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

PG&E HI-TECH CUSTOMER
FACILITY B

Volume 1

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LAWRENCE BERKELEY NATIONAL LABORATORY
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VOLUME 1
FACILITY B.1
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)

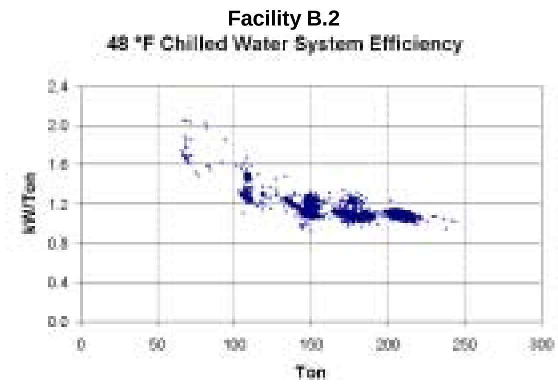
Metric Name	Metric Value	
Chiller Efficiency	0.71	kW/ton
Central Plant Efficiency	0.79	kW/ton
AIT Class 100 Recirculation Fan Efficiency	2,212	cfm/kW
APS/Demo Class 100 Recirculation Fan Efficiency	1,276	cfm/kW
Annual Energy Cost *per Square Foot of Cleanroom**	$19	$/sf·yr

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.1”.

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 15% or more.

Make-up Reheat Control

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

Review Pumping System

The chilled water pumping system experiences a periodic power spike that is damaging to the pumps and deserves investigation.

AIT Cleanroom Air Flow

It may be possible to lower the air flow to the AIT cleanroom by as much as 10% and still maintain class rating. A 10% reduction of air flow could possibly achieve a 27% energy savings.

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.

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.

RCU C3.34 Set Back

Depending on the purpose of the roof mounted RCU C3.34, it is possible that the unit can be set back and still maintain control of the cleanroom conditions.

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.1

A. Campus

Facility B.1 is one of three buildings located in PG&E service territory. Facility B.1 is divided into North and South parts for the purposes of this report, since the power consumption monitoring was divided into panels serving the north or south portion of the building. Each side contains a mix of cleanroom and office space. PG&E billing data reflects power consumption for three buildings at the campus- Buildings X, Y, and Z. Natural gas is metered at two locations in Facility B.1.

B. Facility B.1 Facility

Facility B.1 is a 215,500 sf facility built in 1996 that houses a tool production area 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. The PG&E Hi-tech customer employees assemble tools during two shifts each day, six days a week, but the environmental systems serving the cleanrooms run 8760 hours a year in order to maintain conditions for tool testing and calibration.

Facility B.1 North at 74,400 sf is about 1/3 Class 100 cleanroom for tool production, testing and calibration, 1/4 Class 10,000 area for parts storage and handling and the remainder is office space. Facility B.1 South at 141,000 sf is 90% office space and the remainder Class 100 cleanroom areas. The cleanrooms chosen for the monitoring are the AIT Cleanroom in Facility B.1 North and the APS/Demo Cleanroom in Facility B.1 South, both Class 100 (See Appendix F for building floor plan).

Facility B.1 North has one central plant that serves all of the cleanrooms in that building as well as two smaller cleanroom clusters in Facility B.1 South. Two package units (40 and 75 tons) located on the roof of Facility B.1 North serve office space. The office space in Facility B.1 South is served by a separate set of package units on the rooftop.

Facility B.1 Air Cooled Chillers

The Facility B.1 central plant includes three 270 ton air-cooled chillers serving a chilled water loop system that supplies cooling to make up air handlers (MUA), recirculating air handling units (RCU) and process cooling loads. Each air cooled chiller has multiple compressors that can be staged for more efficient operation at lower loads. There are four chilled water pumps with three running at a time. There is also a small boiler that provides reheat to the make up air handlers. There are two hot water pumps with one running at a time. Two gas fired steam generators on the roof provide humidification. Facility B.1 South has its own boiler for reheat and a steam generator for humidification. The central plant incorporates some redundancy in its pumping system, but there is no redundancy in the chillers or process utilities with the exception of compressed air.

Facility B.1 Boiler

Facility B.1 central plant also provides compressed air, process vacuum, house vacuum, and nitrogen as required by cleanrooms in both Facility B.1 North and South. The compressors operate on a 24 hour lead/lag rotation with one compressor operating at full capacity and the other trimming on demand. The process cooling water is supplied by the primary chilled water loop. There is a separate process cooling loop in Facility B.1 South served by the main chilled water through a heat exchanger. This small system was not monitored as it accounts for less than 5% of the total load.

Facility B.1 Air Compressors

Over the monitoring period from October 9, 2000 to October 18, 2000 the outside air conditions ranged from 51°F to 86°F (see Appendix B *Building Conditions* for trended data). During that time the chillers operated at an average load of 490 tons with a standard deviation of 70 tons and an overall range from 330 to 625 tons. The chilled water pumps draw a steady average power of 38 kW but a 50 kW spike occurs consistently about every 15 minutes. No investigation into the cause has been made but it is most likely due to the cycling of a control valve.

Only one of the pair of air compressors was monitored to reveal the load on each compressor as it operated in both the lead and lag duty. The compressor power ranged from 130 kW at full load (lead) to 35 kW at part load (lag). With both compressors running, one at full load and one at part load the combined total power is 165 kW for the compressed air system.

Energy consumption for Facility B.1 over the monitoring period averaged 2300 kW with a daily range of about 2100 kW to 2600 kW or 13%. The average ambient conditions were 62°F 70.8 % relative humidity, and the dry bulb temperature ranged from 51°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 8%. For this report this discrepancy is neglected and the average power during the monitoring period was taken to represent a yearly average in the annual energy calculations.

C. AIT Cleanroom Design

The AIT Cleanroom in Facility B.1 North is a 21,400 sf Class 100 cleanroom all of which is considered primary area in this report. The cleanroom is divided by return walls into five general zones which are further partitioned into multiple bays. The recirculation air handing units all draw air from the same interstitial space. The air handling system consists of one make-up air handler which distributes conditioned outside air throughout the main portion of the interstitial space. There are 28 recirculation air handler units. Twenty-seven of the 28 recirculation air handler units are located inside the interstitial space and deliver ducted air to HEPA filters covering 33% of the total ceiling area. The last recirculation air handler unit (RCU C3.34) is located on the roof and both draws from and discharges to the interstitial space. It is not clear what the purpose of the RCU C3.34 is, it may be used to add cooling capacity to the space. Six recirculation air handlers mounted on the roof serve the Class 10,000 areas.

AIT Recirculation Air Handler

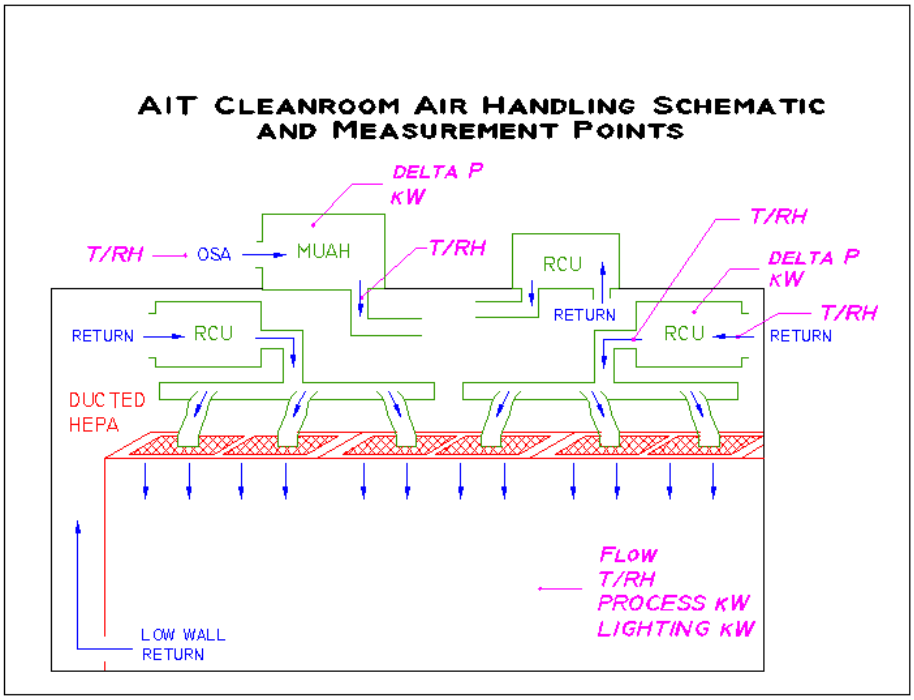
The recirculation air handlers are equipped with VFDs that have been set at a constant speed. There are no VFDs on the rooftop units. Return air is delivered to the interstitial space via return walls. The room is under a positive pressure of 0.07” water gauge as indicated by the wall-mounted Magnehelic pressure gauges in the building corridor, and there is no mechanical exhaust from the cleanroom, only exfiltration. The condition specifications 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.

AIT Ducted HEPA System

Make up air provides about 2.5% of the total recirculated air in the cleanroom, a result of the low ventilation requirements and no exhaust requirements. This low proportion of make up air reduces to a negligible level the impact of outside conditions on the energy consumption required to maintain cleanroom conditions. Supply air from the make up air handler is directed into the interstitial space at one end of the cleanroom.

During the monitoring period, the AIT cleanroom operated at an average temperature of 67.1°F ± 0.5°F and the relative humidity in the room averaged 48%RH ± 3%. The deviation seen on October 13 was a test of the responsiveness of the control system that the facility manager requested.

Flow measurements were taken for about 9% of the 882 ducted HEPA filters throughout the AIT cleanroom with more concentrated readings in the areas of with occupied bays. The average flow was 580 cfm with a standard deviation of 115 cfm and an overall observed range from 90 cfm to 775 cfm. Typical conditions in the tool areas were 500 to 650 cfm and 300 to 500 cfm in the perimeter storage areas. It is possible that further balancing of the ducted system could improve the flow conditions in some filter units.



D. APS/Demo Cleanroom Design

APS/Demo is a 3,940 sf Class 100 fan filter unit (FFU) cleanroom located in the south section of Facility B.1 South. This cleanroom employs a raised floor and chase return design resulting in 2,850 sf of primary cleanroom area and 1,090 sf of secondary (chase) area. It is one of a pair of FFU cleanrooms that are used for research and development. One make up air handler on the roof serves both cleanrooms and discharges air through a duct penetration in the wall directly into each interstitial space above the return chase. The APS/Demo cleanroom has three recirculation units in an interstitial space that draw air from above the return chase and discharge into plenums with several outlet registers to distribute air above the fan filter units. HEPA coverage is approximately 33%. The condition specifications 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.

APS/Demo Interstitial Space
Recirculation Air Handler and discharge registers above Fan Filter Units

During the monitoring period, the Class 100 cleanroom operated consistently at a measured temperature of 65.7°F ±0.6°F. The relative humidity was fairly constant at 50% ±2% during the nighttime hours. During the day the relative humidity would typically drop around 10 a.m., with a minimum of 45% at about 1 p.m. and then climb back up to 50% by 6 p.m.

Flow measurements of about 30% of the filters units indicate an average flow of 550 cfm with a range from 480 to 630 cfm. There were several of the measured fan filter units which were not operating.

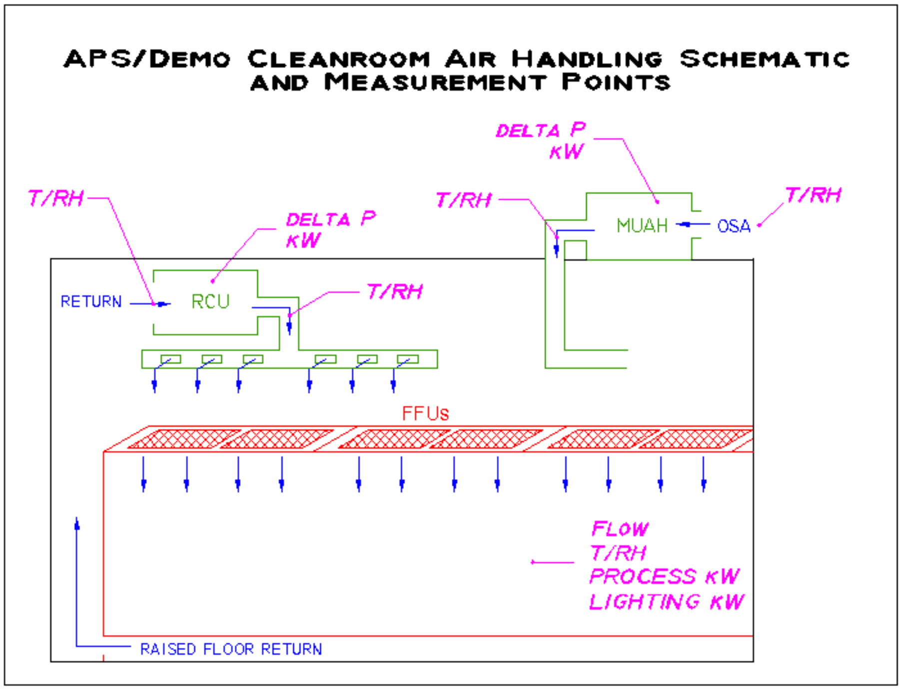


Table 3. Measured Air Handling Parameters for AIT and APS Demo Cleanroom Areas

Description	*AIT Cleanroom*		*APS Demo Cleanroom*	
Class 100 Primary Area	21,400	sf	2,850	sf
Total Make-Up Air	13,500	cfm	N/A*	cfm
Total Make-Up Fan Power	8.5	kW	1.9	kW
Total Recirculation Air **	517,000	cfm	56,700	cfm
Total Recirculation Fan Power ***	270	kW	44	kW
Room Air Changes per Hour	153	ACH	133	ACH
HEPA Filter Efficiency	N/A*	%	N/A*	%
HEPA Filter Ceiling Coverage	33	%	33	%
Average Ceiling Filter Velocity ****	86	fpm	76	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 APS/Demo cleanroom.*

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

IV. SITE ENERGY USE CHARACTERISTICS – Facility B.1

A. Site Energy Use

PG&E electric power billing data available for Facility B.1 was not directly comparable to the power consumption of the areas monitored at the facility. 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 Facility B.1 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 two meters at the Facility B.1 facility. Tables 4 and 5 outline the electricity and gas costs for Facility B.1.

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)
Facility B.1	20,400	$1,330,000	197,000	$148,000	$1,480,000

Source: Facility data provided by PG&E bills August 1999 to August 2000. Facility B.1 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.

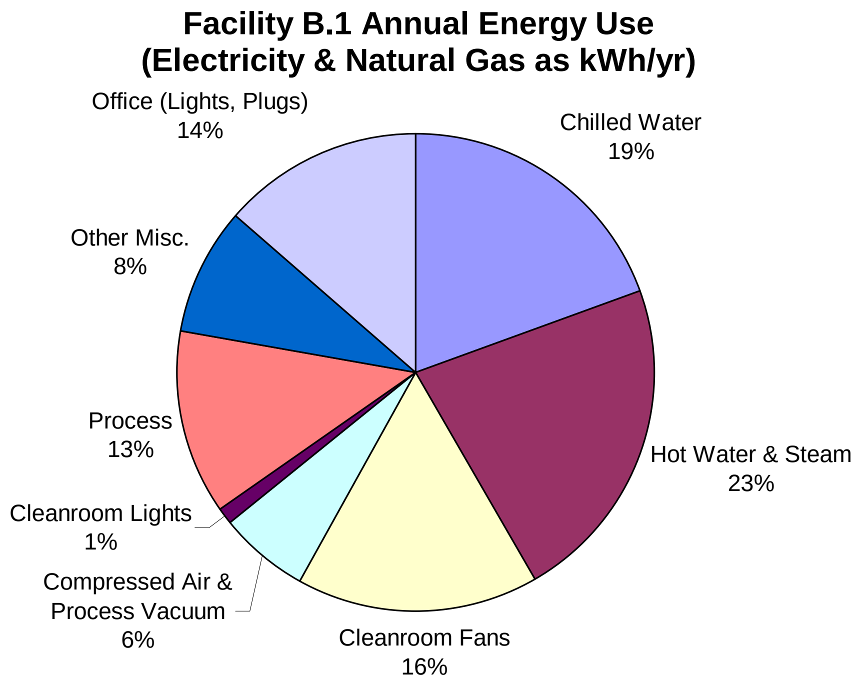
Table 5. Annual EUI and Energy Cost per Square Foot

Meter Level	Area (sf)	Energy Utilization Intensity (kWh/sf·yr)	Annual Energy Cost per Building Square Foot ($/sf·yr)
Facility B.1	215,500	120	$6.90

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

B. Facility B.1 Energy Use

The Facility B.1 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.1, including the process utilities, account for 65% of the total annual energy use for the building. Process power in the Class 100 cleanrooms account for 13% of the total power. The remaining 22% can be attributed to office loads, office HVAC, and other miscellaneous loads in the Class 10,000 and other areas.



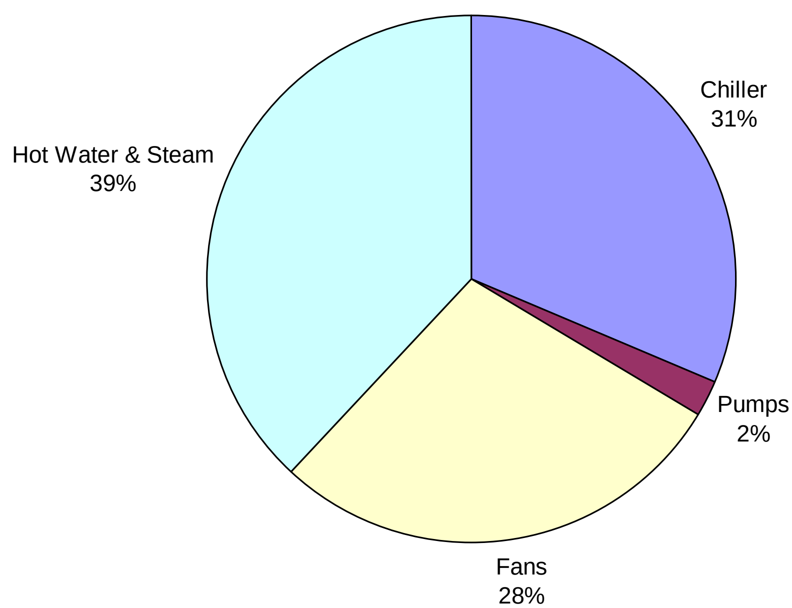
C. Facility B.1 Central Plant Energy Use

Table 6. Central Plant Energy Use by Major Components

Description	Average Load (kW, Therms)	Average Efficiency	Annual Hours of Operation	Electricity (MWh/yr)*	Total Natural Gas** (Therms/yr)	Total Cost ($/yr)***
COOLING						
Chillers	350	0.71 (kW/ton)	8760	3066		$310,000
Pumps	38	0.08 (kW/ton)	8760	331		$21,500
HEATING						
Boiler (Therms)					197,000	$148,000
Pumps (kW)	3.4		8760	29		$1,900
PROCESS UTILITIES						
Compressed Air	166		8760	770		$94,200
Process Vacuum	18		8760	161		$10,500
Other Utilities						
TOTAL	769			6738	197,000	$586,000

* *Annualization based on one week of data.*
** *All natural gas use attributed to boiler load. Gas consumption from billing data.*
*** *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.*

Annual Energy Use of Facility B.1 Cleanroom HVAC Equipment (Electricity & Natural Gas as kWh/yr)



D. AIT Cleanroom Energy Use

The energy consumption attributed to the cleanroom air handling system, process tools, and lighting are reported for the AIT and APS/Demo cleanrooms in Table 7 and Table 8, respectively. This breakdown of energy use by equipment helps identify major loads and related costs. The recirculation fans and the process loads contribute about equally to the overall energy consumption and resulting heat load of the AIT cleanroom. The APS/ Demo cleanroom shows a higher proportion of process power which agrees with our observation that tool use was more concentrated in this demonstration area. Recirculation and fan filter units consume a little over 1/3 of the energy in the APS/Demo cleanroom.

Table 7. AIT Cleanroom Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (CFM/kW)	Annual Hours of Operation	Electricity (MWh/yr)*	Total Cost ($/yr)**
AIR HANDLING					
Makeup Fans	8.5	1,588	8,760	75	$4,800
Recirculation Fans	234	2,212	8,760	2,050	$133,000
PROCESS	192		8,760	1,680	$109,000
LIGHTS	33		8,760	280	$18,300
TOTAL	466			4085	$265,000

* *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.*

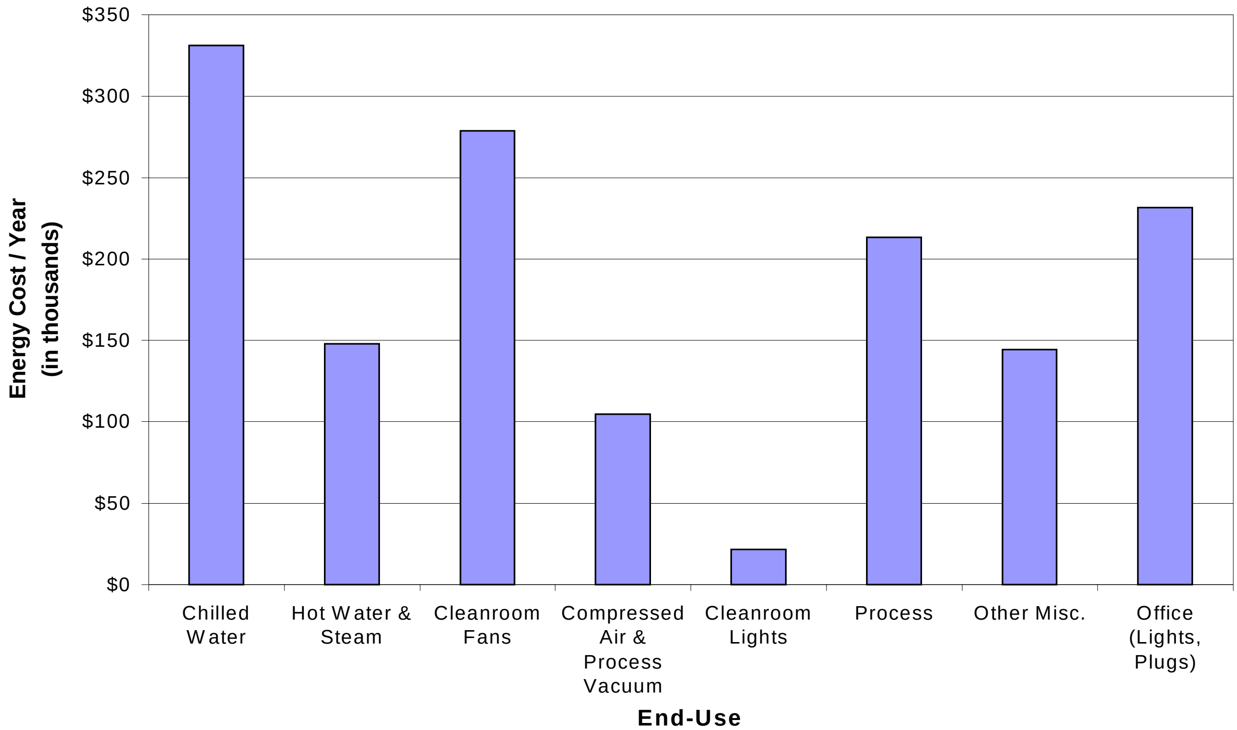
E. APS Demo Cleanroom Energy Use

Table 8. APS Demo Cleanroom Energy Use Breakdown

Description	Average Load (kW)	Average Efficiency (CFM/kW)	Annual Hours of Operation	Electricity (MWh/yr)**	Total Cost ($/yr)***
AIR HANDLING					
Makeup Fans	1.9		8,760	17	$1,100
Recirculation Fans*	44	1,276	8,760	385	$25,000
PROCESS	74		8,760	647	$42,000
LIGHTS	6		8,760	52	$3,300
TOTAL	126			1,100	$71,500

* *Recirculaion fans includes both RCU and Fan Filter Units.*
** *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.*

F. Annual Facility B.1 Energy Costs Bar Chart



The bar chart above illustrates the relative cost of supporting the major energy end-uses in Facility B.1. The largest annual energy cost is attributed to the operation of 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.

V. SYSTEM PERFORMANCE METRICS – Facility B.1

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

Facility B.1 has a significant quantity of office space in addition to the cleanroom space. The following metrics in Table 9 are for the Class 100 AIT cleanroom and based on primary cleanroom area. They are based on 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.

This cleanroom comprises approximately 10% of the total building area and is approximately 10 times the size of the APS/Demo cleanroom space. Despite a very low process load in the space, the energy usage is dominated by internal loads, with less than a 5% difference between the average and peak electrical power demand. 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 65° for these areas. In addition, the space had no process exhaust, resulting in a low make-up air requirement. 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. Annual AIT Class 100 Cleanroom Resource Use

Description	***Metric***	
Annual Energy Cost *per Cleanroom Square Foot*	$19	/sf
Annual Fuel Usage	1.9	Therms/sf/yr
Annual Electricity Usage	270	kWh/sf/yr
Annual Energy Usage	1.1	MBtu/sf/yr
Annual Peak Demand	32	W/sf
Average Power Demand	31	W/sf
Load Factor	0.96	

Based on Facility B.1 energy measurements, weather data, load assumptions and primary cleanroom area.

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. This type of information can be used to diagnose operational problems, such as over pumping or chiller cycling, that wastes energy and/or causes premature equipment failure, as well as evaluate the overall design performance.

Table 10. Central Plant

Description	*Metric*
Chiller Efficiency	0.71 kW/ton
Chilled Water Pumps Efficiency	0.08 kW/ton
Total Chilled Water Plant Efficiency	0.79 kW/ton
Cooling Load Density	120 sf/ton

Cooling Load Density is based on the total area served by the facility central plant, which is the sum of all cleanroom areas in Facility B.1, and the average tonnage of the central plant.

Process Utilities

The measurements required to calculate process utilities metrics were low in the priority list established for the Facility B Site Plan (see Appendix G), so these metrics were not collected during the monitoring period according to that prioritization.

AIT Cleanroom and APS/Demo Cleanroom

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

Both of these cleanroom facilities have moderate to poor air handling efficiency as compared to other Class 100 cleanroom designs. 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.

In the AIT cleanroom a ducted HEPA filter system design is utilized. The extended flexible duct runs that result from connecting each HEPA to the recirculation units results in a rather high pressure drop and associated high fan energy consumption. The result is the air handling efficiency seen in Table 11. Increasing the duct size serving each HEPA would improve the efficiency by lowering the pressure drop, but space constraints and duct layout geometry typically dictate the upper limit of the duct sizing. For a ducted HEPA layout, the recirculation efficiency of the AIT cleanroom is typical. A higher efficiency can be achieved with a ducted HEPA system by lowering the face velocity in the recirculating air handlers (using larger RCUs for a given air volume), employing low pressure drop filters and using more efficient motors or fans.

The APS/Demo cleanroom employs a fan filter unit design with recirculation air handlers mounted in the interstitial space. Though this design provides for a much lower pressure drop air path, 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 AIT cleanroom. 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 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, such as those used in AIT cleanroom recirculation units. Due to the inefficient fans and motors, the FFU system has a significantly poorer performance than the ducted HEPA system.

The monitored cleanrooms are used for the assembly and testing of tools, and subsequently the process tool power densities are quite low. These cleanrooms are operating at only 2 – 26 watts/sf. It may be possible to turn down the recirculation units serving the APS/Demo cleanroom as they serve only to cool the space.

Neither cleanroom had any exhaust so the make-up air serves only to pressurize the space.

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. AIT Cleanroom & APS Demo Cleanroom

Description	***AIT Cleanroom Metric***		***APS Demo Cleanroom Metric***	
Recirculation Air Handler Efficiency	2,210	cfm/kW	1,280	cfm/kW
MUAH Efficiency	1,590	cfm/kW	N/A*	cfm/kW
Make up Air CFM/sf	0.6	cfm/sf	N/A*	cfm/sf
Recirculation Air CFM/sf**	24	cfm/sf	20	cfm/sf
Recirculation Air ACH**	153	ACH	133	ACH
Lighting Power Density	1.6	W/sf	1.9	W/sf
Process Tools Power Density	2.6	W/sf	26	W/sf
Primary Cleanroom to Total Building Area	0.29	Ratio	0.02	Ratio

* *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.*

VI. SITE OBSERVATIONS REGARDING ENERGY EFFICIENCY – Facility B.1

There are a number of potential areas for energy savings in The PG&E Hi-tech customer Facility B.1. This section includes a general description of some of the most significant opportunities observed by the monitoring team.

Evaporative Cooled Chiller

Air cooled chillers are typically less efficient than evaporative cooled chillers. The air cooled chillers in place at Facility B.1 were measured at an average efficiency of 0.71 kW/ton. A high efficiency evaporative cooled chiller system will have a chiller efficiency of 0.55 kW/ton or less and a cooling tower efficiency of 0.05 kW/ton or less, giving an equivalent 0.60 kW/ton for the system. An evaporative cooled chilled water system would reduce the chilled water energy and cost by 15%.

The existing chillers may be retained as backup capacity or peak load capacity. Careful consideration on the sizing of the new unit should be taken to balance the installation and operating costs. Typically an evaporative cooled chiller will last 15 to 20 years as compared to 10 to 15 years for an air cooled unit.

Make-up Reheat Control

The makeup air handlers operate with a fixed off-coil temperature and a fixed reheat setpoint. The current operation has a supply air temperature averaging from 66°F to 68°F after reheat (see Appendix B *Class 100 Cleanroom AIT* and *Class 100 Cleanroom APS/Demo* for makeup air handler trended data). This is needlessly high and can be reduced to between 60°F to 65°F depending on the recirculation off-coil setpoint. By reducing the amount of reheat wasted, both the reheat load on the makeup units (boiler load) and the cooling load on the recirculation air handlers 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 makeup air is only a small fraction of total recirculation air, it is possible for the makeup air handler to supply air colder than the recirculation supply air temperature, which when mixed with the return air in the interstitial space will not enter the RCUs below the supply air temperature, so that control can be maintained.

Review Pumping System

The current chilled water pumping system has an unusual power spike every 15 minutes (see Appendix B *Pumping Power* for chilled water pump 2 hour data). This power surge might be caused by cycling of a control or bypass valve. At this point it will require further investigation before determining the source and solution to this situation.

This type of severe modulation in pumping power is typically harmful to the pump. If a method can be found to better balance the load, the pump should last longer and can be tuned to operate at a higher efficiency.

AIT Cleanroom Air Flow

Currently the AIT cleanroom is operating at an average ceiling filter air velocity of 86 fpm. The APS/Demo cleanroom is operating at 76 fpm while maintaining class rating. It should be possible to lower the AIT cleanroom air flow rate and maintain class rating.

If the air flow rate is lowered 10% it will achieve a theoretical 27% energy reduction as the energy usage is related to the cube of air flow. System effects will vary the energy savings slightly.

Before changing the air flow rate a review of the history of the space for cleanliness issues should be performed. But as the AIT has a higher ceiling filter velocity and similar coverage area as the APS/Demo, it should be possible to achieve equivalent cleanliness at the same ceiling filter velocity.

RCU Nighttime/ Weekend Setback

As the APS/Demo cleanroom employs RCUs as well as FFUs, setting back the RCU flow at off hours would not disrupt the ceiling flow conditions in the cleanroom. When the cleanroom is unoccupied and the lights are turned off, the power use and therefore heat load is minimized. By turning off two of the three RCUs , the cooling load is reduced even more and the third RCU should be able to maintain cleanroom temperature specifications.

Turning down RCUs in the AIT cleanroom should be possible as well as they are already controlled by VFDs. With the VFD, it is possible to reduce the flow to unoccupied zones where particle generation is a minimum. The RCU air flow can be reduced to a predetermined minimum to maintain positive flow through the HEPA filters.

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.

Cleanroom Temperature Control

The cleanrooms monitored were on average 3°F to5°F cooler than the stated specifications of 70°F ± 2°F. If the controls are set for 70°F, the sensors could be out of calibration. Raising the cleanroom temperature can save in cooling load.

RCU C3.34 Set Back

Depending on the purpose of the roof mounted RCU C3.34, it is possible that the unit can be set back and still maintain control of the cleanroom conditions.