HI-TECH INDUSTRY
CLEANROOM BENCHMARKING PROJECT
SITE ENERGY PERFORMANCE ANALYSIS REPORT

PG&E HI-TECH CUSTOMER
FACILITY B

Volume 2

DECEMBER 2000

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VOLUME 2
FACILITY B.2
PG&E SERVICE TERRITORY

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I. EXECUTIVE SUMMARY

As part of PG&E's Cleanroom Benchmarking Project, energy use at four PG&E Hi-tech customer Class 100 cleanroom facilities was monitored during October and November 2000. These cleanrooms are located at two different sites and this report is divided into two volumes – Volume 1 covers Facility B.1 and Volume 2 covers Facility B.2. Two class 100 cleanrooms were monitored over two weeks at each building- the AIT (21,400 sf) and APS/Demo (3,940 sf) cleanrooms at Facility B.1 (Volume 1) and Zone 4 (4,300 sf) and Zone 5 (9,020 sf) cleanrooms at Facility B.2 (Volume 2). Facility B.1 (Volume 1), built in 1996, is a 215,500 sf facility that houses tool assembly and testing areas with 35,300 sf of Class 100 cleanroom, 17,500 sf of Class 10,000 cleanroom and 162,700 sf of office and other spaces. Facility B.2 (Volume 2) is a ten year-old, 68,300 sf facility. One section houses a tool production area with 16,880 sf of Class 100 cleanroom area. There is also 3,000 sf of Class 10,000 cleanroom space, as well as office space and a cafeteria.

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 central plant and cleanroom air handling systems. Some of the most important metrics are summarized below in Tables 1 and 2.

Table 1. Summary of Important Metric Results for Facility B.1 (Volume 1)

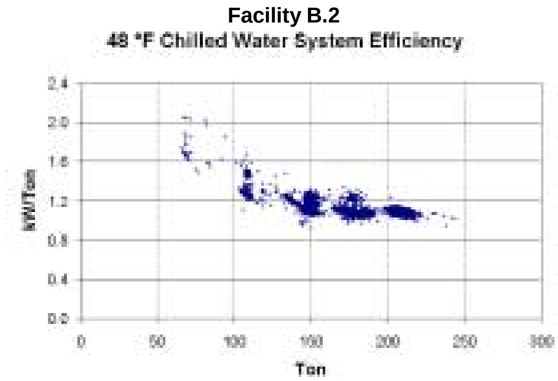
Metric Name	Metric Value	
Chiller Efficiency	0.71	kW/ton
Central Plant Efficiency	0.79	kW/ton
AIT Class 100 Recirculation Fan Efficiency	2,212	cfm/kW
APS/Demo Class 100 Recirculation Fan Efficiency	1,276	cfm/kW
Annual Energy Cost *per Square Foot of Cleanroom**	$19	$/sf·yr

Table 2. Summary of Important Metric Results for Facility B.2 (Volume 2)

Metric Name	Metric Value	
48°F Chiller Efficiency	0.83	kW/ton
48°F Chiller Pump Efficiency	0.28	kW/ton
48°F Chiller Plant Efficiency	1.11	kW/ton
40°F Chiller Efficiency	0.85	kW/ton
40°F Chiller Pump Efficiency	0.10	kW/ton
40°F Chiller Plant Efficiency	0.95	kW/ton
50°F Process Chiller Efficiency	0.81	kW/ton
50°F Process Chiller Pump Efficiency	0.10	kW/ton
50°F Process Chiller Plant Efficiency	0.91	kW/ton
Zone 4 Class 100 Recirculation Fan Efficiency	872	cfm/kW
Zone 5 Class 100 Recirculation Fan Efficiency	1,089	cfm/kW
Annual Energy Cost *per Square Foot of Cleanroom**	$24	$/sf·yr

**Facility B.1 based on AIT Cleanroom only and Facility B.2 based on Zones 4 and 5 combined.*

The metrics indicate that the PG&E Hi-tech customer facilities can find efficiency improvements in several areas. In general an air-cooled chiller plant is less efficient than a combined water cooled chiller and cooling tower system (evaporative cooled). Typical efficiencies for an efficient evaporative cooled system can be 0.6 kW/ton or almost half of that for the systems in place at both Facility B.1 and Facility B.2. Further efficiency gains can be made at Facility B.2 by reducing the pumping for the 48°F chilled water system. This system is operating at a very low differential temperature, so chilled water flow could be reduced, improving both the performance of the chillers (by raising the delta T) and by lowering the pumping power consumption.



Because the chiller efficiency depends on chiller loading, the performance metrics in the above tables are average values. These parameters were monitored at a frequency of one minute over two weeks and used to create a set of kW/ton versus ton graphs (See Appendix B *Metric Plots*). As the example at right shows the efficiency of a chiller improves with loading, so multiple chillers should be staged to achieve maximum efficiency for the system.

The recirculation systems for the Facility B.1 and Facility B.2 cleanrooms are not as efficient as other Class 100 designs, which can achieve from 3,000 – 5,000 cfm/kW, though for a ducted HEPA system like the Facility B.1 AIT cleanroom 2,200 cfm/kW is typical. Ducted HEPA systems require more energy to overcome the pressure losses of the typically long flexible duct runs. 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 than larger air handling units, the second is that the associated 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, reducing air flow in some areas, using lower pressure drop filters, and cutting back on fan operation during off peak hours when the facilities are not being occupied.

The monitoring team observed a number of opportunities for potential energy savings at the PG&E Hi-tech customer facilities. A summary of these observations follows and a more detailed discussion can be found in Section VI "Site Observations Regarding Energy Efficiency – Facility B.2".

Chiller Controls Tuning

Chiller 2 is cycling on and off very frequently. The cycling not only wastes energy, it causes excessive wear on the equipment and could lead to failure. Running fewer chillers at closer to their rated capacity results in higher efficiency.

Pumping Reductions/Improve Delta T

All the 48°F chillers monitored showed a low delta T, from 2°F-5°F which indicates that the chilled water flow is too high. Decreasing the chilled water flow will save pump energy and improve the performance of the chillers by increasing the delta T.

RCU Nighttime/ Weekend Setback

It is possible to reduce the RCU air flow when the space served by these fans are unoccupied. Lowering fan energy also reduces heat load in the space which reduces the chilled water load as well.

Make-up Reheat Control

Energy consumption by boilers could be reduced by lowering the amount of reheat of the make-up air.

Evaporative Cooled Chiller

Use of an evaporative cooled chiller system in place of the current air cooled chiller system could reduce chilled water energy consumption by 30% or more.

Cleanroom Temperature Control

The cleanrooms monitored were on average 3°F to5°F cooler than the stated specifications of 70°F ± 2°F. Raising the cleanroom temperature can save in cooling load.

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 B Cleanroom Benchmarking Site Plan presented to the Facility Engineer October 5, 2000 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, the PG&E Hi-tech customer 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 the PG&E Hi-tech customer can evaluate the performance of its cleanroom facilities. Four cleanrooms at two sites were monitored at the PG&E Hi-tech customer facility. This report is divided by site into two volumes. Volume 1 covers two Class 100 cleanrooms at the first site at Facility B.1 and Volume 2 covers two Class 100 cleanrooms at the second site at Facility B.2. The following information is reported for each site. First, the report reviews the site characteristics, noting design features of the central plant and the cleanrooms monitored. Second, the energy use for the building, central 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 the PG&E Hi-tech customer's facility will be noted. The data collected, trended graphs and methodology documentation are included among the appendices.

III. REVIEW OF SITE CHARACTERISTICS – Facility B.2

A. Campus

The PG&E Hi-tech customer campus consists of 8 buildings, with Facility B.2 and Building X joined and sharing a common café and shipping/receiving area. Only cleanrooms in Facility B.2 were monitored in this study. PG&E electric power billing data reflects metered power to 6 buildings including Facility B.2. The study monitored power to Facility B.2 at its main panel meter. PG&E natural gas billing data reflects one meter that serves all of Facility B.2.

B. Facility B.2 Facility

Facility B.2 is a ten year-old 68,300 square foot (sf) facility. One section houses a tool production area with 16,880 sf of Class 100 cleanroom area. There is also 3,000 sf of Class 10,000 cleanroom space, as well as office space and a cafeteria. The PG&E Hi-tech customer employees test and assemble tools during two shifts each day, six days a week, but the tests continue around the clock. Therefore, the environmental systems serving the cleanrooms operate at all times, 8760 hours per year. The cleanroom areas monitored in this study are Zone 4 and Zone 5, both class 100 cleanrooms, with a combined area of 13,320 sf (See Appendix F for building floor plan).

Facility B.2 48°F Chilled Water System

Facility B.2 has two rooftop mounted chilled water systems. The 48°F chilled water system (Chilled Water System 1) serves recirculating air handling units for all the cleanrooms in Facility B.2 as well as cooling water for the compressed air system. The 40°F Chilled Water System (Chilled Water System 3) serves 5 make up air handling units (MUAH) in both Facility B.2 and Building X. Two of these MUAs serve Cleanrooms Zone 4 and Zone 5 (one per cleanroom). There is a 50°F chilled water system serving a process cooling water loop, though neither Zone 4 or Zone 5 are using any process cooling water. There is also a small natural gas fueled hot water boiler and pumping system to provide reheat water to the make up air handlers, and a small natural gas fueled steam generator to provide humidification capacity as well.

The 48°F chilled water plant includes three air-cooled chillers serving a single primary loop. The total rated cooling capacity is 425 tons: one 175 ton unit and two older 125 ton units. All three chillers generally run all of the time with no available backup or redundancy. Three of the four primary chilled water pumps run at a time and are connected by a common suction and discharge header. There are no variable frequency drives (VFDs) on any of the equipment. The 40°F Chilled Water System is comprised of one 80 ton chiller with the primary only loop served by one pump and one back-up pump. The 50°F chilled water system, located on a pad adjacent to the building, consists of two 80 ton air-cooled chillers alternating on a weekly lead/lag schedule. That system uses a primary-secondary pumping system.

Facility B.2 40°F Chilled Water System

Over the monitoring period from October 26, 2000 to November 2, 2000 the outside air conditions ranged from 46 °F to 86 °F (see Appendix B *Building Conditions* for trended data). During that time the 48°F Chilled Water system operated at an average capacity of 166 tons, ranging from 66 to 244 tons. One of the chillers cycled on and off repeatedly, which may be a control problem or a response to demand. However, the other chillers were always operating at part load. Also each chiller was supplying chilled water at different temperatures, from about 45°F to 50°F, with corresponding temperature differentials ranging from 5°F to 2°F. The 40°F Chilled Water System operated at an average load of 63 tons, ranging from 51 to 76 tons. The chilled water pumps operate at a steady 45 and 6.4 kW for the 48°F Chilled Water System and 40°F Chilled Water System, respectively.

Facility B.2 Recirculation Air Handlers

Energy consumption for Facility B.2 over the monitoring period averaged 1160 kW with a daily range of about 1030 kW to 1330 kW or 12%. The average ambient conditions were 59 °F and the temperature ranged from 46°F to 86°F during that time. The yearly load profile from the PG&E data is relatively flat and the average power during the month of October differed from the yearly average by less than 1%. For this report the average power during the monitoring period was taken to represent a yearly average in the annual energy calculations.

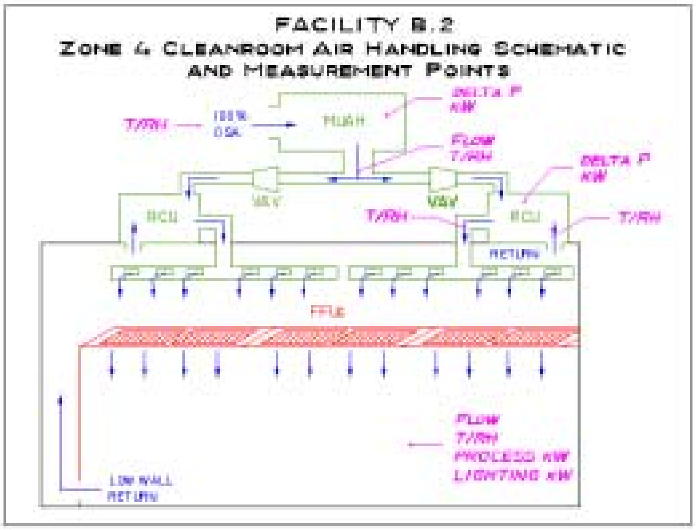
C. Zone 4 Cleanroom Design

Zone 4 is a 4,300 sf Class 100 fan-filter unit (FFU) cleanroom. All of the operational Class 100 area is considered the primary cleanroom space for this report. A single make up air handler supplies conditioned outside air directly to the supply ducts of the four recirculation units through variable air volume control devices. The roof-mounted RCUs deliver air to an 8' interstitial space, and fan-filter units discharge the air through the 44% HEPA coverage in the ceiling. This arrangement of fan pressurization at three levels (MUAH, RCU, and ceiling) is the result of a recent renovation that involved installing the make up air handlers with humidification control to supplement the recirculation units that were previously taking in a portion of outside air yet lacked humidification.

Make up air provides about 2% of the total recirculated air. This fraction is constant, as set by the MUA VAV boxes, and though some recirculation fans have two-speed or variable speed fans, the settings are constant. The return air is routed through return walls. The room is under 0.05" w.g. positive pressure, as indicated by wall mounted Magnehelic gauge, and there is no mechanical exhaust from the cleanroom, only exfiltration.

The design conditions for the cleanroom are 70 °F ±2 °F with no more than a 1°F change within 1 hour; 45% RH ±5% with no more than a 1% change in 1 hour. During the monitoring period, the average measured temperature was 65 °F with a fluctuation of less than 1 °F, and the measured relative humidity was 50% ±5%.

Flow measurements were taken for about 30% of the fan powered HEPA units in the cleanroom. Overall the flow through the FFUs was constant throughout the length of the room, ranging from a low end of 500 to a high of 620 CFM and an average flow of 516 cfm. About 5% of the FFUs measured were found to have very low or no flow indicating they were shut off or otherwise inoperable at the time of testing.



D. Zone 5 Cleanroom Design

Zone 5 is a 9,020 sf Class 100 ducted HEPA cleanroom. Of this 9,020 sf area, 7,950 sf is considered primary area and the remaining 1,070 sf is considered secondary area. Some maintenance and service equipment is located in the entry room area, but there is no other significant service area supporting Zone 5.

As with the Zone 4 air handling system a single make up air handler supplies conditioned outside air directly to the supply ducts of seven recirculation units through variable air volume control devices. The roof-mounted RCUs deliver ducted air directly to the HEPA filters covering 33% of the ceiling area. Return air flows to the interstitial space via return walls. The room is under 0.05" w.g. positive pressure, and there is no mechanical exhaust from the cleanroom, only exfiltration.

The HEPA filters are laid out according to tool placement, with filter coverage heavier over the tool rows and lighter over corridor areas. This results in a number of 'islands' of high HEPA coverage. The ceiling coverage varies considerably and partial curtains hanging down a few feet from the ceiling are employed, presumably in an effort to better define cleaner areas. Flow measurements were taken for about 40% of the ducted HEPA units. Both the ceiling curtains and the tools in the space limited the collection of flow readings above and near some tools. Of the accessible units sampled the flow varied from 340 CFM to 1000 CFM with an average of about 640 CFM. In a ducted HEPA system, the pressure drop of the duct work, which can vary widely for flexible duct installations, has a large effect on filter flow. The wide variation here could possibly be corrected by an adjustment of the balancing dampers if it is not the result of fundamental design or installation problems, such as undersized duct work or crushed or kinked duct runs.

The design conditions for the cleanroom are 70 °F ±2 °F with no more than a 1 °F change within 1 hour; 45% RH ±5% with no more than a 1% change in 1 hour. During the monitoring period, the average measured temperature was 66 °F with a variation of 1 °F, and the measured relative humidity was 49% ±2%.

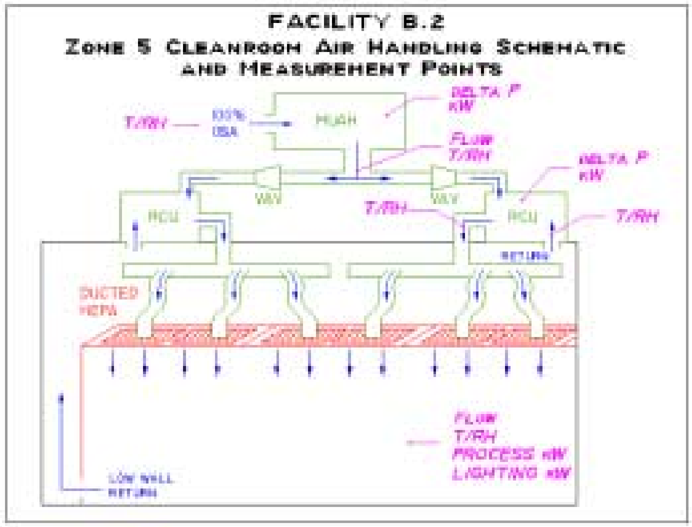


Table 3. Measured Air Handling Parameters for Zone 4 and Zone 5 Cleanroom Areas

Description	***Zone 4 Cleanroom***		***Zone 5 Cleanroom***	
Class 100 Primary Area	4,300	sf	7,950	sf
Total Make up Air	2,660	CFM	6,010	CFM
Total Make up Fan Power	1.5	kW	4.4	kW
Total Recirculation Air **	123,100	CFM	208,400	CFM
Total Recirculation Fan Power ***	93	kW	191	kW
Room Air Changes per Hour	191	ACH	175	ACH
HEPA Filter Efficiency	N/A*	%	N/A*	%
HEPA Filter Ceiling Coverage	44	%	33	%
Ceiling Filter Velocity ****	76	fpm	94	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 average ceiling filter flow from flow hood measurements.*

*** *Recirculation fan power includes both RCU and FFU power for the Zone 4 cleanroom.*

**** *Filter velocity based on average filter flow and 6.8 sf (85%) effective filter area.*

IV. SITE ENERGY USE CHARACTERISTICS – Facility B.2

A. Site Energy Use

The PG&E Hi-tech customer pays $2.5 million annually in energy costs at its Facility B.2 and associated buildings campus. About 30% of this operating expenditure can be attributed to Facility B.2. For purposes of this report all building energy consumption is based on the average power consumption monitored over the monitoring period. The monthly billing data shows that the campus has a fairly consistent electricity demand and a flat load shape due to its constant cleanroom operation. (See Appendix B *Building Conditions*). Natural gas consumption is based on PG&E billing data from one meter at the Facility B.2 facility. Tables 4 and 5 outline the electricity and gas costs for the Facility B.2 facility.

Table 4. Annual Energy Use Data

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)
Campus	38,000				$2,500,000
Facility B.2	10,150	$660,000	70,200	$52,600	$713,000

Source: Facility data provided by PG&E bills August 1999 to August 2000. Facility B.2 electricity values determined by applying average electricity costs to on-site submeter data gathered over the monitoring period. Energy costs are calculated at an average resource price of $0.065/kWh and $0.75/Therm.

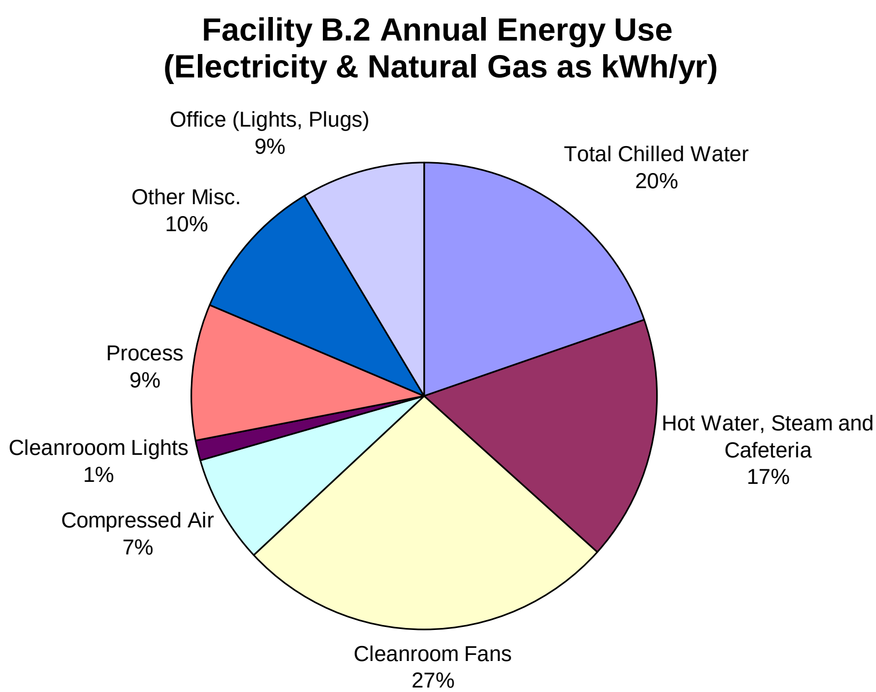
Table 5. Annual EUI and Energy Cost per Square Foot

Meter Level	Area (sf)	Energy Utilization Intensity (kWh/sf·yr)	Annual Energy Cost per Building Square Foot ($/sf·yr)
Facility B.2	68,300	179	$10.40

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

B. Facility B.2 Energy Use

The Facility B.2 energy use reported in Table 4 above can be broken down into the main components of the building energy systems: heating, cooling, air handling, and production. The cleanroom environmental systems of Facility B.2, including the compressed air, account for 70% of the total annual energy use for the building. Process tools account for only 9% total power. This low process tool loading is expected as these facilities are used for testing and assembly of tools and not manufacturing. Office loads along with other miscellaneous loads (other process utilities) account for the remaining 19%.



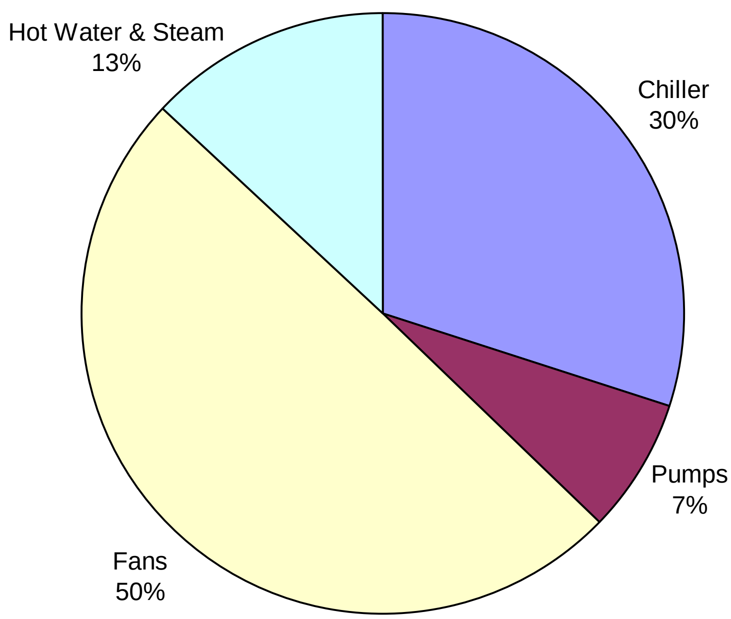
C. Central Plant Energy Use

Table 6. Central Plant Energy Use by Major Components

Description	Average Load (kW, Therms)	Average Efficiency (kW/ton)	Annual Hours of Operation	Electricity (MWh/yr)*	Total Natural Gas** (Therms/yr)	Total Cost ($/yr)***
COOLING						
40°F Chillers	53	0.85	8,760	465		$30,200
Pumps	6.4	0.10	8,760	56		$3,600
48°F Chillers	139	0.83	8,760	1,220		$79,000
Pumps	45	0.27	8,760	395		$25,700
50°F Chillers	30	0.80	8,760	260		$16,900
Pumps	3.5	0.10	8,760	31		$2,000
HEATING						
Boiler (Therms)					70,200	$52,600
Pumps (kW)	4.8		8,760	42		$2,700
PROCESS UTILITIES						
Compressed Air	104		8,760	915		$59,400
Other Utilities						
TOTAL	381			3380		$272,000

* *Simple annualization based on one week of data.*
** *Annual natural gas use from billing data attributed to boiler and steam loads.*
*** *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 ($65/MWh) and $0.75/Therm.*

Annual Energy Use of Facility B.2 Cleanroom HVAC Equipment (Electricity & Natural Gas as kWh/yr)



D. Zone 4 Cleanroom Energy Use

The energy consumption attributed to the cleanroom air handling system, process tools, and lighting are reported for Zone 4 and Zone 5 in Tables 7 and 8 respectively . The recirculation fans, at about 70% of the energy use for both cleanrooms, are the dominate the load. Since the tools in these spaces are primarily inspection tools, not requiring process cooling water, the low process load is not surprising. Zone 4 recirculation fan load includes both the roof mounted recirculation units as well as the fan filter units.

Table 7. Zone 4 Cleanroom Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (CFM/kW)	Annual Hours of Operation	Electricity (MWh/yr)**	Total Cost ($/yr)***
AIR HANDLING					
Make up Fans	1.5	1,800	8,760	13	$840
Recirculation Fans*	93	1,330	8,760	815	$53,000
PROCESS	18		8,760	157	$10,200
LIGHTS	11		8,760	96	$6,300
TOTAL	124			1,100	$70,300

* *Recirculaion fans includes both RCU and Fan Filter Units.*
** *Simple annualization based on one week of data.*
*** *Cost of electricity assumed to be constant (without time of day or demand rate structure): $0.065/kWh.*

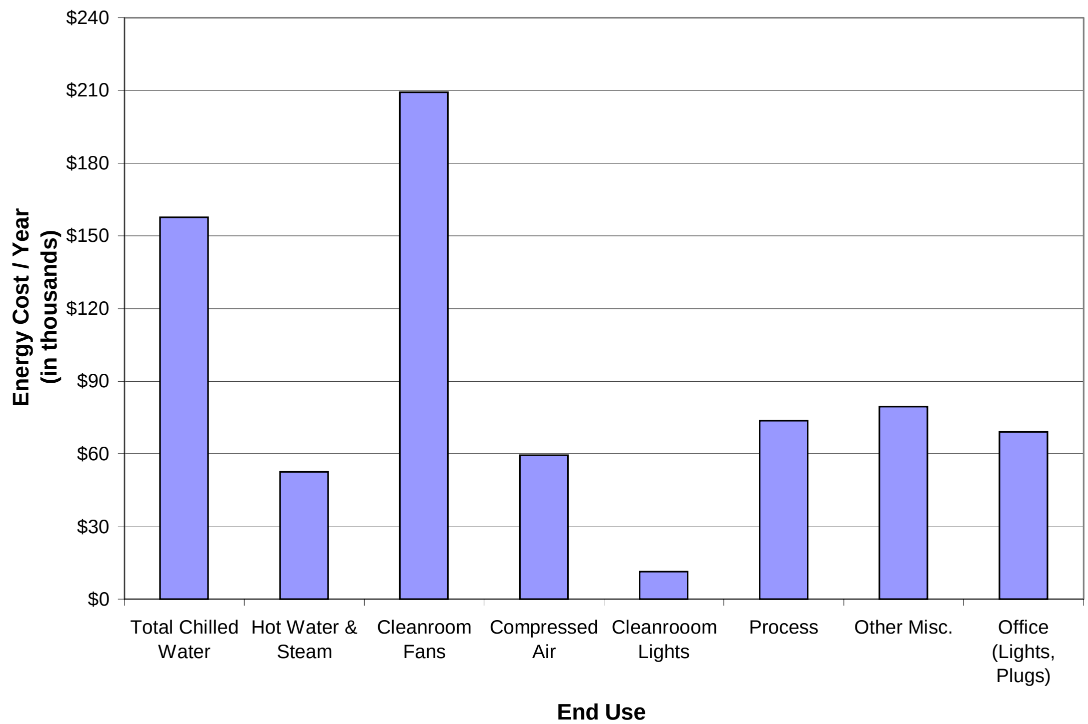
E. Zone 5 Cleanroom Energy Use

Table 8. Zone 5 Cleanroom Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (CFM/kW)	Annual Hours of Operation	Electricity (MWh/yr)*	Total Cost ($/yr)**
AIR HANDLING					
Make up Fans	4.4	1,378	8,760	38	$2,500
Recirculation Fans	192	1,089	8,760	1,680	$109,000
PROCESS	84		8,760	740	$48,000
LIGHTS	22		8,760	190	$12,400
TOTAL	302			2,650	$172,000

* *Simple 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.*

F. Annual Facility B.2 Energy Costs



The bar chart above illustrates the relative cost of supporting the major energy end-uses in Facility B.2. The largest annual energy costs are attributed to the operation of the cleanroom fans and the chilled water plant. Reducing the process load or the cleanroom fans load, while reducing operating costs in these categories directly, has the added benefit of reducing the heat load in the cleanrooms, which decreases the operating costs of the chilled water plant. Therefore investments in energy efficiency should be targeted at reducing energy use at the cleanroom level.

Facility B.2 also has a significant quantity of load related to the office space. The office space is conditioned by small package units. The energy consumption of these office units is placed under the 'Other Misc.' category in this graph.

V. SYSTEM PERFORMANCE METRICS – Facility B.2

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.

Cleanroom Annual Resource Use

The metrics in Table 9 below are for the Zone 4 and Zone 5 cleanrooms combined. They are based on the total primary area and the measured and estimated loads in the space, including process loads, fan loads, lighting and people, and the make-up air conditioning load (annualized using a bin weather data analysis and measured delivery conditions). Gas used while the boiler system is idling was considered negligible and neglected.

As is expected for a cleanroom facility, the energy consumption is dominated by internal loads, as seen by the high load factor. Outdoor conditions have relatively little effect on the power demand. The temperature and humidity conditioning method used for the make-up air usually requires outdoor air to be cooled to the desired dewpoint, then reheated to the desired delivery temperature, observed to be about 60°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. In addition, the space had no process exhaust, resulting in a low make-up air requirement.

Table 9. Annual Class 100 Cleanroom Resource Use

Description	***Metric***	
Annual Energy Cost *per Cleanroom Square Foot*	$24	$/sf
Annual Fuel Usage	1.6	Therms/sf/yr
Annual Electricity Usage	350	kWh/sf/yr
Annual Energy Usage	1.4	MBtu/sf/yr
Annual Peak Demand	42	W/sf
Average Power Demand	40	W/sf
Load Factor	0.95	

Based on Facility B.2 energy consumption and 13,320 sf of primary cleanroom square footage.

Central 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 (see Appendix B - *Metric Plots*) that reflect kW/ton performance at a sampling frequency of one minute over the course of a week.

Three chiller systems were measured, each delivering a different supply temperature. The variation of chiller efficiency on chilled water temperature is as expected, with the higher temperature loop running more efficiently. The pumping efficiency for the 48°F chilled water system is significantly higher than the other pumps. This is indicative of the high pumping rates and lower chiller temperature differential for this system.

Table 10. Central Plant

Description	*Metric*
40°F Chilled Water Plant Efficiency	0.95 kW/ton
40°F Chiller Efficiency	0.85 kW/ton
40°F Chilled Water Pumps Efficiency	0.10 kW/ton
48°F Chilled Water Plant Efficiency	1.11 kW/ton
48°F Chiller Efficiency	0.83 kW/ton
48°F Chilled Water Pumps Efficiency	0.28 kW/ton
50°F Chilled Water Plant Efficiency	0.91 kW/ton
50°F Chiller Efficiency	0.81 kW/ton
50°F Chilled Water Pumps Efficiency	0.10 kW/ton
Cooling Load Density*	102 sf/ton

**Cooling Load Density is calculated for the 48°F chilled water system only, as this is the largest system and serves one building only. The cooling load density is based on the total square foot area served by the central plant, which is the entire area of Facility B.2, and the average tonnage of the central plant.*

Process Utilities

The following metrics for process utilities can also be used for benchmarking cleanroom performance. The measurements required to calculate these metrics were low in the priority list established in the Facility B Site Plan (see Appendix G), so data necessary for the calculation of these metrics were not collected during the monitoring period according to that prioritization.

Zone 4 Cleanroom and Zone 5 Cleanroom

Various metrics regarding cleanroom efficiency are shown below in Table 11.

Both of these cleanroom facilities have moderate to poor air handling efficiency. The ducted HEPA system has a markedly better performance than the Fan Filter Unit (FFU) design, but both have significant energy penalties inherent in their design.

The Zone 4 cleanroom uses FFUs in combination with recirculation air handlers for space conditioning. Though the FFUs themselves operate without large duct losses and with low velocity airflow through plenum spaces, the overall system efficiency is lower than that for the ducted HEPA system in the Zone 5 cleanroom. One reason for this is that there are two stages of motors and fans- the RCUs and the FFUs. The recirculation units are discharging into the interstitial space where the FFUs then push the air through the ceiling filters into the cleanroom. The recirculation units are only acting to condition the air and their fans contribute nothing to the recirculation airflow. 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 ducted HEPA system.

The Zone 4 cleanroom has significantly poorer performance than the Facility B.1 (Volume 1) FFU area (APS/Demo). There are a couple of likely reasons for this. In Zone 4, the sensible cooling requirements of the space are served by air handlers placed on the roof. These air handlers are ducted, requiring a larger static pressure fan. The APS/Demo cleanroom uses recirculation units for space conditioning which are located in the interstitial space, thus eliminating return ducting and minimizing supply ducting.

In the Zone 5 cleanroom a ducted HEPA filter system design is utilized. The extended duct runs that result from connecting each HEPA to the recirculation units results in a rather high pressure drop and associated fan energy consumption. The result is the air handling efficiency seen in Table 11. This efficiency could be improved somewhat by lowering the face velocity in the recirculation air handlers (using larger RCUs for a given air volume) and using more efficient motors or fans. Increasing the duct size serving each HEPA would improve the efficiency further by lowering the pressure drop, but space constraints and duct layout geometry typically dictate the upper limit of the duct sizing. However, the uneven balance between the units in the cleanroom suggests that there are some high pressure drop runs dictating a higher fan pressure for the whole system. Upsizing the ducting serving these critical filters could reduce the required fan power, although VFD fan control would be required to fully take advantage of the savings.

The Facility B.2 cleanrooms are somewhat unusual in the area of process load. Since the cleanrooms are used for the assembly and testing of tools, the load densities are quite low. These cleanroom are operating at only 4 – 11 watts/sf. It may be possible to turn down the recirculation units serving Zone 4, which are used only to cool the cleanroom.

Neither cleanroom had any exhaust so the make-up air served only to pressurize the space. Humidity and temperature conditioned make-up air is energy intensive, so the low make-up requirement improves the overall cleanroom energy per square foot consumption.

For The PG&E Hi-tech customer, the cleanroom components operate at a constant level throughout the year. Therefore, these metrics are based on spot measurements without trended metric plots. All of the metrics involving area are based on the primary cleanroom area..

Table 11. Zone 4 Cleanroom and Zone 5 Cleanroom

Description	***Zone 4 Cleanroom***		***Zone 5 Cleanroom***	
Recirculation Air Handler Efficiency	870	cfm /kW	1,090	cfm/kW
MUAH Efficiency	1,800	cfm /kW	1,400	cfm /kW
Make up Air - cfm /sf	0.6	cfm /sf	0.8	cfm /sf
Recirculation Air - cfm /sf*	29	cfm /sf	26	cfm /sf
Recirculation Air Air Change*	191	ACH	175	ACH
Lighting Power Density	2.5	W/sf	2.5	W/sf
Process Tools Power Density	4.2	W/sf	10.6	W/sf
Primary Cleanroom to Total Building Area	0.06	Ratio	0.12	ratio

* *Recirculation Air is the air delivered to the cleanroom, based on the average ceiling filter flow from flow hood measurements.*

VI. SITE OBSERVATIONS REGARDING ENERGY EFFICIENCY – Facility B.2

There are a number of potential areas for energy savings in Facility B.2. Three of the most attractive are chiller controls tuning, pumping reductions and night time fan setback. This section includes a general description of some of the most significant opportunities observed by the monitoring team. The opportunities range from simple controls modification to more intensive system retrofit or replacement.

Chiller Controls Tuning

A number of controls issues were observed in the 48°F chilled water plant serving Facility B.2. The chiller plant consists of three air cooled chillers operating in parallel. The largest controls problems are related to chiller 2, and could be indicative of equipment damage or improperly set valves. Chiller 2 is cycling on and off very frequently (see Appendix B, *Chiller Power*). The cycling not only wastes energy, it causes excessive wear on the equipment and could lead to failure. This chiller showed a maximum delta T over the monitoring period of just over 2°F, which is far below the typical design delta T of 10 – 15°F (see Appendix B, *Water Loop Temperatures and Flow*). Chiller 2 should be checked for possible flow problems and the controls should be reprogrammed to limit cycling. Additional chillers should not be turned on until the currently running chiller(s) approach their rated load capacity. Running fewer chillers at closer to their rated capacity results in higher efficiency.

Pumping Reductions/Improve Delta T

All the chillers monitored showed a low delta T, from 2°F-5°F (see Appendix B, *Water Loop Temperatures and Flow*). The low delta T indicates that more water than required is being pumped to deliver the necessary cooling. The chillers are designed to provide a larger delta T, and the system is also designed to utilize a larger delta T. The increased pumping requires more pumps, and therefore more pumping energy, to deliver the same cooling as originally designed. The volume of water being pumped should be reduced. This may be as simple as turning off a pump or two, or it may require a few upgrades of equipment. Often, over pumping occurs because an air handler at the end of the loop is not obtaining adequate flow. This can be addressed by closing bypasses upstream of the air handler, removing any obstructions to flow (for example a flow setter or flow balancing valve is not required at far points in the loop and is an unnecessary, and significant, pressure drop).

RCU Nighttime/ Weekend Setback

Based on the process cooling load monitoring (see Appendix B, *Class 100 Cleanroom Zone 4* and *Class 100 Cleanroom Zone 5* for process power trends), there is a significant reduction in load at night. Energy savings can be realized by taking advantage of the shift usage. At night, the recirculation fans can be setback since there are fewer people and activities creating particles in the space. The fan load in the cleanroom is significant, so a minor reduction could result in a reasonable payback. One method of achieving maximum savings would be to use a particle counter in the space (or simply a timer) to control a fan VFD on the recirculation units. In the fan filter unit rooms, some FFUs could be turned off, effectively reducing the coverage when the room is unoccupied. Some of the recirculation units serving to provide cooling to the FFU room could be shut off entirely at night when the load is reduced by the shutting off the lights, reduced process load, less people in the space and reduced fan load.

Reducing air flow also reduces chiller energy consumption as fan energy is added directly to the space and must be removed by the cooling coils in the RCUs.

Make-up Reheat Control

The make-up air handler currently delivers air to the cleanrooms at over 60°F (see Appendix B, *Class 100 Cleanroom Zone 4* and *Class 100 Cleanroom Zone 5* for makeup air handler trends). Heating is required to deliver the air at this temperature, even though the recirculation units are cooling. This simultaneous cooling and heating is a waste of energy and should be minimized. Reheat should be reduced, perhaps eliminated on the make-up air. This will also reduce the overall load on the chiller plant, magnifying the savings.

Evaporative Cooled Chiller

The air cooled chillers used are less efficient than an equivalent water cooled unit. A single tower cooled chiller with a VSD drive could be used to replace the existing three chillers serving the 48°F loop. Such a chiller would have a typical efficiency of about 0.5 – 0 .6 kW/ton, about 30% - 40% better than the existing air cooled units. The VSD drive would allow the chiller to very efficiently follow the load, in some cases actually running more efficiently at part load, making it ideal for the variable loads seen in this building. The existing air cooled chiller plant could be retained to provide redundancy.

Cleanroom Temperature Control

The cleanrooms monitored were on average 5°F cooler than the stated specifications of 70°F ± 2°F (see Appendix B, *Class 100 Cleanroom Zone 4* and *Class 100 Cleanroom Zone 5* for cleanroom temperature trends). If the controls are set for 70°F, the sensors could be out of calibration. Raising the cleanroom temperature can save in cooling load.