Project Funded by the California Institute for Energy Efficiency
- High Tech space such as research laboratories and manufacturing clean rooms serve **California industries of the future**
- High Tech buildings have **unique environmental needs** that are **energy intensive**
- Opportunities for efficiency improvements are significant

CIEE

Energy Efficient High Tech Buildings Sub-Projects

1. Design Intent Documentation
   (Building Life-Cycle Information System)
2. Clean Rooms of the Future
3. Fume Hood Containment - Ultra Low Flow Hoods
4. Airflow Design
5. Field Studies and Performance Feedback
6. Technology Transfer - Laboratory Design Guide

Design Intent Documentation

Objective:

Capture design intent information & performance expectations for use throughout the building's life-cycle.

Design Intent Documentation

Performance Metrics for Laboratories:

- Space Requirements
- Functional Requirements
- Life-Cycle Cost
- Energy-Efficiency
- Indoor Environmental Quality

Illustrative Detail

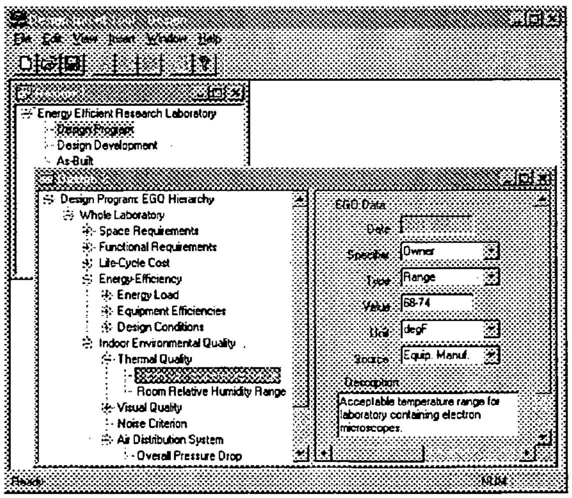
Thermal Quality
- Room Air Temperature Range
- Room Relative Humidity Range (% RH)

Visual Quality

Noise Criterion

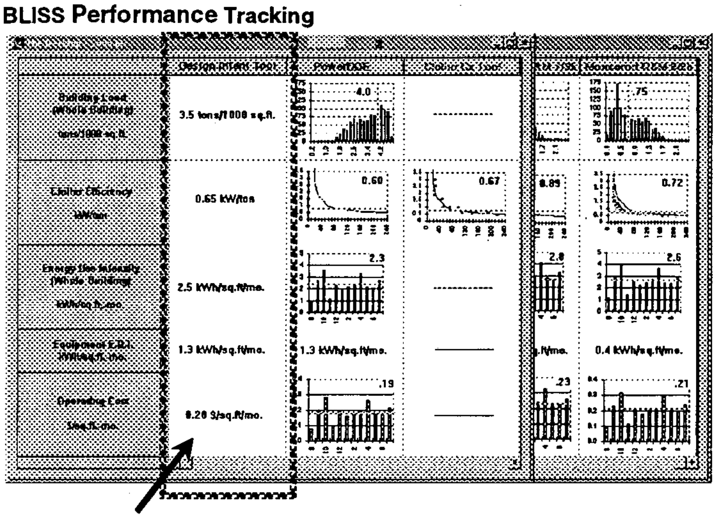
Air Distribution System
- Overall Pressure Drop (in H20, Pa)
- Ventilation
  - Minimum Outside Air
  - Air Changes (ACH)
  - Supply Air Enthalpy
- Air Quality
- Pressurization
- Fume Hoods
- Biological Safety Cabinets
- Air Handling Units
- Exhaust

Design Intent Documentation Tool



Design Intent Documentation Feeds into Building Life-Cycle Information System

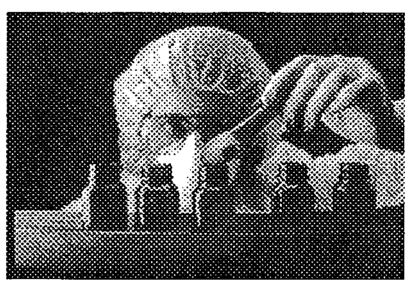
BLISS Performance Tracking



Clean Rooms of the Future

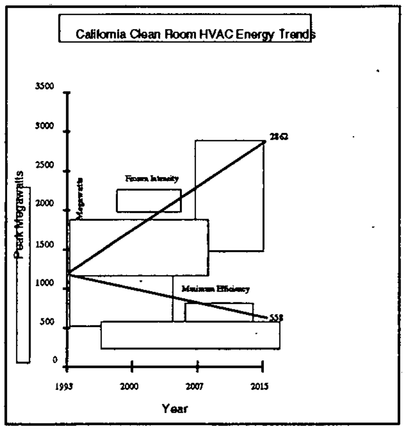
Objective:

Improve energy efficiency and performance of Clean Rooms



California Clean Room Trends

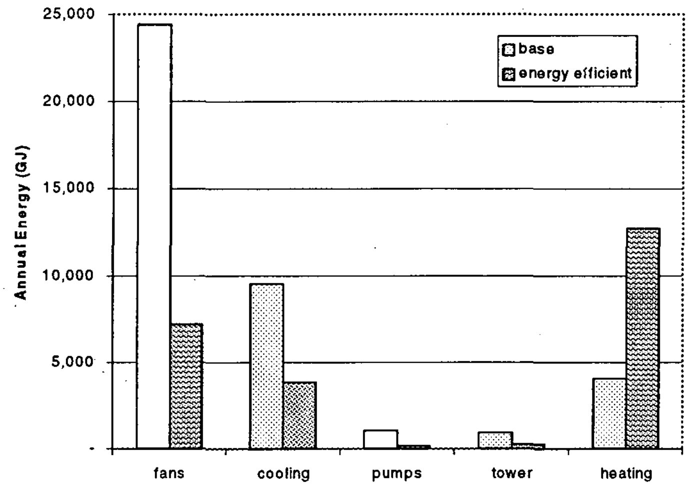
- California Clean Room HVAC consumes 1.2 GW of power and is growing rapidly
- HVAC energy intensities are 10 to100 times higher than ordinary buildings
- Floor area growth projected at 4%/year
- Trend towards cleaner, more energy intensive Clean Rooms
- First order HVAC efficiency potential estimated at 80%
- Savings potential by 2015 exceeds 2 GW of peak capacity



Clean Rooms of the Future: Efficiency Measures

1. Improve motor efficiency and selection
2. Improve fan efficiency (as installed - including system effect)
3. Reduce system static pressure
   - low face velocity/high coolant velocity coils
   - low pressure drop filter systems
   - low velocity (and pressure) air distribution
4. Improve chiller plant efficiency
   - right size
   - separate high and low temperature requirements (e.g. cool recirculated air with 60 degree water)
   - optimize entire system
5. Optimize air flow design
6. Use advanced modeling (CFD) to optimize room design
7. Improve and integrate sensors, controls and monitoring
8. Reduce outside air
9. Improve heating system efficiency
10. Use heat and cool recovery

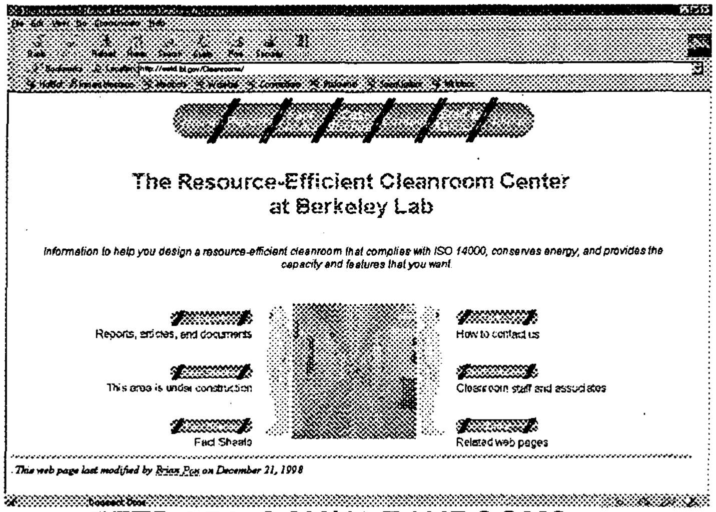
Cleanroom End-Use Energy Breakdowns



Current Cleanroom Work

- Survey of design tools
- Evaluation of design and analysis programs
- Design Charrette
- Technology transfer
  - Workshop
  - Case studies
  - Collaboration w/industry
  - Web site

LBNL Cleanrooms Website

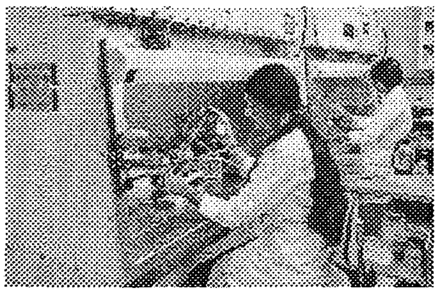


EETD.LBL.GOV/CLEANROOMS

Fume Hood Containment - Ultra Low Flow Hoods

Objective:

Reduce fume hood air flow requirements at least 50%

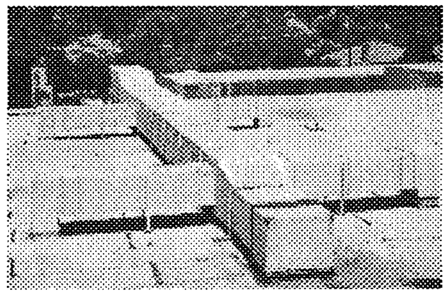


Airflow Design

Objective:

Develop airflow design criteria and tools to optimize fan power consumption

- Airflow design has extraordinary impact on energy and performance of high tech buildings.
- Systems approach required
- Design guide completed
- Model for dynamic multi-fan systems underway

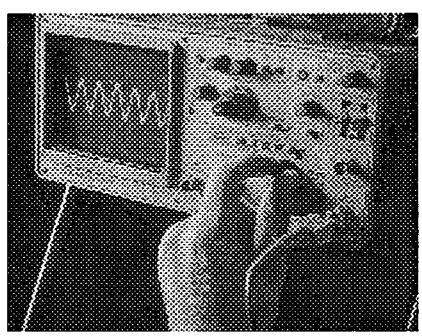


Field Studies / Performance Feedback

Objective:

Provide feedback to designers and operators of actual building loads and performance (reduce oversizing)

- Performance Metrics
- Database
- Feedback Mechanisms



Technology Transfer: Laboratory Design Guide

"I received your guidelines for "Energy Efficient Research Laboratories" today and want to really thank you. I am extremely impressed with its scope and in-depth information. I have read several published books on lab design and mechanical engineering that do not come near to communicating the amount of information that you have assembled in your design guideline." (Frank Kutlak, NIH)

"I handed my copy of your design guide to our plant division and they were in seventh heaven - everyone is very impressed. However, I now do not have a hard copy. In addition they asked for 4 more copies for their various branches..." (Steve Hagan, NIST)

"The FDA is involved in the design of numerous large facilities including laboratories. I have been to the web site and found the information very interesting and useful. I have forwarded your web site address to the numerous A & E firms that the FDA is working with. (Clyde Messerly, FDA)

ATEAM.LBL.GOV/DESIGN-GUIDE

Application of "Air Dam" Technology to Semiconductor Manufacturing

Objective:

Reduce Process Tool Exhaust Requirements

[1] wet benches

[2] spin on coaters

Benefit: Cost Savings

[1] ~$4 per cfm in annual operating expense

[2] >$75 per cfm in capital avoidance

Issues: Adaptability to Semiconductor Process Equipment

Impact on Wafer Yield

Benefits Validation/Technology Acceptance

ES&H Buy In

LBL Exhaust Reduction Technology Potentially Can Reduce Clean Room Cost

7 Commerce Drive
Danbury, CT 06810-4169
Phone (203) 794-1100
Fax (203 794-8040

Development Program Outline For Wet Cleaning Stations

Focus: Open Architecture and Mini Environment

Design: Integrate Air Dam Into Existing State-of-the-Art Equipment

Estimate 3-4 months to complete

Modeling: Optimize Design Using Fluid Dynamic Models

Estimate 1-2 months to complete

Prototypes: Build Full Scale Working Tools

Estimate 6-8 months to build and release prototypes

Testing: Acquire and Assess Fab Operation Data

Estimate 6 months to report results

Technology Development Phase Will Take ~18 Months.
Cooperation With Sematech and OEMs Will Shorten Time

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