CLEANROOM BENCHMARKING PROJECT
SITE REPORT

FACILITY F
BUILDING F

OCTOBER 2001

LAWRENCE BERKELEY NATIONAL LABORATORY
HIGH TECH BUILDINGS PROGRAM

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APPENDICES

I. EXECUTIVE SUMMARY

As part of PG&E's Cleanroom Benchmarking Project, energy use at Facility F's cleanroom facility was monitored during June and July 2001. Facility F Building F, built 5 years ago, is a facility that houses hard disk fabrication and testing cleanroom areas as well as office space. Two class 10 cleanrooms and one class 10/5,000[1] cleanroom located in Facility F Building F were monitored for a period of two weeks.

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. Some of the most important metrics are summarized below in Tables 1 and 2.

Table 1. Important Metric Results for Facility F Building F Central Plant

Metric Name	Metric Value	
Chiller Efficiency	0.41	kW/ton
Primary Chilled Water Pumps Efficiency	0.047	kW/ton
Secondary Chilled Water Pumps Efficiency	0.019	kW/ton
Condenser Water Pumps Efficiency	0.089	kW/ton
Cooling Tower Efficiency	0.069	kW/ton
Total Chilled Water System Efficiency	0.63	kW/ton
Annual Energy Cost	543,000	$/yr

These efficiency numbers are averages of 1-minute samples taken over a period of 4 days (June 13 through June 16, 2001) when all the equipment was running and monitored simultaneously. During this period, the Total Chilled Water System Efficiency varied from 0.48 to 0.94 kW/ton, with a standard deviation of 0.063 kW/ton. See Appendix B for charts of the trended data.

Table 2. Important Metric Results for Facility F Building F

Metric Name	Metric Value	
Cleanroom 1 Class 10 Recirculation Fan Efficiency	3,085	cfm/kW
Cleanroom 1 Class 5,000 Recirculation Fan Efficiency	1,635	cfm/kW
Cleanroom 2 Class 10 Recirculation Fan Efficiency	3,150	cfm/kW
Cleanroom 3 Class 10 Recirculation Fan Efficiency	3,300	cfm/kW

The metrics for the HVAC systems at Building F show that there are opportunities for energy efficiency. The values in Table 1 indicate that the chiller is very efficient and that overall, the plant is performing well. Although the chilled water plant has good efficiency, there is also a potential to increase the efficiency of the plant.

The recirculation systems for the three class 10 area cleanrooms are as efficient as other class 10 designs. The recirculation air handling efficiencies for the three cleanrooms fall within the median of the range of 1,900 – 4,800 cfm/kW. Improvements to the operation efficiency of the cleanroom recirculation air

[1] "Class 5,000" is not a standard industry rating. Facility F has determined the classification based on a particle count in the cleanroom. For purposes of benchmark comparisons, we will compare Facility F's class 5,000 area to class 10,000 areas at other facilities.

handlers can be made without major overhaul; changing the sheaves of the laminar flow units can slow the fan speed down. However, this task is difficult and may affect product yields.

The recirculation fan efficiency of Cleanroom 1 class 5,000 (ducted HEPA) area is above average when compared to other class 10,000 ducted HEPA cleanrooms with an average efficiency of 1,200 cfm/kW.

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 VI "Site Observations Regarding Energy Efficiency".

Target the Compressed Air System for Energy Reduction

During the period of monitoring, the air compressors had an average electric load nearly as great as the combined chiller. The energy consumed for the amount of compressed air delivered is much higher than we are accustomed to seeing. Even a small percentage reduction in this energy use will yield significant savings. We recommend contacting the Compressed Air Challenge for assistance with this effort.

Lower the Condenser Water Supply Temperature to the Chillers

Lowering the condenser water supply temperature to the chillers will allow the chillers to operate more efficiently. In general, for a large centrifugal chiller a 1.2% increase in efficiency is expected for each degree the condenser water temperature is lowered. Currently the chillers are being supplied with condenser water at an average temperature of 74°F. The two Trane CVHF model chillers can accept a minimum of 55°F to 60°F condenser water.

Chilled Water Supply Temperature Reset

During the nighttime and winter hours, less or no 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 chilled water can be increased. Raising the temperature will reduce the energy input to the chillers by improving the chiller efficiency.

Lower Ceiling Velocity in Cleanrooms

The class 10 cleanrooms have measured average ceiling filter face velocities that range from 132 to 158 fpm. The standard minimum velocity for new class 10 cleanroom construction is 70 fpm. Cleanroom cleanliness can be maintained at this operating level, with lower fan energy use. Fan energy is reduced since a lower pressure drop needs to be overcome by the fan.

Tune Controls for Make Up Air Handler AHU 27

The supply temperature of make up AHU 27 had a ±3°F band during the monitoring period. This is poor control resolution for a cleanroom air handler. One resulting problem possibility is simultaneous cooling and heating of the air stream. The positions of the cooling coil and heating coil valves are bouncing back and forth to maintain the setpoint as a result of poor control tuning. This cycling is unwanted and results in a waste of energy.

Use Low Pressure Drop Filters

When replacing HEPA filters in the cleanroom ceiling use filters of the same efficiency but with lower pressure drop. These filters reduce the recirculation fan power required. Replacing pre-filters and final filters in the make up air handlers with ones that have a lower pressure drop will also save fan energy. In addition, the final filters on the recirculation air handlers should be considered.

Fill Condenser Water Drain Air Traps and Plug Holes of the Air Handlers

Fill the air traps of the condenser water drains of the air handlers with water to prevent air leakage to the outside environment. Additionally, plug the holes used for measurements in the air handlers when not in use. A leaking air handler results in a wasted amount of conditioned air that could have been supplied to the cleanroom. Reducing the air leakage should result in fan, cooling and heating energy savings.

II. INTRODUCTION

The Cleanroom Benchmarking project established 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 F Cleanroom Benchmarking Site Plan presented to the Facility Engineer May 31, 2001 describes the monitoring process used in collecting the data presented in this Site Report. (See Appendix F.) The General Plan for the Cleanroom Benchmarking Project provides additional information on the program.

With this report, Facility F 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 F 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 F'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. Site

Facility F's site in the PG&E territory consists of a single building. Chilled water is produced in a central plant and distributed throughout the building. This chilled water serves the cleanroom recirculation and make up air handlers, process cooling, and office space air handlers. The chilled water central plant is made up of 3 centrifugal water-cooled chillers, 2 cooling towers, 5 chilled water pumps and 3 condenser water pumps.

Hot water and steam are generated by separate boiler systems. However, steam is used to produce vaporized de-ionized (DI) water through a steam to steam humidifier. Hot water is provided as preheat and reheat to the make up air handlers, and to reheat coils in the supply ducts of the recirculation air units. There are two hot water boilers with one serving as backup, connected by a primary-secondary loop. The primary loop has two pumps, and the secondary loop has two pumps (one backup) controlled by a VFD. Two boilers generate steam, with one normally on standby. DI water, process and housekeeping vacuum, and compressed air are also generated in the central plant to serve the cleanrooms.

B. Building F

Facility F Building F was built five years ago and houses hard disk fabrication and testing cleanrooms. Facility F employees work around the clock during two-12 hour shifts each day, seven days a week. The environmental systems serving the cleanrooms run 8,760 hours a year in order to maintain conditions.

The cleanrooms chosen for monitoring are Cleanroom 1 (7,630 sf), Cleanroom 2 (1,010 sf), and Cleanroom 3 (995 sf). (See Site Plan Appendix – Appendix F for building layout.) Cleanroom 1 is class 5,000 with localized class 10 bays and Cleanrooms 2 and 3 are class 10 facilities.

Chilled water is produced by three water-cooled chillers connected by a common header. Two chillers are rated at 800 tons apiece and one chiller at 500 tons. Normally, one 800 ton chiller runs with either the 500 ton or 800 ton chiller, depending on the load. All three chillers are each controlled by a variable frequency drive (VFD). Two cooling towers with 3 cells each provide cooling water to the chillers. The chilled water system employs a primary-secondary loop pumping system. During the monitoring period, primary chilled water was supplied at 42.7 ± 0.4°F. The secondary pumps draw the chilled water from the primary loop and supply it to all the make up air handlers (MUAH), recirculation air handlers (RCU), laminar flow units, and office space air handlers. Some process tools require chilled water; these are supplied by tertiary loops with their own pumps. The tertiary loops are isolated from the secondary loop by heat exchangers.

Cooling Towers

Over the chiller monitoring period from June 13, 2001 through June 20, 2001 the outside air temperature ranged from 56°F to 101°F (see Appendix B for trended data). During that time the two 800 ton chillers operated at a combined average load of 952 tons with an overall range from 538 to 1630 tons. The standby chiller did not run during this period.

There are two boilers used to generate hot water for use in preheat and reheat coils of the make up air handlers. Hot water is also used for reheat coils located in the ductwork of the recirculation air handlers. Two boilers are used to generate steam to supply the steam to steam humidifiers of the make up air handlers.

The compressed air produced at the central plant is used for HVAC control valves and sandblasting, and also sent through a series of dryers to produce clean dry air (CDA). The central plant has three vacuum pumps; one for process vacuum, one for dust collecting, and another for housekeeping (janitorial) use. In addition, some cleanroom tools, such as the sputter lines, have their own, separate vacuum systems.

The cleanrooms are supplied with DI water. Chemical waste is treated by an industrial waste treatment system. Cleanrooms are equipped with exhaust fans; no air scrubbers are fitted.

Air Compressor

C. Cleanroom 1 Design

Cleanroom 1 as measured in this report is a total of 7,630 sf, including both primary and secondary (air return) areas. (See Appendix F for a cross sectional diagram.) The cleanroom is a class 10/5,000 cleanroom. The cleanroom is split into two classes such that the class 10 bays exist at the location of the testing tools and the class 5,000 areas exist at the pre-testing areas. Cleanroom 1 is primarily used for cleaning, lubing (oiling) and testing of the product.

The testing area (class 10) is 2,180 sf with 210 sf of return area. Recirculation air is provided by laminar flow units with a HEPA filter coverage of 90%. Air is returned through low wall returns. Laminar flow unit is a synonymous name for a pressurized plenum (box) RCU. The remainder of the room is the class 5,000 area; 5,025 sf with 215 sf of return area. It is served by ducted HEPA RCUs with 13% HEPA coverage. Air is returned through low wall returns and the ceiling.

Cleanroom 1 is served by one make up air handler, three recirculation air handlers for sensible cooling and 10 laminar flow units. The make up unit delivers its air to the intake ducts of the RCUs and the supply side of the laminar flow units. The make up air handler is served with chilled water from the central plant, heating hot water, and de-ionized water. Central plant steam is used to vaporize DI water to humidify the air stream. The recirculation air handlers and laminar flow units are served with only central chilled water. There are 2 general exhaust fans that serve the cleanroom; they exhaust directly to the outdoors without a scrubber.

Recirculation Air Handler

The condition specifications for the class 5,000 area of the cleanroom are 68°F ± 3°F and 55% ± 5% relative humidity. During the monitoring period, the average measured temperature for the class 5,000 area was 69°F with a fluctuation of less than 2°F, and the average measured relative humidity was 54% with a fluctuation of 3%. For the test area (class 10), the conditions are 69°F ± 1°F and 45% ± 5% relative humidity. During the monitoring period, the average measured temperature for the class test area was 69°F with a fluctuation of less than 1°F, and the average measured relative humidity was 52% with a fluctuation of 2%.

D. Cleanroom 2 Design

Cleanroom 2 is a 725 sf class 10 pressurized plenum cleanroom with 90% ULPA filter coverage. The entire room is considered primary cleanroom area. One end of an 85-foot long sputter machine occupies the center of the cleanroom; the remainder extends into an adjoining clean support room rated at class 10,000.

Cleanroom 2 is served by a single make up air handler, AHU 36, located on the roof. The supply air is ducted directly into the supply side of 4 laminar flow units located in the interstitial space. The laminar flow units provide recirculation air to the class 10 area. The cleanroom return air is directed through a raised floor return, then to an adjoining, 285 sf chase.

The make up air handler is served with hot water, de-ionized water for humidification and chilled water from the central plant. The laminar flow units are served with only chilled water from the central plant. There is one exhaust fan that serves Cleanroom 2.

AHU 36 was installed relatively recently; it does not appear in the building design drawings. Its filter sequence is assumed to be similar to AHU 8, the make up air handler for Cleanroom 3. The design specifications for the laminar flow units call for 24” by 48” ULPA (99.999% efficient) filters.

The design specifications for the cleanroom air conditions are 68°F ±1°F and 45% ± 2.5% relative humidity. During the monitoring period, the average measured temperature was 68°F with a fluctuation of less than 1°F, and the measured relative humidity was 47% with a fluctuation of 1.3%.

E. Cleanroom 3 Design

Cleanroom 3 is very similar to Cleanroom 2; they have the same process and similar physical dimensions. Cleanroom 3 is a 710 sf class 10 pressurized plenum cleanroom with 90% ULPA filter coverage. The entire room is considered primary cleanroom area. One end of an 85-foot long sputter machine occupies the center of the cleanroom; the remainder extends into an adjoining clean support room rated at class 10,000.

Cleanroom 3 is served by a single make up air handler, AHU 8, located on the roof. The supply air is ducted directly into the supply side of 5 laminar flow units situated in the interstitial space. The laminar flow units provide recirculation air to the class 10 areas. The cleanroom return air is directed through a raised floor return, then to an adjoining, 285 sf chase.

The make up air handler is served with hot water, de-ionized water for humidification and chilled water from the central plant. The laminar flow units are served with only chilled water from the central plant. There is one exhaust fan that serves Cleanroom 3.

The make up air handler design specifications call for a two-layer primary filter: First a 2” thick pleated panel filter of 25-30% efficiency, then a 21” deep non-supported pocket filter of 95% efficiency. The final filter is a 12” deep high-capacity HEPA filter of 99.99% efficiency. The design specifications for the laminar flow units call for 24” by 48” ULPA (99.999% efficient) filters.

The design specifications for the cleanroom air conditions are 68°F ±1°F and 45% ± 2.5% relative humidity. During the monitoring period, the average measured temperature was 65.4°F with a fluctuation of less than 1°F, and the measured relative humidity was 40% with a fluctuation of 2.5%. The cleanroom temperature and humidity sensors may need to be calibrated.

Table 3. Measured Cleanroom Air Handling Parameters

Description		***Cleanroom 1***		***Cleanroom 2***	***Cleanroom 3***
		Class 5,000	Class 10	Class 10	Class 10
Primary Area	sf	5,025	2,180	725	710
Ceiling Height	ft	12	12	12	12
Total Make Up Air	cfm	19,475	2,400	8,260	6,985
Total Make Up Fan Power	kW	17.8		13.3	5.3
Total Recirculation Air [1]	cfm	82,385	221,605	85,740	73,280
Total Recirculation Fan Power [2]	kW	50.4	71.8	27.2	22.2
Room Air Changes per Hour	ACH	82	508	591	516
HEPA Filter Ceiling Coverage	%	13	90	90	90
Average Ceiling Filter Velocity [3]	fpm	148	133	158	132

1. *Recirculation Air is the air delivered to the cleanroom, based on the measured filter flow.*
2. *Recirculation fan power includes RCU and LAM power.*
3. *Filter velocity based on average filter flow and 6.8 sf (85%) effective filter area.*

IV. SITE ENERGY USE CHARACTERISTICS

A. Site Energy Use

Facility F paid over $2 million in calendar year 2000 for energy use in Building F in California. Table 4 gives a breakdown. The building has a fairly consistent electricity demand and a flat load shape due to its constant cleanroom operation. Table 5 calculates two key values to use in comparing Building F to other facilities with similar operations.

Table 4. Annual Energy Use

Meter Level	Annual Electricity Usage (MWh/yr)	Annual Electricity Cost ($/yr)	Annual Natural Gas Usage (therms/yr)	Annual Natural Gas Cost ($/yr)	Annual Total Cost ($/yr)
Building F	25,250	1,642,000	679,000	417,500	2,060,000

Source: PG&E bills for the year 2000.

Table 5. Annual Energy Utilization Intensity (EUI) and Energy Cost per Square Foot

Meter Level	Area (sf)	Energy Utilization Intensity (kWh/sf·yr)	Annual Energy Cost per Square Foot ($/sf·yr)
Building F	156,000	289	13.2

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

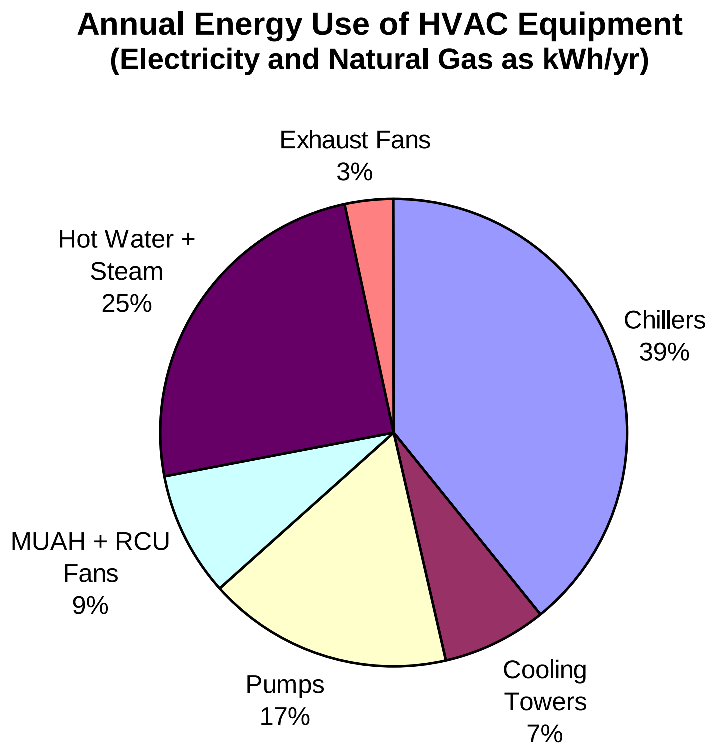
B. Central Plant Energy Use

More than a quarter of the total energy cost, and nearly half of the total electricity use at Building F occurs at the central plant. The central plant provides the chilled water, hot water, and de-ionized water (for humidification) required by the air handlers that serve the entire building. The central plant also provides de-ionized water, compressed air, and process vacuum to the cleanrooms to support the tools and processes located there.

Table 6. Central Plant Energy Use by Major Components

Description	Ave. Load (kW)	Ave. Load (therms /hr)	Average Efficiency	Annual Hours of Operation	Electricity (MWh/yr)	Total Natural Gas (therms/yr)	Total Cost (per yr)*
COOLING							
Chillers	360	-	0.41 kW/ton	8,760	3,150	-	$205,000
Primary Chilled Water Pumps	41	-	0.047 kW/ton	8,760	359	-	$23,000
Secondary Chilled Water Pumps	17	-	0.019 kW/ton	8,760	149	-	$9,700
Condenser Water Pumps	78	-	0.089 kW/ton	8,760	680	-	$44,000
Cooling Tower Fans	65	-	0.069 kW/ton	8,760	570	-	$37,000
HEATING & HUMIDIFICATION							
Hot Water & Steam Boilers	-	7.8	-	8,760	-	67,900	$51,000
Hot Water Pumps	20	-	-	8,760	175	-	$11,000
PROCESS UTILITIES							
Compressed Air	295	-	-	8,760	2,580	-	$168,000
De-Ionized Water	63	-	1.18 kW/gpm	8,760	552	-	$36,000
TOTAL	922	1.20	-	8,760	10,500	67,900	$586,000

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. Cleanroom Energy Use

The energy consumption attributed to the cleanroom air handling system, process tools, and lighting are reported for Cleanroom 1, Cleanroom 2 and Cleanroom 3 cleanrooms in Tables 7, 8 and 9, respectively. This breakdown of energy use by equipment helps identify major loads and related costs.

Table 7. Cleanroom 1 Estimated Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (cfm/kW)	Annual Hours of Operation	Electricity (MWh/yr) [2]	Total Cost (per yr) [3]
AIR HANDLING					
Make Up Fans	17.6	1,230	8,760	154	$10,000
Recirculation Fans [1]	122	-	8,760	1,070	$69,500
PROCESS [4]	-	-	8,760	-	-
LIGHTS	18.5	-	8,760	162	$10,500
TOTAL [4]	-			-	-

1. *Recirculation Fans include both Class 10 and Class 5,000 units.*
2. *Annualization based on one week of data.*
3. *Cost of electricity and gas assumed to be constant (without time of day or demand rate structure): $0.065/kWh and $0.75/Therm.*
4. *Process loads for Cleanroom 1 are distributed among many electrical panels and not easily identified or segregated. The total process load, and hence the total cleanroom load, is not reported here.*

Table 8. Cleanroom 2 Estimated Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (cfm/kW)	Annual Hours of Operation	Electricity (MWh/yr) [2]	Total Cost (per yr) [3]
AIR HANDLING					
Make Up Fans	13.3	623	8,760	116	$7,540
Recirculation Fans [1]	27.2	3,150	8,760	238	$15,500
PROCESS [4]	-	-	-	-	-
LIGHTS	2.0	-	8,760	18	$1,160
TOTAL	-			-	-

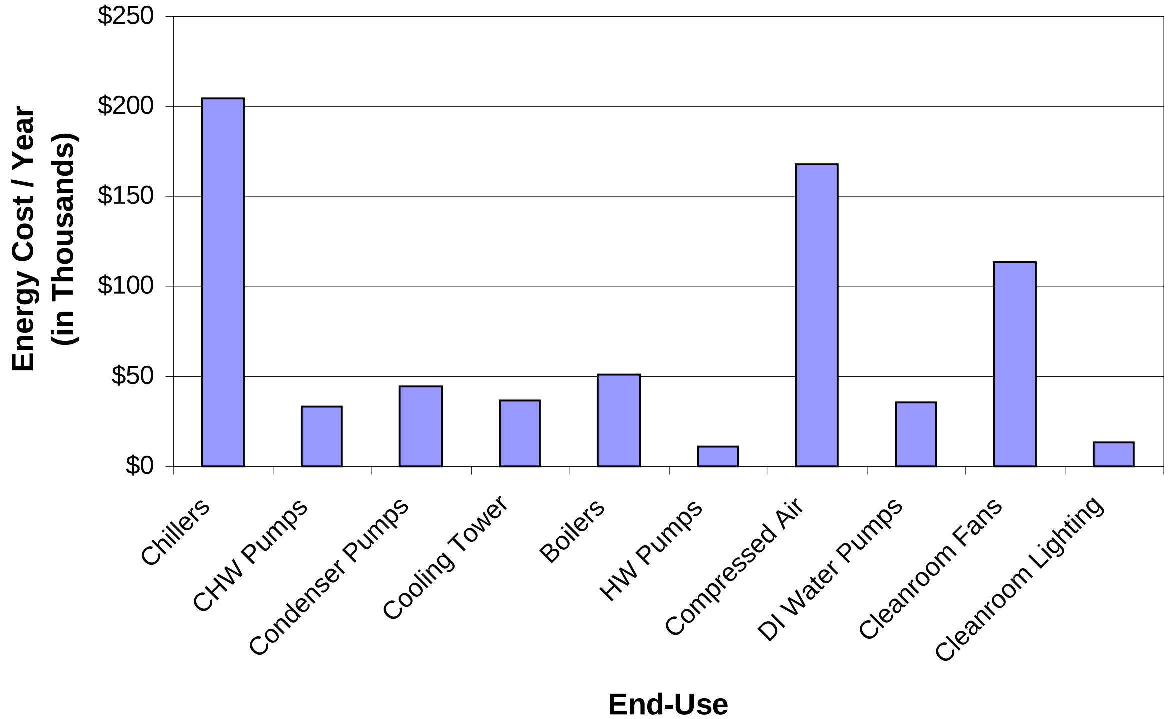
1. *Recirculation Fans refer only to the Laminar Flow Units; there is no rooftop RCU serving this cleanroom.*
2. *Annualization based on one week of data.*
3. *Cost of electricity and gas assumed to be constant (without time of day or demand rate structure): $0.065/kWh and $0.75/Therm.*
4. *Cleanroom 2's sputter line was not operational during the period of monitoring. The total process load, and hence the total cleanroom load, is not reported here.*

Table 9. Cleanroom 3 Estimated Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (cfm/kW)	Annual Hours of Operation	Electricity (MWh/yr) [2]	Total Cost (per yr) [3]
AIR HANDLING					
Make Up Fans	5.25	1,330	8,760	46	$3,000
Recirculation Fans [1]	22.2	3,300	8,760	194	$12,600
PROCESS	140	-	8,760	1,230	$79,700
LIGHTS	2.6	-	8,760	23	$1,470
TOTAL	170			1,490	$96,700

1. *Recirculation Fans refer only to the Laminar Flow Units; there is no rooftop RCU serving this cleanroom.*
2. *Annualization based on one week of data.*
3. *Cost of electricity and gas assumed to be constant (without time of day or demand rate structure): $0.065/kWh and $0.75/Therm.*

D. Annual Central Plant & Measured Cleanroom Estimated Energy Costs



The bar chart above illustrates the cost of supporting the central plant and three measured cleanrooms in Building F. The largest annual energy cost is attributed to the operation of the chillers, followed closely by the air compressors.

V. 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.

Central Plant

Metrics of “kW/ton” are based on the total average equipment power and the average operating tonnage of the 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. Central Plant Efficiency

Component [1]	***Metric***	
Chillers	0.41	kW/ton
Primary Loop Chilled Water Pumps	0.047	kW/ton
Secondary Loop Chilled Water Pump	0.019	kW/ton
Condenser Water Pump	0.089	kW/ton
Cooling Tower Fans	0.069	kW/ton
Total Chilled Water Plant	0.63	kW/ton
Cooling Load Density [2]	164	sf/ton

1. *Where more than one piece of equipment of the given type exists, the metric refers to all the units combined.*
2. *Cooling Load Density is the total conditioned area of the building served by the central plant, divided by the average plant tonnage.*

Process Utilities

Metrics for the DI water plant are presented below. Data for other process utilities (vacuum, hot water) were not collected, due to time constraints. These other measurements were assigned lower priority in the initial site monitoring plan.

The components used to calculate the DI water plant metric include all of the pumps power in the system that distribute and recirculate water to produce DI water (RO pumps, city water pumps, recirculation pumps, etc.), and the DI water consumed in gpm. The DI water plant metric for a similar benchmarked cleanroom was 0.094 kW/gpm. The compressed air power use at Facility F is very large – second only to the power used by the chillers – and should be a primary focus of energy-saving efforts. We recommend contacting the Compressed Air Challenge (www.knowpressure.org). This is a voluntary association of industrial users, manufacturers & distributors, facility operating personnel, consultants, state R&D agencies, energy efficiency organizations, and utilities that work together to improve the performance of compressed air systems.

Table 11. Process Utilities Efficiency

Utility	***Metric***	
De-Ionized Water Plant	1.18	kW/gpm

Cleanroom, Cleanroom 2, and Cleanroom 3

For Facility F, the cleanroom HVAC components operate at a nearly 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, unless otherwise noted.

Cleanroom 1 is a mixed class cleanroom: class 10/5,000. The class 5,000 areas were analyzed separately from the class 10 areas. The class 5,000 ducted HEPA recirculation air handling efficiency was 1,635 cfm/kW. When compared to other ducted HEPA cleanroom facilities of various class ratings with efficiencies ranging from 1,090 – 2,210 cfm/kW, the class 5,000 RCU air handling efficiency is average or moderate.

The make up air handler efficiency (cfm/kW) of the Cleanroom 1 out ranks the benchmarked values for class 10 cleanrooms. However, when compared to all benchmarked facilities, the efficiency falls within the range of 590 – 1,800 cfm/kW and meets the average of 1,300 cfm/kW.

Cleanroom 2 and Cleanroom 3 have moderate recirculation air handling efficiency as compared to other benchmarked class 10 cleanrooms. The range of efficiency determined for the benchmarked class 10 cleanrooms was 1,900 – 4,800 cfm/kW. The data gathered was from a ducted HEPA cleanroom and a pressurized plenum cleanroom. Cleanroom 2 and Cleanroom 3 are pressurized plenum cleanrooms that have an average recirculation air handling efficiency of 3,200 cfm/kW, falling in the middle of the range. Efficiencies in the upper range should be attainable. The moderate efficiency can be due to the high ceiling filter face velocities of 158 fpm (Cleanroom 2) and 132 fpm (Cleanroom 3) maintained in the cleanrooms. Higher air flow velocities tend to result in higher pressure drops through the recirculation air system. More fan energy is required to overcome a higher pressure drop.

Table 12. Cleanroom 1 Metrics

Description		***Cleanroom 1 Combined***	***Class 5,000 Area Ducted HEPA***	***Class 10 Area Laminar Flow Units***
MUAH Efficiency	cfm/kW	1,230	N/A	N/A
Make Up Air	cfm/sf	3.0	N/A	N/A
Make Up Fan Power Density	W/sf	2.5	N/A	N/A
Recirculation Air Handler Efficiency	cfm/kW	N/A	1,635	3,085
Recirculation Air	cfm/sf	N/A	16.4	102
Recirculation Air Changes per Hour	ACH	N/A	82	508
Recirculation Fan Power Density	W/sf	N/A	10.0	32.9
Lighting Power Density	W/sf	3.3	3.1	3.8
Process Tools Power Density [1]	W/sf	N/A	N/A	N/A

1. *Process loads for Cleanroom 1 are distributed among many electrical panels and were not measured.*

Table 13. Cleanroom 2 and Cleanroom 3 Metrics

Description		***Cleanroom 2***	***Cleanroom 3***
MUAH Efficiency	cfm/kW	623	1,330
Make Up Air	cfm/sf	11.4	9.8
Make Up Fan Power Density	W/sf	18.3	7.4
Recirculation Air Handler Efficiency	cfm/kW	3,150	3,300
Recirculation Air	cfm/sf	118	103
Recirculation Air Changes per Hour	ACH	591	516
Recirculation Fan Power Density	W/sf	37.5	31.3
Lighting Power Density	W/sf	3.4	3.4
Process Tools Power Density [1]	W/sf	-	55

1. *Calculated as total kW load of all process tools, divided by the combined area of the cleanroom and the support room that contains the process tools.*

VI. SITE OBSERVATIONS REGARDING ENERGY EFFICIENCY

There are a number of potential areas for energy savings in Facility F Building F. This section includes a general description of the most significant opportunities observed by the monitoring team.

Target the Compressed Air System for Energy Reduction

During the period of monitoring, the air compressors had an average load of 295 kW – nearly as much as the combined chiller load of 360 kW. The power-per-air-flow metric was 24.4 kW/cfm, which is 16 times greater than we have observed at a similar site. Even a small percentage reduction in this energy use will yield significant savings. Contact the Compressed Air Challenge at www.knowpressure.org for assistance with this effort.

Lower the Condenser Water Supply Temperature to the Chillers

Lowering the condenser water supply temperature to the chillers will allow the chillers to operate more efficiently. In general, for a large centrifugal chiller a 1.2% increase in efficiency is expected for each degree the condenser water temperature is lowered. During the monitoring period, an average approach temperature of 14°F with a range of 6.7°F to 23°F was observed. The two Trane CVHF model chillers can accept a minimum of 55°F to 60°F condenser water. Further investigation should be done to determine the actual lowest possible condenser water temperature in addition to determining the third chiller's minimum condenser water temperature. Typically, the manufacturer will supply this information.

Chilled Water Supply Temperature Reset

During the nighttime and winter hours, less or no 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 chilled water can be increased. Raising the temperature will reduce the energy input to the chillers by improving the chiller efficiency. The current operation modulates the chilled water flow to the coils with a constant chilled water temperature of 43°F. Modulating the flow reduces pumping energy somewhat, but increasing the supply temperature of the chilled water will dramatically reduce the energy consumption of the chillers. As previously mentioned, chillers work more efficiently when the temperature difference between the chilled water supply temperature and the condenser water supply temperature is smaller.

Lower Ceiling Velocity in Cleanrooms

Investigate lowering the ceiling filter face velocity for Cleanrooms 1, 2 and 3 class 10 areas. Cleanroom 2 and Cleanroom 3 have velocities of 158 fpm and 132 fpm, respectively. The class 10 areas of Cleanroom 1 have an average velocity of 133 fpm. The standard minimum velocity for new class 10 cleanroom construction is 70 fpm. At this operating level, cleanroom cleanliness can be maintained at a lower energy use. A lower velocity means a much lower pressure drop in the air stream. Fan energy is reduced since a lower pressure drop needs to be overcome by the fan. Pressurization of the cleanroom will not be affected, since it is maintained by the make up air handler. Implementation of a lower ceiling velocity is typically a difficult task, but offers the potential for large savings.

Tune Controls for Make Up Air Handler AHU 27

The supply temperature of AHU 27 had a ±3°F band during the monitoring period. This is poor control resolution for a cleanroom air handler. Similar units measured had a supply temperature resolution of ±0.5°F. Two possibilities can result from a poorly tuned controller of a make up air handler. One problem is simply the extra wear and tear on the valves and its controllers. The second problem is simultaneous cooling and heating of the air stream. The positions of the cooling coil and heating coil valves are bouncing back and forth to maintain the setpoint as a result of poor control tuning. For example, the cooling coil overshoots the setpoint; to correct for the overcooling, the reheat coil heats the air, but also overshoots the setpoint; cooling is then required, and again, the air is overcooled. This cycling is unwanted since it degrades temperature stability control and results in a waste of energy.

Use Low Pressure Drop Filters

When replacing filters in the laminar flow units, use filters of the same efficiency but with lower pressure drop. These filters are often thicker (larger dimension in the direction of air flow), so some minor modification of the filter mounting frames may be necessary. These filters have a larger surface area and a corresponding 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 fan power required. Replacing pre-filters and final filters on the make up air handlers with ones that have a lower pressure drop will also save fan energy. In addition, the final filters on the recirculation air handlers should be considered. Extended surface minipleat filters are recommended for replacing the current final filters.

Fill Condenser Water Drain Air Traps and Plug Holes of the Air Handlers

Fill the air traps of the condenser water drains of the air handlers with water to prevent air leakage to the outside environment. Additionally, plug the holes used for measurements in the air handlers when not in use. During the monitoring period, a significant amount of air was observed to be leaking from the air trap of AHU 36. Typically, the condenser water drain is filled with condensed water from the air stream. Over time, the water can evaporate when the conditions are dry and/or hot, which results in a wasted amount of air that could have been supplied to the cleanroom. Reducing the air leakage should result in some fan energy, cooling and heating savings.