Energy Consumption of Building 39

by

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ABSTRACT

The MIT community has embarked on an initiative to the reduce energy consumption and in accordance with the Kyoto Protocol. This thesis seeks to further expand our understanding of how the MIT campus consumes energy and with that knowledge be able to recommend methods of reducing energy consumption by minimizing and even eliminating careless energy use. The largest energy consuming building per square foot, Building 39, was selected and analyzed in detail. This thesis proves the unnecessarily high airflows and irresponsible fan use are the source of Building 39's wasteful consumption of energy. Research revealed that the recirculating fans drew the most energy and were continuously running on full power. If the fans were turned down during off peak times the consumption of electricity could be decreased by as much as approximately 26% and save the Institute $250,000 a year in electrical costs.

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Chapter 1: INTRODUCTION

1.1 Energy Consumption in the World

Global energy issues have been ignored for far too long and are now coming to light with a vengeance. Currently, the world as a whole consumes more that 400 exajoules of energy a year. The United States greedily consumes 100 exajoules, 25%[1] of the total yet only accounts for 5% of the world's population and 6% of the total global land area[2]. Buildings, both residential and commercial, use about 40% of the total US energy yearly. Unfortunately, this massive energy consumption only continues to grow at worrisome rates. Significant advances have been made in sustainable energy technology but cannot keep up with the increasing demand for energy. However, all hope is not lost. A temporary solution to this global problem is behavioral modification. In other words, a noticeable impact could by made in today's energy consumption by significantly reducing irresponsible energy usage. For example, according to stopglobalwarming.org, if every household changed just 5 incandescent light bulbs to fluorescent it would be like taking 8 million cars off the road a year.

A large step forward that the global community has made to curb greenhouse gas emissions is the Kyoto Protocol. The Kyoto Protocol is an agreement made under the United Nations Framework Convention on Climate Change (UNFCCC). Countries that ratify this protocol commit to reduce their emissions of carbon dioxide and five other greenhouse gases, or participate in emissions trading if they maintain or increase emissions of these gases. The objective is the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." [14]. Unfortunately, the United States chose to not ratify it.

1.2 Energy Consumption at MIT

MIT, being a world leader in so many other technological fields, is also striving to be a leader in energy initiatives. Under current President Susan Hockfield, an initiative has been developed known as the Walking the Talk program included in the *Report of the Energy Research Council.* It outlines how MIT seeks to set an example for United States and the world by meeting and even beating the guidelines set out by the Kyoto Protocol through tirelessly researching into renewable energy sources and efficient energy usages and methods on campus.

The most effective way of implementing this initiative is to determine and attack the largest energy sinks on campus first. According to research done by Tiffany Amber Groode[4], the largest energy sinks are all the laboratories across campus. Currently, laboratory buildings consume over 70 % of the campus utilities yet only comprise 55% of square footage as seen in Table 1. This is due to the plug loads, specialized lighting systems, and intensive HVAC systems to protect both researchers and the products from possibly dangerous contamination. The Co-Generation plant that is supplemented by N Star, the local electricity company, provides all the campus' energy including steam, chilled water, and electricity.

Fiscal Year 2003 Data			
	MIT Campus Building Square Feet	**Number of MIT Buildings**	**% Of Total Campus Square-Feet**
Lab	5,825,683	89	55.5%
Office	2,360,828	47	22.5%
Housing	2,316,068	26	22.1%
Total	10,502,579	162	100.0%

Table 1: MIT Building square footage by usage[4]

It is difficult to assign an exact cost for the electricity and steam generated by the Co-Gen plant because the cycle of the combustion turbine and heat recovery steam generator is linked. However, for accounting purposed the Facilities Department determined a reasonable estimation of $0.115 per kilowatt-hour for electricity and $14.30 per 100 pounds of steam produced[3].

Total energy consumption for each MIT building is ranked using a sum of the total energy for chilled, water steam and electricity. Facilities has developed a conversion factor for energy from natural gas—the energy used to get the steam and chilled water—to electricity. The conversion factor takes into account the turbine generator and distribution losses. Energy conversion from natural gas to electricity has an efficiency of about 30% but much of the lost energy in used to make steam using the heat recovery steam generator (HRSG). So the overall efficiency-- from a first law of thermodynamics approach-- of the Co-Gen plant is about 75% [4]

Chapter 2: BUILDING 39

Although there are energy inefficiencies all across campus, the best method is to work building-by-building and only thoroughly focus on one building at a time. Based on Tiffany Amber Goodwin's thesis, laboratory buildings would be the best to focus on first since they consume the largest portion of MIT's energy. From those laboratory buildings, choosing and analyzing the largest energy consumer would have the greatest impact on MIT's energy bills. According to MIT's energy rankings, normalized by area, building 39—the Stanley Gordon Brown Building—uses the most energy per square foot as can be seen in table 2 and hence emits the largest amount of CO2 per square foot as well.

Bldg #	Building Name	Electricity (kWh)	kWh/sf	KBtu/sqft/yr
39	BUILDING 39-COMPUTATION CENTER	8,042,462	106.61	2647
56	BLDG 56-WHITAKER LIFE SCIENCES	10,817,674	75.43	1375
16	BUILDING 16	7,674,644	66.05	1340
68	BUILDING 68	13,904,113	53.43	1078
18	BUILDING 18-DREYFUS CHEMISTRY	7,208,348	54.09	1033

Table 2: Top 5 energy consuming buildings on MIT's campus[5]

For a full understanding of the energy consumption of any building, all aspects of the building's operations need to be taken into consideration. In most buildings, lighting is usually a focal point of energy waste. However, building 39 is a special case due to the high concentration of energy guzzling equipment within the building. For this reason, lighting was taken into account but not focused on in depth.

Building 39 will inherently always be a large energy consumer due to the energy requirements associated with cleanroom air systems. However, there are many things that can be done to minimize irresponsible energy usage.

2.1 Cleanroom Background

Currently, one of the largest users of cleanrooms is the semi-conductor industry. It would be inconceivable to have the microelectronics that have become commonplace without the development of cleanrooms because of all the contamination related issues. The products from these industries have become so minuscule that it would be ruined by one particle 0.1 microns in diameter, the equivalent of one one-thousandth the diameter of an average human hair.

The basic concept of cleanrooms is very simple: A cleanroom is a room in which efforts have been made to control the amount of particulate matter within it. The amount of effort affects the quantity of particulate present in a given room which defines what class a cleanroom is, anywhere from Class 1 at the most stringent requirements to a class 100,000 with more lax guidelines. Table 3 shows the different particle content standards that must be met for the different classes.

	particles/ft^3				
Class	**0.1 μm**	**0.2 μm**	**0.3 μm**	**0.5 μm**	**5 μm**
1	35	7	3	1	
10	350	75	30	10	
100		750	300	100	
1,000				1,000	7
10,000				10,000	70
100,000				100,000	700

Table 3: US FED STD 209E cleanroom standards

Although the 209E standards were canceled in 2001, building 39 still follows these standards. The new set of standards that replaced the 209E are the ISO 14644-1 cleanroom standards shown in Table 4.

	particles/m³					
Class	**0.1 μm**	**0.2 μm**	**0.3 μm**	**0.5 μm**	**1 μm**	**5 μm**
ISO 1	10	2				
ISO 2	100	24	10	4		
ISO 3	1,000	237	102	35	8	
ISO 4	10,000	2,370	1,020	352	83	
ISO 5	100,000	23,700	10,200	3,520	832	29
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293
ISO 7				352,000	83,200	2,930
ISO 8				3,520,000	832,000	29,300
ISO 9				35,200,000	8,320,000	293,000

Table 4: ISO 14644-1 cleanroom standards

The following classes are mostly equivalent, although the testing standards differ.

ISO 14644-1	**FED STD 209E**
ISO 3	1
ISO 4	10
ISO 5	100
ISO 6	1,000
ISO 7	10,000
ISO 8	100,000

Table 5: Standard comparisons

People are the largest emitters of particles within in a lab even with the most minimal activity. For example, humans emit 100,000 particles per minute just by standing still. Table 6 the quantity of particles emitted by simple activities commonly performed by people.

Motion performed	Particles/minute
Light head and arm motions	500,000
Average arm motions	1,000,000
Standing up from a sitting position	2,500,000
Slow walk (2 mph)	5,000,000
Climbing stairs	10,000,000

Table 6: Human particle emission of particles 0.5 micron diameter or larger

Although wearing over garments, commonly referred to as "bunny suits," reduces human particle emissions significantly, they still cannot eliminate particle generation entirely and as a result, several other techniques must be implemented in addition to maintain particulate count within standard.

A particle's ability to land in vulnerable locations within a cleanroom is dependent upon the airflow and thus filtration as well. For the control of airborne particulates, cleanrooms use High Efficiency Particulate Air (HEPA) filters. These filters remove 99.9997% of particles less than 3.0 microns in diameter from the incoming air. While using HEPA filters considerably reduces the particulate count within the room, they alone are not enough because airflow patterns strongly determine the cleanliness of a room. Using the regular well mixed flow in an office is not applicable to the cleanrooms because this flow pattern puts particles into arbitrary places and then brings them back into the airflow at random locations and times. Instead, this is why vertical laminar flow is now used in cleanrooms. This type of flow is achieved by introducing air into a room confined on all sides at low velocity through an opening with the same cross sectional area as the confined space. [6]

2.2: Building Background

Building 39 was built in the 1960's and had the original purpose of being the MIT Information Processing Center. However, in 1985, extensive renovations were done to convert it into a major new VLSI (very-large-integration) research-and-fabrication facility and in December 1985 the Corporation named building 39 the Gordon Stanley Brown Building after the 6th Dean of the School of Engineering.

The building, now home of the Microsystems Technology Laboratories (MTL) includes the following work areas: the Integrated Circuits Laboratory (ICL), a CMOS-compatible device fabrication facility; the Technology Research Laboratory (TRL), a semiconductor device fabrication facility; and the Exploratory Materials Lab (EML), a flexible, thin film deposition lab where a great variety of materials can be processed. The general operations of the building are managed by MTL under MIT's Electrical Engineering and Computer Science Department.

The six-floor building has an overall area of ~75,000 sqft. And has a footprint of~10,500 sqft. The 1st floor is just a lobby. The 2nd, 4th and 5th floors are a combination of cleanrooms and offices with a layout similar to that in figure 1. The 3rd floor is mostly occupied by the recirculation system consisting of fans and filters. The basement contains the electrical room and all the large mechanical equipment is located on the 6th floor.

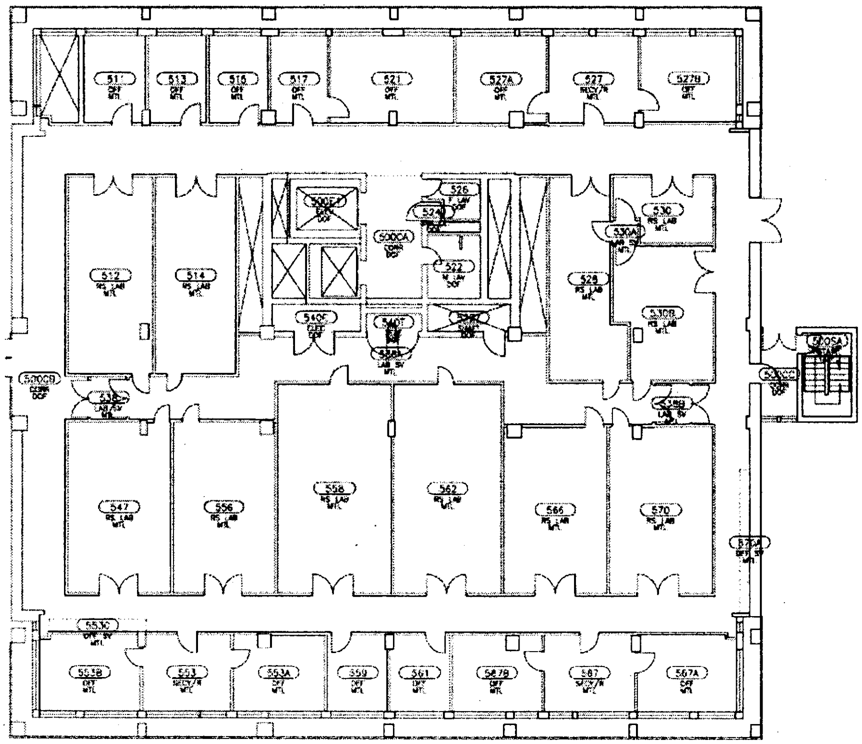

Figure 1: Floorplan of the 5th floor of Building 39[5]

Since the floor of the building has a footprint of only 10,500 sqft, it was necessary to stack the cleanrooms on separate floors. The ICL on the 2nd floor is rated as Class 10 and occupies 3500 sqft. The TRL on the 4th floor is rated as Class 100 and occupies 3000 sqft. Lastly, the EML on the 5th floor is rated as Class 10,000 and occupies 9000 sqft.

The 3rd floor is used for air-recirculation fans, which are install in two casings that segregate return air from the cleanrooms on the second and fourth floors. The air-handling system is made up of small fans in relatively compact recirculation units. Figures 3 and 4 below provide a better depiction of the airflows within the building. Each 20 horsepower fan moves air at a rate of 30,000 CFM. Although the units are supposedly equipped with variable-speed controls so that fans can be easily reduced when cleanrooms are unoccupied, these variable speeds are never utilized and the fans run full power 24/7.

Each recirculation unit is equipped with three banks of ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) filters, two at 30% and one at 95% collection efficiency. Return air is pre-filtered before it reaches the HEPA filters, thus minimizing any return-air contamination caused by equipment in the chases. HEPA filters (with 99.97% efficiency) are also installed on all makeup-air systems for filtration of air prior to its introduction into the third-floor interstitial space. Due to safety reasons, MIT requires that all the air from the 27 fume hoods and equipment exhaust be 100% exhausted.

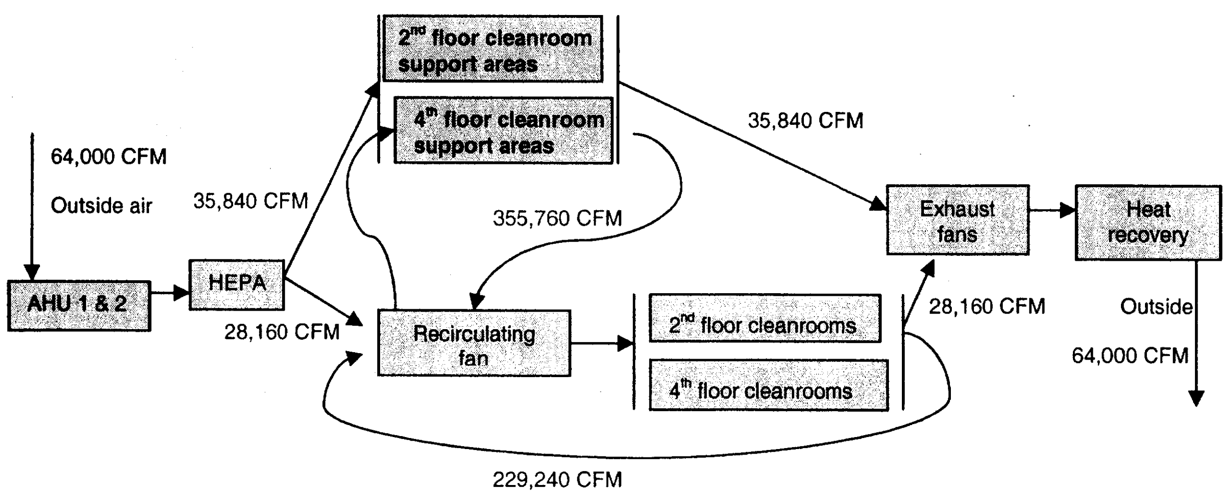

Figure 3: Airflow diagram for AHU 1 & 2

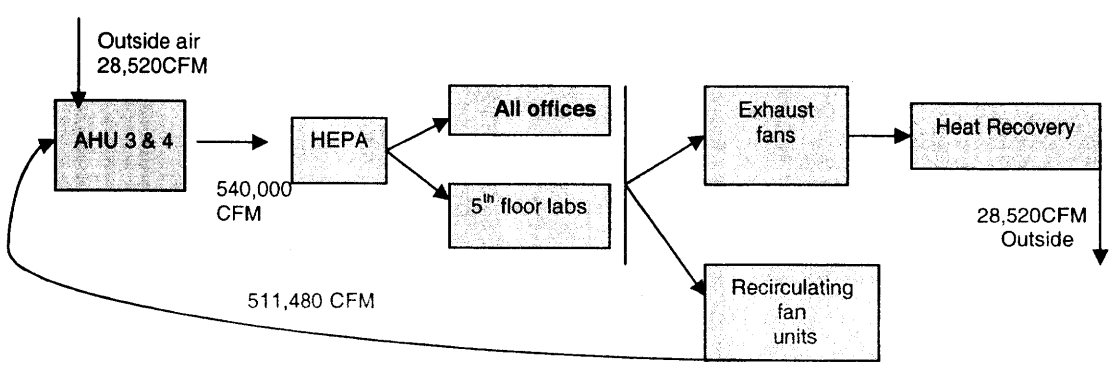

Figure 4: Airflow diagram for AHU 3 & 4

The ventilation system consists of four air-handling units (AHU), 31 exhaust fans (EF), and 16 recirculation fans (RCF). AHU 1 and 2 draw 100% outside air and serves all the cleanrooms. AHU 3 and 4 provide the air for any other area that is not a cleanroom such as offices. AHU 3 draws 78% outside air while AHU 4 only draws 40% outside air, the remainder is recirculated. This is better detailed in Table 7 below:

	% Outside air	Areas served
AHU 1	100	Cleanrooms on 2nd and 4th floors
AHU 2	100	Cleanrooms on 2nd and 4th floors
AHU 3	78	offices and 5th floor labs
AHU 4	40	offices and 5th floor labs

Table 7: Air handling units' air source and areas served

A pressurized open-plenum system was chosen for the cleanrooms because of flexibility and space restrictions. Return air leaves the cleanroom through low sidewall returns; all sidewalls have full grilles and dampers that create vertical laminar flow. Where the width of a cleanroom bay exceeds 12-14 ft, a center-floor return is utilized.

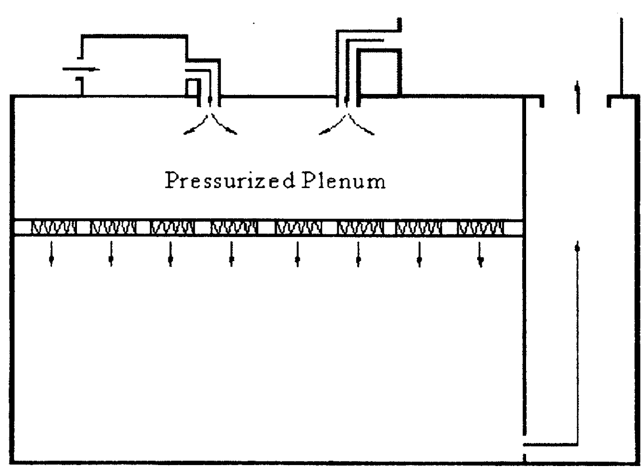

Figure 2: Simple schematic of a pressurized plenum system used in Building 39

Chapter 3: CURRENT PRACTICES

3.1 Airflow Mapping

Air-handling units 1 and 2 both draw 100% outside each at a rate of about 32,000 CFM. For AHU 1, 65% of the flow runs through a HEPA and then serves cleanroom support areas on the 2nd and 4th floors: 15% to the 4th floor and 50% to the 2nd floor, running through heating coils first. The remaining 35% is distributed between recirculating fan units on the 3rd floor serving the 2nd and 4th floors: 25% to the 2nd floor units and 10% to the 4th floor units.

AHU 2 has a similar distribution to that of AHU 1. 47% of the air flows through a HEPA filter; of that 24% flows through a heating coil into cleanroom support areas on the 4th floor supplementing the airflow from AHU 1. The remaining 23% flows straight into cleanroom support areas on the 2nd floor supplementing the airflow from AHU 1. The remaining 53% of the airflow from AHU 2 is fairly evenly distributed between recirculating fan units on the 3rd floor serving the 2nd floor and the 4th floor cleanrooms.

Air-handling unit 3 serves offices on all floors (2nd-5th) and labs on the 5th floor. AHU 3 draws 78% of its air from outside and a total of 20,250CFM flow through AHU 3. 68% of that 20,250CFM flow through HEPA filters followed by heating coils before entering lab space on the 5th floor. The remaining 32% serves office space on the 2nd through 5th floors.

Air-handling unit 4 has a similar flow pattern to that of AHU 3. AHU 4 draws 60% of its air from outside and has a total flow rate of 21,207 CFM. 63% of its total flow serves lab spaces on the 5th floor, the rest go to offices on the 2nd through 5th floors.

Amongst all the air-handling units, there is a total of about 85,000 CFM of air drawn from the outside which is equal to the rate of air exhausted from the building in order to keep the building balanced at the set standards. The cleanrooms on the 2^{nd} and 4^{th} floors have an area of 6500 sqft and have an average air velocity of 90 ft/min. This results in a total flow rate of 585,000 CFM for the cleanrooms on the 2^{nd} and 4^{th} floors. For these given rooms, about 70,000 CFM is exhausted and thus 88% of the air is recirculated. The 12% of the airflow that is exhaust passes through a heat exchanger first preventing all the energy from the conditioned air from being wasted. The labs on the 5^{th} floor have a total airflow of 540,000 CFM and only exhaust 34,000 CFM meaning that 93% of the air is recirculated. All the offices recirculate 77% of their airflow.

3.2 Electrical Energy Balance

In 2006, Building 39 consumed 8.04 kilowatt hours of electricity, 4.9 million Ton-hours of chilled water, and 47.8 million pounds of steam[5]. The break down and end usage of the chilled water and steam are known since each only has one basic purpose. However, the breakdown of the electrical consumption is more involved and must be looked at more closely.

The building's electrical system consists of a normal primary service and an emergency primary service. Power is provided by medium voltage load break type switchgear, unit substations and 480V and 208V distribution equipment including a bus duct riser, panel boards and motor control centers. The normal primary service feeding the building is provided from MIT's 13.8kV power plant. The primary service to building 39 consists of two 13.8kV feeders that terminate in the main-tie-main configuration switchgear located in the main electrical room in the basement. The emergency primary service is provided from a 2.3 kW generator backed up power plant. The normal and emergency low voltage power is distributed throughout the building from a bus duct riser, panel boards, emergency distribution panels, and motor control centers (MCC) fed from the normal substations.

In a typical office building, lighting uses approximately 20% of the total electrical power per year. However, building 39 is not a typical office building and the bulk of the electrical usage powers the mechanical equipment used to maintain the cleanrooms such as fans, pumps and the air handlers. Regardless, all of the light fixtures were still tallied in order to be able to do a complete energy balance of the building and it was determined that the lighting only accounted for 7 % of the total load as can be seen in Appendix C. The load from lighting was determined with the assumption that all the lights are continuously on for the whole year.

Currently, the building's administration is looking into having several major renovations done since much of the mechanical equipment has become antiquated and is thus inefficient. Because of this, they have had the engineering consulting firm; Symmes Maini & McKee do a preliminary assessment of the building's electrical system. They took current measurements of the majority of the large equipment such as the substations, panels, and motor control centers. Using the measured amperage, one can calculate the power using equation (1)

$$P=I*V*\sqrt{3}*p_f \tag{1}$$

Equation 1: 3-Phase Electrical Power Consumption

Where I is the current drawn by the equipment, V is voltage supplied through the outlet and p_f is the power factor. The power factor of an AC electric power system is defined as the ratio of the real power to the apparent power, and is a number between 0 and 1.

Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power is equal to or greater than the real power. If the power factor of a piece of equipment is unknown, a good rule of thumb number to use is 0.8. Finally, everything is multiplied by the square-root of three because all the power coming into the building is 3-phase. In a three-phase system, three circuit conductors carry three alternating currents (of the same frequency) which reach their instantaneous peak values at different times. Taking one conductor as the reference, the other two currents are delayed in time by one-third and two-thirds of one cycle of the electrical current. This delay between "phases" has the effects of giving constant power transfer over each cycle of the current, and also makes it possible to produce a rotating magnetic field in an electric motor.

The load approximation for the three motor control centers which feed all the mechanical equipment including pumps, all the fans, and air handling units is equal to 3.7 million kilowatt hours which comprise 49 percent of the building's total energy consumption[7]. A more thorough breakdown of what the MCCs feed is detailed below and a breakdown of each MCCs power consumption can be found in Table 7.

Motor Control Center MCC-3 in the 6th floor mechanical room feeds:

* air handling units for the whole building
* chillers
* condensing units
* Chilled water pumps
* Air compressors
* Vacuum pump and cleaner
* DI water system
* Process water pumps
* Domestic hot water pumps
* Heat recovery pumps

Motor Control Center MCC-1 in the 3rd floor mechanical room feeds:

* All the recirculating fans for the cleanrooms
* The vacuum system
* Fan Coil Units
* Return Line Pumps

MCC-4 in the 6th floor mechanical room feeds:

- All the exhaust fans for the building.

Unit	Current (A)	Energy (kWh/yr)
mcc-1	268	1.496E+06
mcc-3	264	1.474E+06
mcc-4	123	6.868E+05

Table 7: amperage and energy consumption for the 3 MCCs

Although the MCCs comprise a large portion of the total power usage, there is still 51 percent of the power consumption unaccounted for. The two main consumers left are Panel D found in the basement and the bus duct riser. Panel D, which feeds the elevators, all the lighting and all the receptacles for the building, contributes 17 percent to the buildings total power consumption. The last 34 percent of the power travels through the bus duct riser to several panels on each floor that feed all the cleanroom process equipment.

This overview by SMMA gave a good basis from which to start but was not detailed enough about the power consumption of the different individual mechanical equipment. To arrive at these values the infrastructure testing done by Leonhardt Company was referenced and several measurements were performed manually using an ampemeter. From this information it was determined that the 32 exhaust fans, which constantly run, consume 11 percent of the total power consumption. The 16 recirculating fans and 12 recirculating fan coil units consumed 24 percent of the total. Adding these together, it can be seen that the fans alone consume 35 percent of the total. The power breakdown can be seen in Appendix A.

3.3 Recirculating Fan Intensity

Of all the power consumers in Building 39, the ones of special interest are all the fans because the largest amount of change can be made with the smallest amount of effort by simply modifying their usage. The building's facilities staff periodically has infrastructure testing done to verify the building's compliance with all the required safety and cleanroom requirements. In November of 2005, Leonhardt Company tested the average airflows, air velocities and amperages of all the fans and air-handling units within the building. Their findings can be seen in Appendix B.

Currently, the recirculating fans supply air to the cleanrooms at an average velocity of 90FPM which is a longstanding standard for most cleanrooms. However, in her Masters thesis, Maribel Vazquez showed that reducing the air velocity to 70FPM and even 50FPM actually reduced the amount particle deposition thus making the rooms cleaner. Using the Fan Affinity Laws the power savings attained by reducing the air velocities. Equation 2 shows that the power of a fan relates to the cube of the airflow.

$$P_1 / P_2 = (q_1 / q_2)^3 \qquad (2)$$

Where P is power and q is airflow. Airflow is the product of the air velocity and the area through which it travels. Since the area is a constant for the two airflows being analyzed, it means that power also relates to the cube of air velocities giving Equation 3

$$P_1 / P_2 = (v_1 / v_2)^3 \qquad (3)$$

Using these equations, by reducing the air velocity of the recirculating fans to 70 FPM would reduce the power consumption and thus the cost for running the fans by 53%. Velocity reduction to 50 FPM would reduce the power consumption and cost by a surprising 83%.

These findings don't even take occupancy into account. Currently, all the fans, both recirculating and exhaust run on a continuous basis at a power that maintains velocities of 90FPM regardless of population density of the lab spaces. Since humans are the largest particle emitters within the lab space, it makes sense that the fan speeds could be turned down even more than already suggested by Maribel Vazquez during off-peak times when the cleanrooms are completely empty. They could never be fully turned off because, although particle emissions from the lab equipment are minimal compared to human emissions, it's still significant enough to contaminate the cleanrooms if the fans were to be turned completely off.

Whatever amount the recirculating fans are turned down is the same amount the exhaust fans should be turned down in order to maintain a constant flow and sustain the prescribed pressure within the cleanrooms.

3.4 Cleanroom Occupancy Observations

One of the most important factors for particle emissions and thus room cleanliness is the occupancy rate in the cleanrooms at any given point in time. Through observations over a month, occupancy rates were obtained for the regular working hours of Monday through Saturday from 9AM-6PM. In addition, through conversations with graduate students that work in building 39, occupancy rates for the off-peak times were obtained. More solid data was difficult to obtain because although there is a log of when machines are in use through the software, CORAL, that does not necessarily mean people are in the labs during the whole time because the machines can be left to run a process for several hours on their own. The results can be seen in table 8 below.

	Mon-Sat 9AM-6PM	Mon-Sat 6PM-12AM	Mon-Sat 12AM-8AM; all Sun.
2nd floor	3 - 4	1 - 2	0
4th floor	6 - 8	1 - 2	0

Table 8: Average number of people in the cleanrooms at different times of day

Using this information, it can be seen that the recirculating fans can definitely be turned down for 72 hours a week when the cleanrooms are completely empty. They could also probably be turned down during the slower times of the day when only one or two people are working in the cleanrooms. Supposedly however, the cleanroom fans are left running on full power continuously because the Building 39 cleanrooms are meant to be 24 hour facilities available to researchers at any time of day or day of the week.

3.5 Cost Savings

In 2006, Building 39 used a total of 8,042,462 kWh and at the price of $0.115/kWh, cost MIT $924,883 for electricity alone. Currently, all the fans combined cost $291,840 to run, 32% of the total building's electrical cost. By reducing the air speed to 70 FPM, the cost to run the fans would reduce to $137,313, thus becoming only 18% of the building's total cost. By reducing the air speed even further to 50 FPM, the cost to run all the fans would reduce to $50,041 making it only 8% of the building's total bill. The cost savings were also found for the scenario where the fans are completely turned off for the 72 hours a week that the labs are unoccupied, but then run at the high speed during the rest of the week. All these estimates can be better seen in Table 9.

	Total Energy (kWh)	Total Electrical Cost
Current at 90 FPM	8,042,462.0	$924,883
Reduction to 70 FPM	6,698,749.9	$770,356
Reduction to 50 FPM	5,939,865.9	$683,085
Off for 72 hrs/wk	6,957,840	$800,152

Table 9: Cost savings using lower fan speeds

Chapter 4: CONCLUSIONS & FURTHER RESEARCH

Through general estimations it has become apparent what the major energy sinks within Building 39 are. From this break down of energy consumption it was determined that the recirculating fans were the largest energy consumer that was the simplest to adjust. The air-handling system already comes equipped with variable-speed controls so that fan speeds can be easily reduced when cleanrooms are unoccupied. However, the variable speed controls are not used out of fear that there could be possible contamination. Hence the fans run at full power on a continuous basis. By implementing a reduction of the recirculating fan power, the exhaust fans power must all be reduced in order to maintain equilibrium of airflow in and out according to conservation of mass.

Another concern brought up by the administration of the building was the ramp up time necessary to get the fans back up to fully functional capacity after they have been reduced due to cleanroom vacancies. This was an issue that could not be addressed through this research because of restrictions on being able to vary the air speeds in order to collect data. This is something that should be researched further in order to ensure those weary of changing the fan power levels that reducing the fan speeds during vacant periods will not compromise the cleanliness of the rooms.

APPENDIX A: ELECTRICAL BREAKDOWN

			current (A)	Power (W)	Energy (kWh)	% of total	Energy (kWh)	% of total
Substation 1, side 1 (514)								
	DPH-B		4	2826.706918	24761.9526	0.29%	24761.9526	0.31%
	MCC-3		264	186562.6566	1634288.872	19.08%	1634289	20.45%
Substation 1, side 2 (948)								
	MCC-1		268	189389.3635	1659050.824	19.36%	1659051	20.76%
	ATS/EDPH		152	107414.8629	940954.1988	10.98%		
		MCC-4	119	84094.53081			736668.0899	9.22%
	Bus Duct Riser		463	327191.3258	2866196.014	33.45%		
		DPH-2	160	113068.2767			990478.1041	12.39%
		DPH-4	122	86214.561			755239.5543	9.45%
		DPH-5	0.7	494.6737106			4333.341705	0.05%
		DPL-2	7.5	5300.075471			46428.66113	0.58%
		DPL-3	16	11306.82767			99047.81041	1.24%
		DPL-4	17	12013.5044			105238.2986	1.32%
		DPL-5	80	56534.13836			495239.052	6.20%
Substation 2 (242)								
	Panel D		233	164655.678	1442383.739	16.84%	1442384	18.05%
		lighting		69358	607576.08	7.09%		
		elevator			438000	5.11%		
	(feeds elevators, lighting, receptacles)				**8567635.6**		**7993158.865**	
					106.53%		**99.39%**	

Table 10: The energy column on the left shows a break down of the larger components such as the bus duct riser. The energy column on the right shows a deeper breakdown of the subcomponents that make up the larger components.

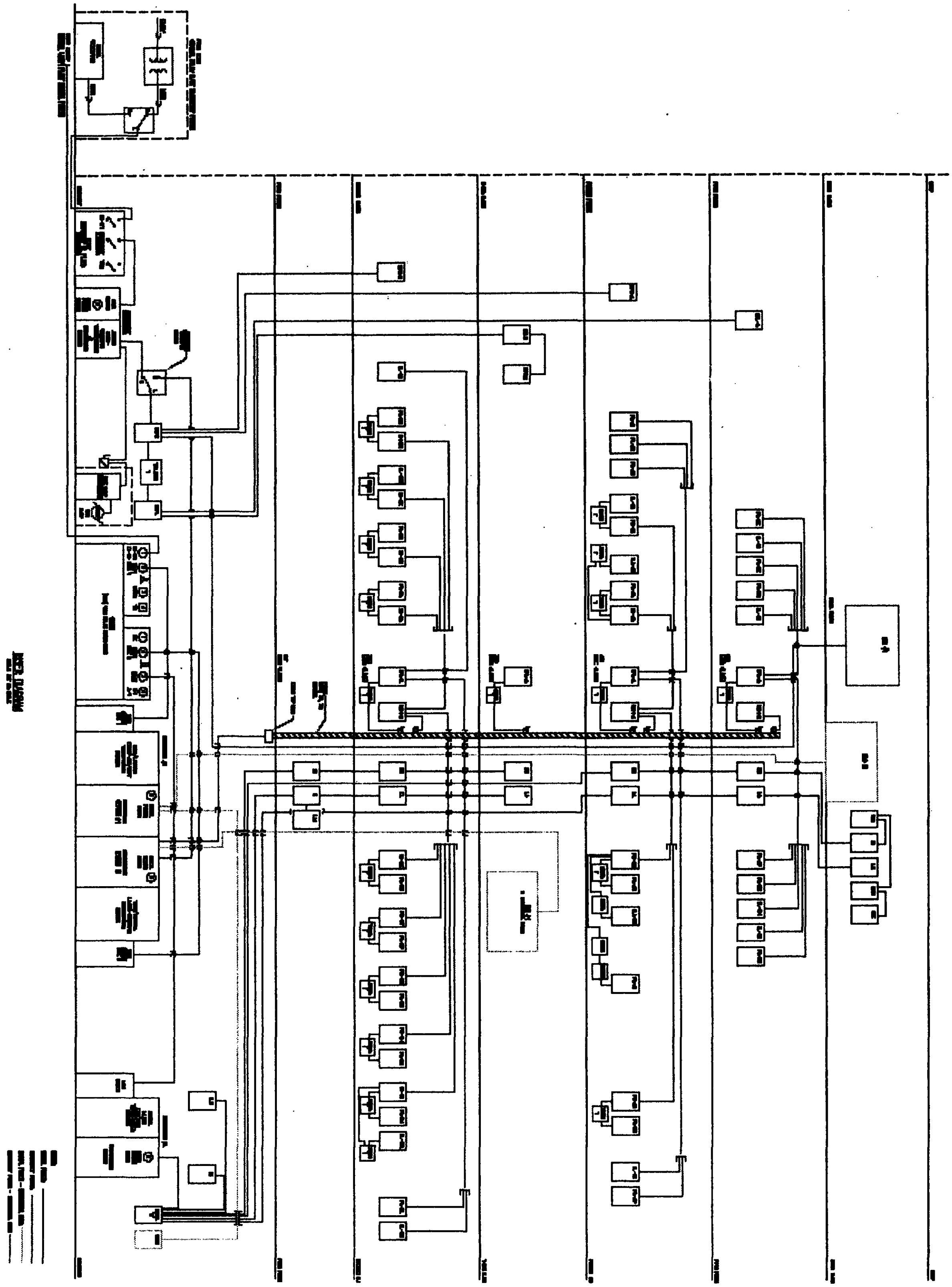

Figure 5: Riser diagram for Building 39 (8)

APPENDIX B: AIRFLOW BREAKDOWN

Fan	CFM	FPM	Comments
EF 27	2,032	1,270	
EF 28	2,448	1,761	
EF 29	--	--	not running
EF 30	3,020	2,180	
EF 31	311	224	
EF 1	2,658	1,913	
EF 2	1,861	1,339	
EF 3	2,027	1,458	
EF 4	2,623	1,887	
EF 5	2,017	1,451	
EF 14	--	--	backup
EF 15	3,900	1,060	lab 512
EF 15	2,837	771	rm295/297
EF 16	5,528	1,988	
EF 17	3,161	1,796	
EF 18	2,337	1,271	
EF 19	440	1,000	
EF 20	12,397	1,756	
EF 21	5,382	2,469	
EF 22	1,737	1,250	
EF 23	814	1,494	
EF 24	--	--	not running
EF 25	727	1,325	
EF 26	4,427	1,410	
EF 6	637	1,168	

Fan	CFM	FPM	Comments
EF 7	1,616	2,971	
EF 8	1,152	1,468	
EF 9	1,237	2,269	
EF 10	2,537	1,825	
EF 11	6,664	1,811	
EF 12	2,206	1,587	
EF 13	954	542	
			(full load on MCC 4---6.87E5 kWh)
	79,687		**Total Exhausted**
AHU 1	31,091	290	100% outside air
AHU 2	32,699	305	100% outside air
AHU 3	20,250	325	15858 CFM outside air 4392 CFM return fans 1&2
AHU 4	21,207	277	8543 CFM outside air 12664 CFM return fans 3&4
			(Part of MCC 3---1.47E6 kWh)
	88,191		**Total outside intake**

RCF 1	28,436
RCF 2	24,699
RCF 3	28,188
RCF 4	28,927
RCF 5	38,649
RCF 6	24,791
RCF 7	28,742
RCF 8	21,450
RCF 9	30,127
RCF 10	22,584

Fan	CFM	FPM	Comments
RCF 11	30,229		
RCF 12	30,112		
RCF 13	28,456		
RCF 14	41,624		
RCF 15	24,508		
RCF 16	28,918		
	460,440		**Total RCF**
RFCU 1	5,778	1,735	
RFCU 2	2,960	740	
RFCU 3	7,290	2,010	
RFCU 4	2,760	920	
	18,788		**Total RFCU**
			(Part of MCC 1---1.496E6 kWh)
Adding RCF and RCFU		**479,228**	**TOTAL thru recirc. Fans**

Table 11: Airflow and air velocities measured at all the building's fans

APPENDIX C: LIGHTING

Fixture Type	Lamp type	Power
A	F40WW/RS/WM	34
B	F40WW/RS/WM	34
C	F40WW/RS/WM	34
D	F40WW/RS/WM	34
E	F40WW/RS/WM	35
F	200A/99	200
G	LUI100/D	100
H	40/30	34
I	F40WW/RS/WM	34
J	150RS/VS	150
K	100A/99	100
L	150A/99	150
M	150A/99	150
M1	100A/99	100
N	F40WW/RS/WM	34
P	75R30	65
R	70W	70
T	F40WW/U/6	
U	F40WW/RS/WM	34
V	F40WW/RS/WM	34
W	F40WW/RS/WM	34
X	HR100 WDX38-4	100
CC	F40WW/RS/WM	34
DD	F40WW/RS/WM	34

Table 12: The power consumption of the different fixture/lamp types

fixture type	quantity	power (W)	total power	Energy (kWh)
B	160	34	5440	
BB	4		0	
C	35	34	1190	
CC	15	34	510	
D	2	34	68	
DD	33	34	1122	
E	10	34	340	
F	7	200	1400	
G	6	100	600	
H	12	34	408	
I	2	34	68	
J	208	150	31200	
K	14	100	1400	
L	112	150	16800	
M	9	150	1350	
M1	14	100	1400	
P	2	65	130	
T	18	40	720	
U	3	4	12	
X	52	100	5200	
		TOTAL	**69358**	**607576.08**

Table 13: Quantity of each fixture type and the total power consumption due to lighting

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