CLEANROOM BENCHMARKING PROJECT
SITE REPORT

FACILITY E
BUILDING E.1

AUGUST 2001

LAWRENCE BERKELEY NATIONAL LABORATORY
HIGH TECH BUILDINGS PROGRAM

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PREPARED BY:
SUPERSYMMETRY
99 LINDEN STREET
OAKLAND, CA 94607
WWW.SUPERSYM.COM

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Project Team

Pacific Gas & Electricity

Kathleen Benschine
Stephen Fok
Dino Pecararo
Don Hall

Lawrence Berkeley National Laboratory

Dale Sartor
Bill Tschudi
Tim Xu

Supersymmetry

Peter Rumsey
Larry Chu
Dave Harsh
Peter Stevens
Richie Rodriguez
Joe Regester
John Weale

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APPENDICES

I. EXECUTIVE SUMMARY

As part of PG&E's Cleanroom Benchmarking Project, energy use at a cleanroom facility was monitored during April and May 2001. Two class 100 cleanrooms located in Facility E Building E.1 were monitored for a period of two weeks. Facility E Building E.1, built in the 1960's, is a facility that houses wafer fabrication and testing cleanroom areas.

This site report reviews the data collected by the monitoring team and presents a set of performance metrics as well as a complete set of trended data points for the end uses of energy for equipment supporting and located in the cleanrooms. In addition, data from Facility E's central chilled water plant is included in this report. Some of the most important metrics are summarized below in Tables 1 and 2.

Table 1. Summary of Important Metric Results for Facility E's Central Plant*

Metric Name	**Metric Value**	
Central Plant Chiller Efficiency	0.58	kW/ton
Central Plant Chilled Water System Efficiency	0.93	kW/ton
Annual Energy Cost	4,250,000	$/yr

* *This data is from year2000.*

Table 2. Summary of Important Metric Results for Facility E Building E.1

Metric Name	**Metric Value**	
Glycol Chilled Water System Efficiency	1.6	kW/ton
Cleanroom 1 Class 100/1000 Recirculation Fan Efficiency	2,390	cfm/kW
Cleanroom 2 Class 100 Recirculation Fan Efficiency	4,830	cfm/kW
Annual Energy Cost *per Square Foot of Cleanroom – Cleanroom 1**	27	$/sf·yr
Annual Energy Cost *per Square Foot of Cleanroom – Cleanroom 2**	56	$/sf·yr

* *This data represents an estimate.*

The metrics of the central plant indicate that the chillers are operating at a good efficiency level. The metrics for the HVAC systems at Building E.1 show that there are opportunities for energy efficiency. In general a glycol chilled water system is less efficient than a water-only chilled water system. The efficiency of the glycol chilled water system of 1.6 kW/ton is very poor. This is due to the use of central plant chilled water for the condenser side of the glycol chillers. An efficiency gain can be made by the glycol chilled water system by installing a cooling tower to supplement the central plant chillers.

The recirculation systems for the Cleanroom 2 is as efficient as other class 100 designs, which can achieve from 3,000 – 5,000 cfm/kW. Cleanroom 1, a fan filter cleanroom has an efficiency of 2,390 cfm/kW. This efficiency is above average when compared to other class 100 fan filter based cleanrooms with a typical average efficiency of 1,500 cfm/kW. Fan filter unit based systems are less efficient for two reasons, one is that the fan filter units themselves operate with smaller, inherently less efficient motors, the second is that the recirculation air handling units expend energy to move air only for sensible cooling and contribute nothing to the delivery of air into the cleanroom. Improvements to the operation efficiency of these cleanroom air handling systems, without major overhaul, could be achieved through balancing and using lower pressure drop filters.

The monitoring team observed a number of opportunities for potential energy savings at the facility. A summary of these observations follows and a more detailed discussion can be found in Section VII "Site Observations Regarding Energy Efficiency".

Cooling Tower for Glycol Chiller and Process Chilled / Cooling Water Heat Exchangers

A cooling tower can be used to provide cooling to the glycol chillers, and process chilled water and process cooling systems, replacing chilled water from the plant altogether at times. Overall, for a significant portion of the year when the cooling tower is operating, the load to the central chilled water plant will be reduced.

Glycol Chilled Water Supply Temperature Reset

During the nighttime hours, less dehumidification of the air stream in the make up air handler is required. Based on the outside air conditions at night, the supply temperature of glycol chilled water can be increased. Raising the temperature will reduce the energy input to the glycol chillers by improving the chiller efficiency.

Reheat Control for Cleanroom 1

The make up air handler operates with a fixed reheat setpoint. By reducing the amount of reheat, both the reheat load on the make up unit and the cooling load on the recirculation air handler are reduced.

Replace Electric Humidifiers

Electric humidifiers are the most energy intensive method of humidification and alternative humidifier types should be considered when the electric units require major repair or replacement. A steam to steam humidifier would be a good choice since steam is already plumbed to Building E.1. An airless humidifier should also be considered.

Low Pressure Drop HEPA Filters and Pre-filters

When replacing HEPA filters in the cleanroom ceiling, use filters that are 4" or 7" thick. These filters reduce the recirculation fan power required. Replacing pre-filters with ones that are deeper or with bag filters will also result in less pressure drop.

II. INTRODUCTION

The Cleanroom Benchmarking project aims to establish energy metrics with which cleanroom owners can evaluate their energy efficiency performance and identify opportunities for improvements that reduce their overall operating costs. The project is administered by PG&E and funded through the California Institute for Energy Efficiency. The Facility E Cleanroom Benchmarking Site Plan presented to the Facility Engineer April 11, 2001 describes the monitoring process used in collecting the data presented in this Site Report. (See Appendix G.) The General Plan for the Cleanroom Benchmarking Project provides additional information on the program.

With this report, Facility E is receiving the energy monitoring data collected at its facilities as a service provided by PG&E to participants in the Cleanroom Benchmarking Project. This Site Report summarizes the data collected and presents energy performance metrics with which Facility E can evaluate the performance of its cleanroom facilities. First, the report reviews the site characteristics, noting design features of the mechanical plant and the cleanrooms monitored. Second, the energy use for the mechanical plant and cleanrooms is broken down into major components. Third, performance metrics recorded through the Cleanroom Benchmarking Project are presented. Finally, key energy efficiency observations for Facility E's facility will be noted. The data collected, trended graphs and methodology documentation are included among the appendices. Data for all cleanrooms benchmarked under this program will appear on the LBNL website in an anonymous fashion.

III. REVIEW OF SITE CHARACTERISTICS

A. Campus

Facility E's Campus in PG&E's service territory consists of more than 20 buildings. Chilled water is produced at a central plant located in Building E.2 and dispersed throughout the entire campus. This chilled water serves recirculation and make up air handlers, glycol chillers, process cooling and process chilled water heat exchangers, and compressor cooling water. The chilled water central plant is made up of 12 centrifugal water-cooled chillers, 1 cooling tower with 5 cells, 12 chilled water pumps and 5 condenser water pumps. The central plant also provides steam and compressed air for the cleanrooms in Building E.1.

B. Building E.1 Facility

Facility E Building E.1 was built in the 1960's and houses wafer fabrication and wafer testing cleanrooms. Facility E employees work around the clock during three shifts each day, seven days a week. The environmental systems serving the cleanrooms therefore run 8,760 hours a year in order to maintain conditions.

The cleanrooms chosen for the monitoring are Cleanroom 1 (7,075 sf) and Cleanroom 2 (12,100 sf). (See Appendix F for building layout). Cleanroom 1 is a class 100/1000 rated facility and the Cleanroom 2 is a class 100 rated facility.

Glycol chilled water is produced in a building adjacent to Building E.1 by five water-cooled chillers connected by a common header. The glycol chilled water serves two buildings in addition to Building E.1. The chillers are rated at 200 nominal tons apiece. One of the chillers is controlled by a variable frequency drive (VFD). Glycol chilled water at a temperature of 36°F is supplied to the make up air handlers that use a dehumidifying cooling coil. Glycol chilled water is used in the make up air handler in Cleanroom 1.

Over the monitoring period from April 24, 2001 to April 30, 2001 the outside air conditions ranged from 47°F to 83°F (see Appendix B for trended data). During that time the glycol chillers operated at an average load of 497 tons with a standard deviation of 69 tons and an overall range from 311 to 782 tons. In addition, only three chillers of the five were in operation during the monitoring period.

Hot water is provided in a secondary loop through a heat exchanger with steam being the primary source. Hot water is used in the reheat coils of the make up air handlers. Steam is used in Cleanroom 1 make up air handler's humidifier. Steam is also used to regenerate the desiccant of the desiccant dehumidifying make up air handlers in the Cleanroom 2.

Process Chilled Water Heat Exchanger

Process chilled water and process cooling water are circulated in secondary loops through heat exchangers with the central chilled water. The two loops of water are used for cooling of the process tools located in the building's several cleanrooms. Process cooling water is mixed with de-ionized (DI) water, while process chilled water is unmixed. Process chilled water is used in the Cleanroom 2, while neither is used in Cleanroom 1.

The compressed air produced at the central plant is sent through a series of dryers located in Building E.1 to produce clean dry air (CDA). Process vacuum is produced by many different systems. In addition, process vacuum is shared between cleanrooms. Several cleanrooms in Building E.1 are supplied with de-ionized water as well as liquid nitrogen. Chemical waste is treated by an industrial waste treatment system shared by the entire campus. General air exhaust and scrubbed exhaust are also used in the cleanrooms. A carbon absorption scrubber exhaust unit is shared among the cleanrooms in Building E.1 and two other buildings. Cleanroom 2 is a heavy user of the scrubber. As a lower priority, the monitoring team did not collect energy use data for components of these systems.

C. Cleanroom 1 Design

Cleanroom 1 is a 7,075 sf class 100/class 1,000 fan filter based facility. The fabrication area is split into two classes such that the class 100 area exists at the location of the tools and the class 1,000 area exists at the walkways. The fabrication area is 5,480 sf composed of 1,830 sf of class 100, 2,120 sf of class 1,000 area and 1,530 sf of core areas (return air chase areas). Cleanroom 1 also includes a class 1,000 gowning area (620 sf), a class 10,000 Change Room (175 sf) and 800 sf of locker space. Only the class 100/1000 fabrication areas are considered primary cleanroom area, totaling 3,950 sf. The return cores are considered secondary cleanroom areas, which is 1,530 sf.

Cleanroom 1's area is served by 406 fan filter units with HEPA filter coverage of 100% for the class 100 areas, 50% for the class 1000 areas and 30% for the class 10,000 areas. Of the 406 fan filter units, 360 serve the fabrication area. Cleanroom 1 is served by one make up air handler and one recirculation air handler for sensible cooling. Both units are located on the roof. The make up air unit delivers its air to two discharge ducts connected to the recirculation air handler: one duct serving the fabrication areas and one serving the gowning/locker areas. The supply air to the fabrication areas is delivered near the bottom of the core return areas. The make up and recirculation air handlers are equipped with VFDs.

Make Up Air Handler

The make up air handler is served with chilled water from the central plant, glycol chilled water, heating hot water, steam and de-ionized water. Steam is used to make humidifying DI water. The recirculation air handler is served with only central plant chilled water. There is one general exhaust fan that serves the fabrication areas and exhausts directly to the outdoors without a scrubber.

Recirculation Air Handler

The condition specifications for the cleanroom are 70°F ± 2°F and 40% ± 5% relative humidity. During the monitoring period, the average measured temperature was 70°F with a fluctuation of less than 0.5°F, and the measured relative humidity was 42% with a fluctuation of 3%. The room was under a positive pressure of 0.07" water gage with respect to the corridor. This was a spot measurement taken during the monitoring period.

D. Cleanroom 2 Design

Cleanroom 2 is a class 100 pressurized-plenum cleanroom with approximately 100% HEPA coverage. Cleanroom 2 is 12,100 sf, consisting of 10,570 sf of fabrication area, and 1,530 sf of return chases. All of the class 100 fabrication area is considered primary cleanroom area. The return cores are considered secondary cleanroom areas.

Cleanroom 2 is served by a single make up air handler system located on the roof. The make up air handler system consists of two heat- regenerated desiccant air handlers in series with a pair of cooling/reheat coil air handlers (see cleanroom schematic in Appendix F). The pair of cooling/reheat coil air handlers is used to cool the discharged air from the desiccant dehumidifier units since the air leaves them at temperatures over 100 °F when dehumidifying. The reheat is used for heating the air when dehumidification is not needed. The cooling/reheat coil air handlers are equipped with VFDs. In Cleanroom 2, the supply air is ducted into an interstitial space in which 30 recirculation air handlers for sensible cooling are situated. The recirculation units are controlled by VFDs that have been set to a constant speed. The return air for Cleanroom 2 is directed through a raised floor return.

Desiccant Dehumidifier Make Up Air Handler

The desiccant dehumidifier air handler is served with steam and chilled water from the central plant, while the cooling/reheat coil air handlers are served with central plant chilled water, and heating hot water. Eight electric humidifiers using DI water are plumbed into the supply trunk that enters the interstitial space. The recirculation air handlers are served with only chilled water from the central plant. There are four exhaust fans and a shared scrubbed exhaust that serve the Cleanroom 2 area.

The condition specifications for the cleanroom are 71°F ± 1°F and 38% ± 2% relative humidity. During the monitoring period, the average measured temperature was 71°F with a fluctuation of less than 0.5°F, and the measured relative humidity was 35% with a fluctuation of 2%. The room was under a positive pressure of 0.05" water gage with respect to the corridor. This spot measurement was taken during the monitoring period.

Table 3. Measured Air Handling Parameters for Cleanroom 1 and Cleanroom 2

Description	*Cleanroom 1*		*Cleanroom 2*	
Class 100 Primary Area	3,950	sf	10,570	sf
Total Make Up Air	4,100	cfm	82,660	cfm
Total Make Up Fan Power	3.9	kW	104	kW
Total Recirculation Air **	148,200	cfm	486,100	cfm
Total Recirculation Fan Power ***	62	kW	101	kW
Room Air Changes per Hour	225	ACH	276	ACH
HEPA Filter Ceiling Coverage	73	%	98	%
Average Ceiling Filter Velocity ****	61	fpm	55	fpm

* *This data was either not measured or unavailable at the time of the report.*
** *Recirculation Air is the air delivered to the cleanroom, based on the measured filter flow.*
*** *Recirculation fan power includes both RCU and FFU power for Cleanroom 1.*
**** *Filter velocity based on average filter flow and 6.8 sf (85%) effective filter area.*

IV. SITE ENERGY USE CHARACTERISTICS – Building E.1

A. Site Energy Use

PG&E gas and electricity billing data was not available for Building E.1 since it is not metered at this level. For purposes of this report all energy consumption is based on the average power consumption monitored over the monitoring period unless noted otherwise.

Table 4. Annual Energy Utilization Intensity (EUI) and Energy Cost per Square Foot

Description	Primary Area (sf)	Energy Utilization Intensity (kWh/sf·yr)	Annual Energy Cost per Square Foot ($/sf·yr)
Cleanroom 1	3,950	468	27
Cleanroom 2	10,570	1090	56

Energy from natural gas has been converted to kWh for the EUI calculation.

B. Central Plant (Building E.2) Energy Use

The monitoring of the central plant was not included in the scope of this project. However, the data presented below was from trended data for the year 2000.

Table 5. Central Plant Energy Use by Major Components

Description	Average Load (kW)	Average Efficiency (kW/ton)	Annual Hours of Operation	Electricity (MWh/yr)	Total Natural Gas (Therms/yr)	Total Cost (per yr)*
COOLING						
Chillers	4,640	0.58	8,760	40,700	-	$2,640,000
Cooling Towers	1,500	0.19	8,760	13,100	-	$852,000
Pumps	1,330	0.17	8,760	11,600	-	$756,000
TOTAL	7,470			65,400	-	$4,250,000

* *For the purposes of benchmarking comparisons, cost of electricity and gas assumed to be constant (without time of day or demand rate structure): $0.065/kWh and $0.75/Therm.*

C. Building E.1 Mechanical Plant Energy Use

The glycol chilled water plant can be examined by treating the system as a whole system. Treating the system as a whole to get an effective energy use can be achieved by accounting for the load the central plant has to reject. Recall that the condenser loop of the glycol chillers is actually connected to the chilled water loop of the central plant. The process chilled water system can be analyzed in the same manner.

Table 6. Estimated Energy Use by Major Components

Description	Average Load (kW)	Average Efficiency (kW/ton)	Annual Hours of Operation	Electricity (MWh/yr)	Total Cost (per yr)*
COOLING					
Glycol Chillers	[222]**	0.58	8,760	[1,950]	[-]**
Pumps	[32]**	0.17	8,760	[283]	[-]**
Glycol Chilled Water System	792	1.6	8,760	6,930	$451,000
Central Chilled Water Plant Power Attributed to PCHW Heat Exchanger Load	146	0.94	8,760	1,280	$83,100
PCHW Pumps	33	0.22	8,760	290	$18,900
TOTAL	971			8,500	$553,000

* *For the purposes of benchmarking comparisons, cost of electricity and gas assumed to be constant (without time of day or demand rate structure): $0.065/kWh and $0.75/Therm.*

** *Load and cost is accounted for in the "Glycol Chilled Water System" field.*

D. Cleanroom Energy Use

The energy consumption attributed to the cleanroom air handling system, process tools, and lighting are reported for Cleanroom 1 and Cleanroom 2 in Table 7 and Table 8, respectively. This breakdown of energy use by equipment helps identify major loads and its related costs. A further step was taken to determine the amount of energy used by the cooling/reheat coils and humidification of the make up and recirculation air handlers, as well as the energy used by the steam regenerating dehumidifiers.

Table 7. Cleanroom 1 Estimated Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (CFM/kW)	Annual Hours of Operation	Electricity (MWh/yr)**	Natural Gas (Therms/yr)	Total Cost (per yr)***
AIR HANDLING						
Make Up Fans	3.9	1,070	8,760	34	-	$2,190
Recirculation Fans*	62	2,390	8,760	546	-	$35,500
Glycol Chiller Power Attributed to MUAH Dehumidifying Glycol Cooling Coil Load	-	-	-	41	-	$2,690
Central Chilled Water Plant Power Attributed to MUAH + RCU Cooling Coil Loads	-	-	-	286	-	$18,600
Humidification	-	-	1,550	-	297	$223
Heating	-	-	-	-	12,900	$9,670
PROCESS	58	-	8,760	508	-	$33,000
LIGHTS	4.8	-	8,760	42	-	$2,750
TOTAL	129			1,460	13,200	$105,000

* *Recirculation Fans includes both RCU and Fan Filter Units.*

** *Annualization based on one week of data.*

*** *Cost of electricity and gas assumed to be constant (without time of day or demand rate structure): $0.065/kWh and $0.75/Therm.*

The energy use of the environmental systems for Cleanroom 1 is broken down by component with the exception of exhaust use. The recirculation fan energy (RCU Fan + FFU) accounts for 42% and heating energy accounts for roughly one-third of the total environmental systems energy use. Recirculation fan energy is a large portion of the energy use due to the two stages of fans. Heating energy is also a large portion of the pie since reheat is used almost year-round to heat up the low temperature air off of the dehumidifying coil. Central plant chilled water energy use for sensible cooling is also a notable portion of the environmental system energy use.

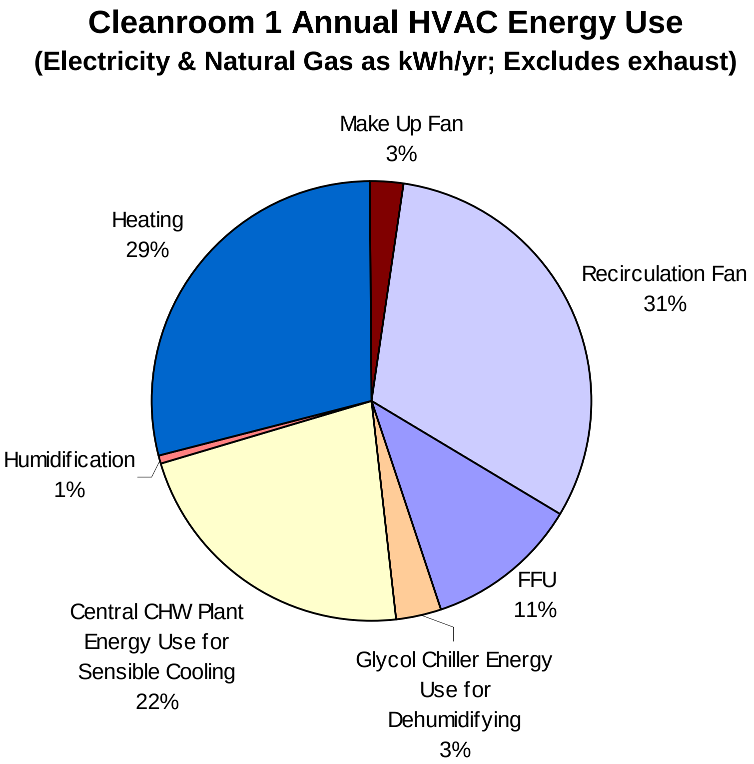


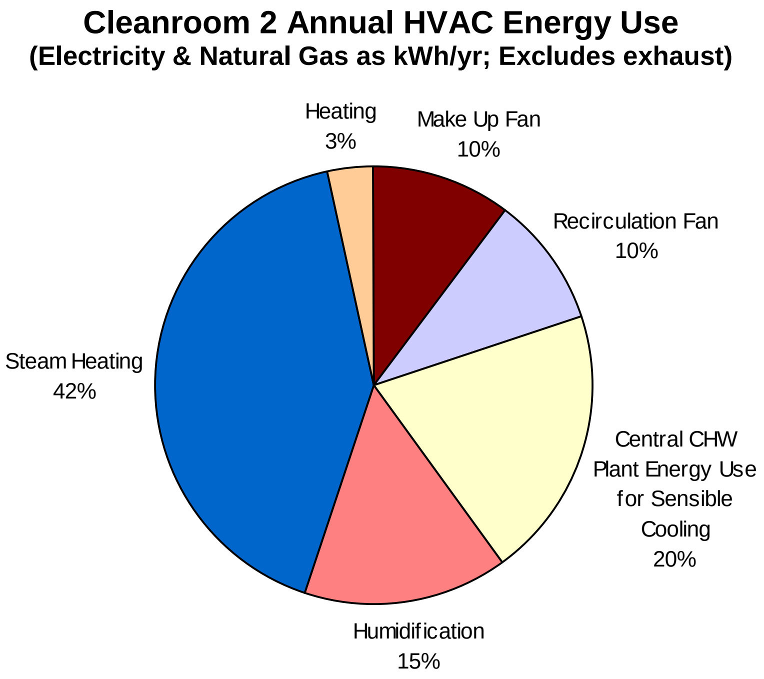
Table 8. Cleanroom 2 Estimated Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (CFM/kW)	Annual Hours of Operation	Electricity (MWh/yr)*	Natural Gas (Therms/yr)	Total Cost (per yr)**
AIR HANDLING						
Make Up Fans	104	793	8,760	914	-	$59,400
Recirculation Fans*	101	4,830	8,760	882	-	$57,300
Central Chilled Water Plant Power Attributed to MUAH System + RCU Cooling Coil Loads	-	-	-	1,790	-	$116,000
Humidification	151	-	8,760	1,320	-	$86,000
Heating	-	-	-	-	138,000	$103,000
PROCESS	272	-	8,760	2,380	-	$155,000
LIGHTS	24.4	-	8,760	214	-	$13,900
TOTAL	652			7,500	138,000	$591,000

* *Annualization based on one week of data.*

** *Cost of electricity and gas assumed to be constant (without time of day or demand rate structure): $0.065/kWh and $0.75/Therm.*

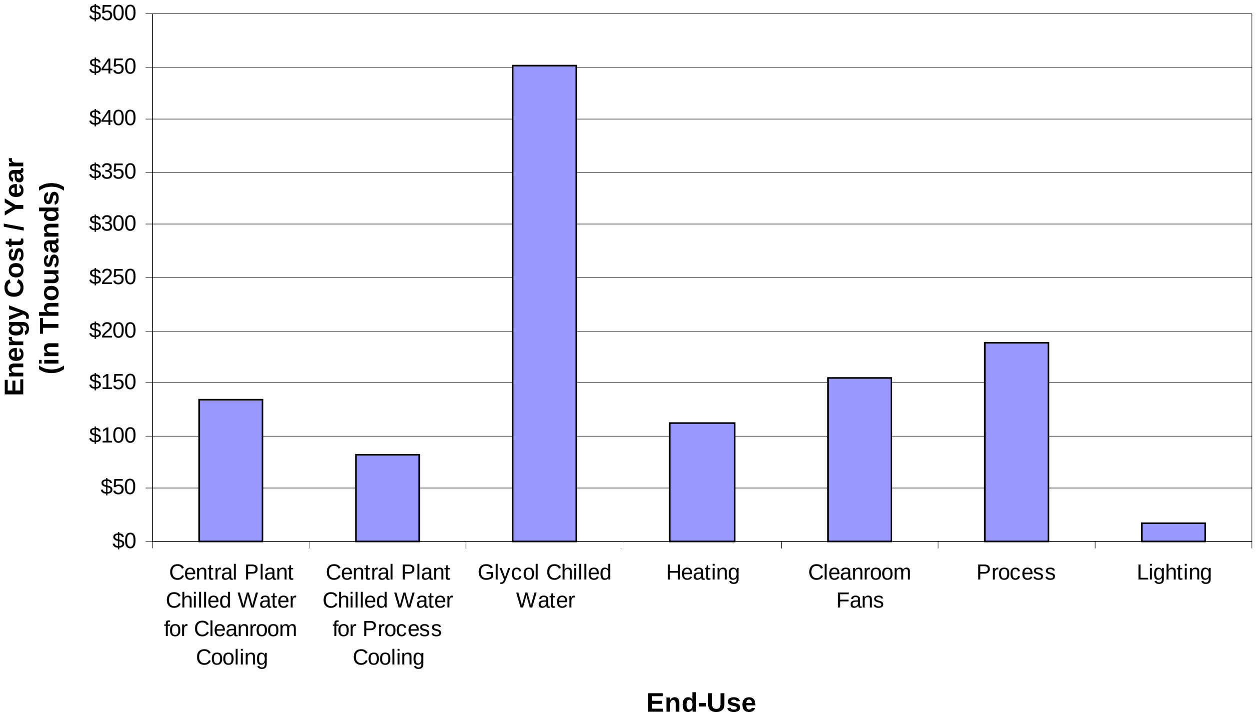
The following pie chart breaks the energy use of the cleanroom environmental systems into components with the exception of exhaust use. The make up fan is a heavier user of energy due to the large volume of exhaust in the cleanroom and the type of system used. This make up air handler system uses desiccant as a means of dehumidifying and has five fans in operation. Steam used for regenerating the desiccant continuously flows through the coil regardless of dehumidification needs. This accounts for 42% of the HVAC energy use. Humidification energy accounts for 15% of the total environmental energy use since electric humidifiers are energy intensive. The desiccant dehumidifying make up air handler may be currently over dehumidifying, resulting in re-humidification of the air stream.



Cleanroom 2 Annual HVAC Energy Use

(Electricity & Natural Gas as kWh/yr; Excludes exhaust)

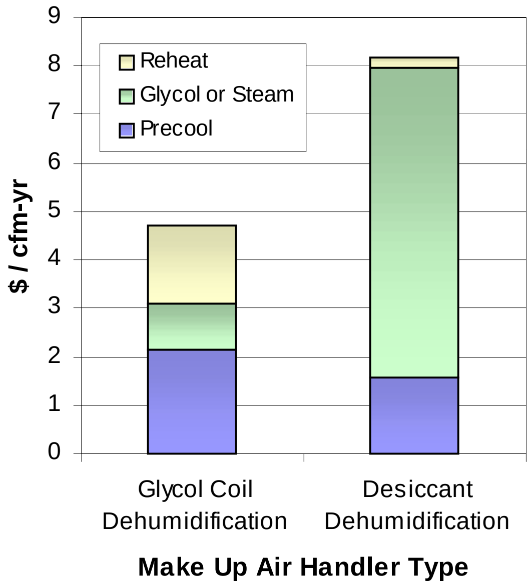
E. Annual Building E.1 Estimated Energy Costs



The bar chart above illustrates the cost of supporting the major energy end-uses in Cleanroom 1 and Cleanroom 2, including the costs of the glycol chilled water and process chilled water systems. The largest annual energy cost is attributed to the operation of the glycol chilled water plant. This is due to the condenser coils of the glycol chillers using central plant chilled water, adding an extra load to the chillers of the central plant.

V. COMPARISON OF DESICCANT DEHUMIDIFYING & GLYCOL COIL DEHUMIDIFYING

The cost of the two methods of dehumidifying air in make up air handlers is compared below. Air in both types of make up air handlers is dehumidified until the dewpoint setpoint of the cleanroom temperature is reached. However, steam that is supplied to the heating coil for regeneration of the desiccant is fed at a constant rate regardless of dehumidification requirements. This results in a significant amount of energy expended to generate steam. The cost of desiccant dehumidification is about 1.7 times as much as using glycol for dehumidification. The comparison uses the design conditions (outside air drybulb temperature of 72 °F and 86.5% RH) of the desiccant dehumidifier as a base case.



Desiccant Dehumidifying Versus Glycol Coil Dehumidifying

VI. SYSTEM PERFORMANCE METRICS

Metrics are ratios of important performance parameters that can characterize the effectiveness of a system or component. In order to gage the efficiency of the entire building system design and operation, the Cleanroom Benchmarking Project tracks 35 key metrics at four different system levels – energy consumption, central plant, process utilities, and cleanroom. These metrics can be used to compare designs or determine areas with the most potential for improvement via retrofit or replacement.

Cleanroom Annual Resource Use

The following metrics in Table 9 are for Cleanroom 1 and Cleanroom 2. They are based on the measured loads in the space, including process loads, fan loads, lighting, and the make up air conditioning load (annualized using a bin weather data analysis and measured delivery conditions).

The temperature and humidity conditioning method used for the make up air usually requires outdoor air be cooled to the desired dewpoint then reheated to the desired delivery temperature, observed to be about 68 °F for these areas. The constant cooling and reheat base load reduces the impact of outside conditions and results in a fairly constant energy demand even for the load most directly tied to outdoor conditions.

Table 9. Estimated Cleanroom Annual Resource Use*

Description	***Cleanroom 1***		***Cleanroom 2***	
Annual Energy Cost *per Cleanroom Square Foot*	27	$/sf	56	$/sf
Annual Fuel Usage	3.34	Therms/sf/yr	13.0	Therms/sf/yr
Annual Electricity Usage	370	kWh/sf/yr	710	kWh/sf/yr

** Based on Building E.1 energy measurements, weather data, load assumptions and primary cleanroom area.*

Mechanical Plant

Metrics of kW/ton are based on the total average equipment power for the chilled water plant and the average operating tonnage of the total chilled water plant. These figures are useful for making comparisons between facilities, but more substantial information is expressed in the metric plots in Appendix B that reflect kW/ton performance at a sampling frequency of one minute over the course of a week. This type of information can be used to diagnose operational problems as well as evaluate the overall design performance.

Table 10. Mechanical Plant

Description	*Metric*
Total Glycol Chilled Water Plant Efficiency	1.6 kW/ton
Glycol Chilled Water Pumps Efficiency	0.07 kW/ton

Process Utilities

The measurements required to calculate process utilities metrics were low in the priority list established for the Facility E Site Plan (see Appendix G). These metrics were not collected during the monitoring period due to time constraints.

Cleanroom 1 and Cleanroom 2

For Facility E, the cleanroom HVAC components operate at a fairly constant level throughout the year. Therefore, these metrics are based on spot measurements. All of the metrics involving area are based on the primary cleanroom area, which is the area that passes certification for Class 100.

Both of these cleanroom facilities have moderate to good recirculation air handling efficiency as compared to other Class 100 cleanroom designs. The pressurized plenum system has a markedly better performance than the fan filter unit (FFU) design.

Cleanroom 1 employs a fan filter unit design with recirculation air handlers for sensible cooling mounted in the interstitial space. Though this design provides for a much lower pressure drop air path with low velocity airflow through plenum spaces, the overall system efficiency is lower than that for the pressurized plenum system in the Cleanroom 2. One reason for this is that there are two stages of motors and fans - the RCUs and the FFUs. The recirculation units (and make up air) are discharging into the interstitial space where the FFUs then push the air through the ceiling filters into the cleanroom. The recirculation units are essentially acting as fan coil units to condition and distribute the air, and their fan energy contributes nothing to the recirculation air delivery to the cleanroom. Also the small fans and motors in the FFUs are inherently less efficient than larger fans. Due to the inefficient fans and motors, the FFU system has a significantly poorer performance than the pressurized plenum system.
The make up air handler in Cleanroom 1 is performing poorly. The high face velocity due to the physical proportions of the make up air handler results in high pressure drops, and therefore higher fan energy consumption. Cleanroom 2’s make up air handler system’s efficiency is also poor. This is due to the fact that the dehumidifying desiccant wheel make up air handler has multiple fans: three for the reactivation side and one for the cleanroom supply side. Furthermore, another fan is used in the cooling/reheat coil make up air handler.

The cleanroom components operate at a constant level throughout the year. Therefore, the following metrics below are based on a spot measurement. The metrics involving area are based on primary cleanroom area.

Table 11. Cleanroom 1 & Cleanroom 2*

Description	*Cleanroom 1 Metric*		*Cleanroom 2 Metric*	
MUAH Efficiency	1,070	cfm/kW	793	cfm/kW
Make Up Air CFM/sf	1.0	cfm/sf	7.8	cfm/sf
Make Up Fan Power Density	1.0	W/sf	9.9	W/sf
Recirculation Air Handler Efficiency	2,390	cfm/kW	4,830	cfm/kW
Recirculation Air CFM/sf**	38	cfm/sf	46	cfm/sf
Recirculation Air ACH**	225	ACH	276	ACH
Recirculation Fan Power Density	16	W/sf	9.6	W/sf
Lighting Power Density	0.7	W/sf	2.3	W/sf
Process Tools Power Density	15	W/sf	26	W/sf

* *This data was calculated based on measured data.*

VII. SITE OBSERVATIONS REGARDING ENERGY EFFICIENCY – Building E.1

There appears to be a number of potential areas for energy savings in Facility E Building E.1. Some areas of energy savings in Building E.1 will also create energy savings in the Building E.2 central plant. This section includes a general description of some of the most significant opportunities observed by the monitoring team.

Cooling Tower for Glycol Chiller and Process Chilled / Cooling Water Heat Exchangers

The glycol chilled water plant is currently operating at 1.60 kW/ton due to the use of the central plant return chilled water in the glycol chiller condenser loop. Installing a supplemental cooling tower will reduce the energy consumption of the campus. During periods of low outdoor air temperature or humidity, such as during the winter or at nightime, the cooling tower would provide low temperature condenser water to the glycol chiller, almost halving the overall energy cost of the glycol loop chilled water.

For a notable portion of the year, the cooling tower loop can also serve the current central plant chilled water loop feeding the process chilled water and process cooling water heat exchangers. The current efficiency of the process chilled water system is 0.98 kW/ton. A cooling tower can be used to provide free cooling to the system, replacing chilled water from the plant altogether at times.

Overall, for a significant portion of the year when the cooling tower is operating in free cooling mode, producing water at or below 55°F, the load to the central chilled water plant will be reduced. At times when the tower is merely serving the glycol chiller, the power consumption of the central plant will still be reduced. Implementing this measure would require investigation into the condenser water requirements on the glycol chiller and the process load that could be served. Only a lightweight tower would be needed since the central plant system would remain available as backup at all times. Oversizing a cooling tower can also result in energy savings since a lower face velocity is required. The power consumption is related to the cube of the flow rate. Lowering the face velocity or flow rate by half reduces the power consumption by 1/8th.

It has been noted that a cooling tower was used before to serve the glycol chillers. They were removed due to mist droplets falling onto automobiles and added moisture and contamination to the intake air of the make up air handlers. Usually when there is too high of an air velocity, droplets will be carried out of the cooling tower. This is undesirable and a variable frequency drive will resolve the problem of mist dropping onto automobiles. In addition, a cooling tower can be placed strategically to avoid the problem of introducing moisture and contaminants to the air intake of the makeup air handlers.

Glycol Chilled Water Supply Temperature Reset

During the nighttime hours, less dehumidification of the air stream in the make up air handler is required. Based on the outside air conditions at night, specifically the dewpoint/absolute humidity, the supply temperature of glycol chilled water can be increased. Raising the temperature will reduce the energy input to the glycol chillers by improving the chiller efficiency. The current operation just modulates the flow to the glycol coil with a constant glycol chilled water temperature of 36°F. Modulating the flow reduces pumping energy somewhat, but increasing the supply temperature of the chilled water will dramatically increase the efficiency and reduce the energy consumption of the chillers.

In general, chillers work more efficiently when the temperature difference between the chilled water supply temperature and the condenser water supply temperature is smaller. When this occurs, the chiller uses less power (kW) for every unit of cooling (ton) produced.

Reheat Control for Cleanroom 1

The make up air handler operates with a fixed reheat setpoint. The current operation has a supply air temperature of 68°F after reheat. For a typical cleanroom space with constant internal loads, reheating the make up air while cooling return air in sensible cooling units is essentially simultaneous heating and cooling. By reducing the amount of reheat wasted, both the reheat load on the make up unit (boiler load) and the cooling load on the recirculation air handler are reduced.

Care should be taken not to reduce the reheat point to the extent that overcooling is reached and the entering air to the RCU is below the space cooling requirements. But as make up air is only a small fraction of the total supply air, it is possible for the make up air handler to supply colder air and mix with the return air so that control can be maintained.

Replace Electric Humidifiers

Electric humidifiers are the most energy intensive method of humidification and alternative humidifier types should be considered when the electric units require major repair or replacement. A steam to steam humidifier would be a good choice since steam is already plumbed to Building E.1. Another option would be an atomizing humidifier that gives the advantage of an evaporative cooler in the summer. Note that absorption length is crucial for successful application of an atomizing humidifier. During humidification hours, reheat in the make up air handler (AHU 3-2 and 3-3) would be utilized to heat up the air to a low relative humidity allowing the air to absorb water. A final option would be a natural gas to steam unit.

Low Pressure Drop HEPA Filters and Pre-filters

When replacing HEPA filters in the cleanroom ceiling use filters that are deeper. These filters have a larger surface area and a correspondingly lower pressure drop, reducing fan energy. In addition, these filters load up much more slowly, and reduce the sensible heat load somewhat by reducing the recirculation fan power required. This may not be possible in a fan filter based cleanroom. Replacing pre-filters that are deeper or with bag filters will also save fan energy.