Energy Efficiency Strategies for Cleanrooms without Compromising Environmental Conditions

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ABSTRACT

Traditional cleanroom filtration design and operation relies upon high recirculation air change rates as a means of maintaining acceptable contamination control. Cleanroom professionals accept recommended air-change rates that were established somewhat arbitrarily as rules of thumb. The guidelines were based upon historically adequate cleanroom conditions, but they are not optimized. Disadvantages of this practice include paying a high cost for excessive airflow, as is usually the case, but also production or other work in the cleanroom could be adversely affected by too much or too little airflow. This paper describes research and several case study projects that suggest that control of recirculation airflow by monitoring cleanliness, or other control strategies, is a viable means to improve energy efficiency. One strategy being researched by Lawrence Berkeley National Laboratory and Cornell University in separate projects involves use of particle counters to continuously measure particle counts to automatically control recirculation air handlers using the building control system. Given that people are the number one source of contamination in cleanrooms, other less sophisticated strategies, such as timed setback or use of occupancy sensors to reduce airflow, have also been studied. This paper discusses the energy-saving potential for routine use of these methods and provides case study results where setback strategies were successfully in use.

INTRODUCTION

Suggested air change rates for cleanrooms have been published in various technical publications including the *2003 ASHRAE Handbook—HVAC Applications*, chapter 16 (Table 2), and IEST Recommended Practice 012.1; however, these and other sources provide conflicting recommended ranges of air change rates, and the range of values is very broad. Air change rates apparently were developed based upon historical rules of thumb, relying on what previously worked for similar contamination control areas, or pure guesswork. ISO Standard 14644-1 defines various cleanroom cleanliness classes in terms of allowable numbers of particles of various sizes. ISO 14644-4 Annex B provides recommended air velocities and air change rates for some applications. Other standards in the 14644 series describe monitoring and testing, design and construction, molecular contamination, etc. There are various recommended ranges of air change rates that evolved based upon what seemed to work in most situations, but in general there are no accepted guidelines based upon the science of particle transport. Guidelines would necessarily be complex to adequately account for all of the contamination control situations, sources of contamination, geometries, thermal effects, etc. Studies of particle concentrations of various sizes and their relationship to airflow suggest that more airflow is not always better and that there is often a "sweet spot" of optimal airflow where increasing or decreasing airflow would allow more contamination.

A strategy of controlling airflow including detecting excessive particles and automatically controlling cleanroom fans could provide a means to better optimize the airflow in a cleanroom. Better optimization of airflow would have large energy savings implications but could also improve cleanliness conditions due to less turbulence in the room, lower noise levels, and potentially lengthen the life of the fan equipment. This paper discusses two studies using this strategy in both university and national laboratory settings and case study results from an industrial cleanroom where recirculation airflow set back is successfully being used.

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BACKGROUND

Demand-controlled filtration (DCF) is described as a method of controlling cleanliness (particle concentrations) in a room by changing the recirculation flow rate based upon real-time measurements of particle concentrations. Prior research conducted at Lawrence Berkeley National Laboratory in 1994-1995 (Faulkner et al.) suggested that energy savings of 60% to 80% were possible while maintaining desired cleanliness. Other anecdotal evidence suggested that a number of cleanroom operators are experimenting with reducing recirculation airflow when rooms are not occupied. Various control schemes are employed, ranging from simple use of timers, occupancy sensors, or combinations of automatic and manual control. Demand-controlled filtration represents another control option that has the potential to more closely optimize airflow by sensing particle concentrations and adjusting airflow to optimize cleanliness.

Contamination may be created by people in the space or by activities or processes occurring in the room. As a result, if lower airflow can still achieve the desired cleanliness when these contamination generators are not present, large energy savings may be possible by turning down the recirculation airflow. A small change in the fan speed will cause a large reduction in the power consumed by the fan since fan power is approximately proportional to the cube of the fan speed. One case study where airflow was reduced by use of timers realized a 70% reduction in fan power.

With the need to maintain very low particle concentrations, most cleanrooms currently rely on a constant high rate of air recirculation (e.g., 600 room air volumes per hour) through HEPA filters. Compared to a commercial building that may have an air change rate of 1-2 air changes per hour, cleanrooms use much larger amounts of energy for air movement (e.g., 100-800 air changes per hour).

NATIONAL LABORATORY— RESEARCH PILOT STUDY

A pilot project to investigate the feasibility of controlling airflow based upon real-time particle monitoring was conducted in a 300 ft^2 ISO Class 5 (previously Fed. Std. 209 Class 100) cleanroom at Lawrence Berkeley National Laboratory. This project involved measuring particle concentrations of multiple particle sizes while changing the recirculation fans speeds. This cleanroom is typically used a few hours per week by researchers making detectors for physics experiments and is unoccupied during other times. The room had been previously used to conduct demand-controlled filtration experiments in 1994 and 1995 for a prior study (Faulkner et al.). In the current pilot study, the cleanroom was monitored while occupants used the room, as well as during unoccupied periods. The speed of the recirculation fans was varied from 100% to 50%, and the time between changes in fan speed varied from one minute to one hour.

A particle counter detected 0.10 to 1.0 micron particles and separated them into six size bins (0.1-0.15, 0.15-0.2, 0.2-0.3, 0.3-0.5, 0.5-1.0, and >1.0) using a sample flow rate of 1 cfm.

The particle counter was installed in an adjacent Class 10,000 cleanroom and sample lines inserted through a hole in the wall to an alcove in the Class 100 cleanroom. See Figure 1.

PILOT STUDY APPROACH AND FINDINGS

The instrument logged data for 23 days in 2004. Initially, during the first few days, the instrument recorded data with recirculation fans speed at or near 100% as they were normally operated. The user of the cleanroom continued to use the room and logged when he entered and exited the room. The user occupied the cleanroom on multiple occasions on several of the days during this period.

After baseline data were recorded, the speed of all four recirculation fans was programmed to change over several days. All fans were programmed to follow the same schedule and, therefore, they were always operating at the same speed. Various schedules were used that varied the fan speed from 100% to 50% in jumps of 10% to 50%. The time between each change in fan speed varied from one minute to one hour.

There was some correlation between changing the fan speed and particle counts. After some jumps to a lower fan speed, the particle counts decreased. If the jump to a lower fan speed was too great (from 100% to about 50%), then the particle counts increased in general. This points to possibly finding an optimum fan speed where particle counts are minimized. This minimum fan speed is likely to be room and layout dependent and also dependent upon the occupancy and processes in the cleanroom.

Figure 1 Particle monitoring equipment.

From the four plots of data during a three-day period, there were times with the fan speeds at 100% and, thus, the normal variation in particle counts can be seen. With the fans at full speed, the particle counts, in the 0.1 to 0.15 micron size range, vary by a factor of two or three. Whereas, before or after these times, when the fan speeds were reduced, there is a larger change in particle counts, by a factor of ten or more. Most of the time when the fan speeds were reduced, particle counts decreased or stayed the same. It was only when the fan speeds became too low, about 50% of full speed, that the particle counts rose or stayed at the nominal level. See Figures 10 and 11 at the end of the paper.

LABORATORY PILOT STUDY CONCLUSIONS

Higher fan speeds do not necessarily mean lower particle counts. There may be an optimum recirculation fan speed that is unique to each facility, its arrangement, occupancy, and/or processes contained in the cleanroom.

Implementing DCF can result in large savings in energy. Since fan energy approximately varies with the cube of fan speed, small changes in fan speed will lead to large changes in fan energy. In a previous study (LBNL report 38869) it was estimated that implementing DCF had a payback time of one to four years.

Significant energy savings (60% to 80%) were realized by controlling the recirculation fan speed based on real-time particle counts.

Based upon the pilot study, demonstrations using this technology are in progress. These demonstration projects in industrial settings will involve experimenting with various control strategies from the simple to complex. In additon, other considerations, such as number of sampling points and their placement, will be explored for optimum energy savings while maintaining certified cleanroom conditions.

UNIVERSITY PILOT STUDY

A major university in New York state is currently undergoing one of the most aggressive capital expansion initiatives in its history. Over $1B (5M sf) of new research, teaching, and support space will be installed by 2010. Of this, approximately $500M (1M sf) is committed to expanding the engineering, life sciences, and physical sciences research space. Unlike the university's teaching and support space, its research space is expected to be highly energy-intensive. On average, the university estimates that total energy use for new research space will range from $10/sf (35W/sf) for conventional wet-dry lab space to over $50/sf (175W/sf) for state-of-the-art cleanroom space. Overall, the university's total energy use is expected to increase by $5M (17MW) annually.

To minimize the impact of increased energy use on the university's existing infrastructure, the university's Department of Utilities and Energy Management implemented an equally aggressive energy conservation initiative. The primary task of the energy conservation initiative is to reduce campus-wide energy use for its existing and new buildings by at least 20% as compared to 2000 baseline energy use. This will be accomplished, in part, by implementing new and creative energy conservation measures in its high-energy-use research facilities. For example, the recently completed $60M, 150k sf, nanoscale science and engineering research and teaching facility was originally designed such that its total annual energy-use would have been 6MW ($1.75M). However, to reduce energy use, the university worked closely with New York State's public interest energy organization to study, design, and implement an estimated $650k of energy conservation measures that would reduce energy use at the facility by almost 20% (1.2MW) annually.

Perhaps the most creative and significant energy conservation measure implemented was the installation of a demand-controlled filtration system in a 16,000 ft^2 cleanroom. Although the cleanroom represented less than 20% of the building's total space, its design required almost 75% of the energy. Therefore, special emphasis was placed on reducing energy use in the cleanroom while maintaining exact lighting, temperature, humidity, pressure, and contamination control conditions. Since the cleanroom was scheduled to operate continuously, there was limited ability to substantially reduce the lighting, supply/exhaust air, or process equipment loads. On the other hand, it was determined that the recirculation air change rates had been set arbitrarily high with the expectation of maintaining classification level. In fact, as indicated in Table 1, the average air change rate for the cleanroom was 142 air changes per hour (ach) with a high ach of 246.

In sum, it was determined that the air change rates for each of the cleanroom's 25 recirculation air-handing units (RAHU#1-#25) could be reduced provided the cleanroom's particle count level was less than that required to maintain classification level in the individual cleanroom spaces. As a result, a demand-controlled filtration system was proposed that controlled the recirculation air change rates as a function of real-time particle count. The total installed cost of the system including hardware and software was $167k. Based upon the estimated annual energy savings of $51k, the simple payback for the demand-controlled filtration system is expected to be slightly more than three years.

CONTROL SYSTEM

The demand-controlled filtration system for the cleanroom was designed, installed, and commissioned by the university. Specifically, the system includes particle monitors, control logic, and direct digital control/energy management control (DDC/EMC) communication. Figure 2 illustrates the layout of the cleanroom and approximate locations of RAHUs #1-#25 and associated particle monitors.

The particle monitors are remote optical particle monitors. There are 25 particle monitors located throughout the cleanroom. The monitors operate on 120VAC and have self-contained vacuum pumps. The communication lines are hard-wired and connected to the units with seven-pin connectors. The particle monitors measure particles in two ranges: greater than 0.5 µm and greater than 5.0 µm with a 1.0

Table 1. Air Change Rates

Item	Room							RAHU		HEPA Filters			ACR	FFV
#	#	Name	Class.	Area [ft.^{2}]	Clg. [ft.]	Vol. [ft.^{3}]	CFM [ft.^{3}/min.]	#	Hp	2'x2' [qty.]	2'x4' [qty.]	Area [ft.^{2}]	[ac/hr.]	[ft./min.]
1	126	SEMS	1,000	480	9	4,320	11,025	1	7.5		18	144	153	77
2	124	E-Beam	1,000	330	9	2,970	7,500	2	5.0		15	120	152	63
3	122	E-Beam	1,000	330	9	2,970	7,500	3	5.0		15	120	152	63
4	118	E-Bean Resist	1,000	286	9	2,574	6,900	4	5.0	5	9	92	161	75
5	114	Central Proc.	10,000	616	9	5,544	10,440	5	7.5		15	120	113	87
6	110	Nanobiology	1,000	496	9	4,464	11,550	6	7.5		24	192	155	60
7	106	Nanobiology	1,000	403	9	3,627	11,000	7	7.5	5	10	100	182	110
8	102	Nanobiology	1,000	330	9	2,970	11,550	8	7.5		25	200	233	58
9	103	Furnace	1,000	368	9	3,312	7,000	9	5.0		18	144	127	49
10	103	Furnace	1,000	368	9	3,312	10,500	10	7.5		18	144	190	73
11	103	Furnace	1,000	368	9	3,312	10,000	11	7.5		18	144	181	69
12	107	Thin Film Proc.	1,000	522	9	4,698	10,500	12	7.5		23	184	134	57
13	107	Thin Film Proc.	1,000	522	9	4,698	10,500	13	7.5		23	184	134	57
14	111	Thin Film Proc.	1,000	562	9	5,058	10,540	14	7.5		20	160	125	66
15	111A	Thin Film Proc.	1,000	280	9	2,520	6,825	15	5.0		13	104	163	66
16	115	Tunnel	1,000	624	9	5,616	11,315	16	7.5		24	192	121	59
17	131	Chemistry	1,000	195	9	1,755	4,968	17	7.5	3	7	68	170	73
17	10046	Corridor	1,000	608	9	5,472	4,968	17			17	136	54	37
18	131	Chemistry	1,000	195	9	1,755	5,050	18	7.5	3	7	68	173	74
18	10047	Corridor	1,000	544	9	4,896	5,050	18			14	112	62	45
19	117	Thin Film	1,000	351	9	3,159	10,000	19	7.5		18	144	190	69
20	121	Photolith.	1,000	575	9	5,175	12,000	20	10.0		24	192	139	63
21	133	Photolith.	1,000	420	9	3,780	9,500	21	7.5	4	16	144	151	66
22	137	Photolith.	1,000	308	9	2,772	10,600	22	7.5		14	112	229	95
23	137	Photolith.	1,000	308	9	2,772	11,345	23	7.5		14	112	246	101
24	123	Instruments	10,000	723	9	6,507	10,500	24	7.5		20	160	97	66
25	141	Togging	10,000	456	9	4,104	5,538	25	7.5		14	112	81	49
25	143	Storage	10,000	170	9	1,530	5,538	25			3	24	217	231
Subtotal (Lab Spaces)				11,738	9	105,642	249,702		177.5	20	456	3,728	142	67
Subtotal (Service Spaces)				4,682	18	84,276								
Total				16,420		189,918	249,702		177.5	20	456	3,728	142	67

cubic feet per minute (cf/m) sensor and a concentration limit of 1,000,000 particles per cubic foot of air (p/cfa). The monitors provide 4-20 mA analog outputs (e.g., 4 mA = 0 count and 20 mA = maximum count) updated every second on a rolling-average basis. Since desktop particle monitors were not permitted, specially fabricated, "horizontal" shelf-mounted units were designed and installed. Figures 3 and 4 demonstrate a typical particle monitor installation.

The control logic required to implement demand-controlled filtration includes consideration of fan speed, room cooling, and particle count logic. The fan speed control logic essentially requires one analog input each from the cooling and particle count control logic modules. The combination of output signals from both control modules will control the RAHU's VSD/fan speed and chilled water valve position. Figure 5 illustrates the fan speed, cooling, and particle counter control logic for RAHU#1.

In sum, the DDC system will maintain constant supply air static pressure for each of the RAHUs. As the supply air static pressure increases (as the result of filter loading), the RAHUs' variable-speed drives will increase to maintain static pressure setpoint. The RAHUs will operate at reduced static pressure setpoint when the particle counts are below a predetermined setpoint. However, if the space requires increased cooling, the fan speed will be increased and (if necessary) the chilled water valve will be opened to maintain the space temperature setpoint. On the other hand, the RAHUs will operate at increased static pressure setpoint when the particle counts are above a predetermined setpoint. For example, if the particle count at 0.5 microns is greater than 750 particles per cubic foot of air (p/cfa) for a class 1,000 space (or 7,500 p/cfa for a class 10,000 space), the RAHU fan speed will be increased incrementally and the control algorithm repeated until the particle count requirements are satisfied.

The above control algorithm was commissioned and operated as intended. However, the university has commenced a 12-month acceptance phase for review and comment by the cleanroom users. Once the acceptance phase has been completed and the authorization to proceed has been received by the users, the control algorithm will be implemented in its entirety. Until then, only the cooling control logic has been enabled. That is, during the acceptance phase, the fan speed logic will be programmed such that the fan speed is set at approximately 85% maximum and the particle count logic disabled.

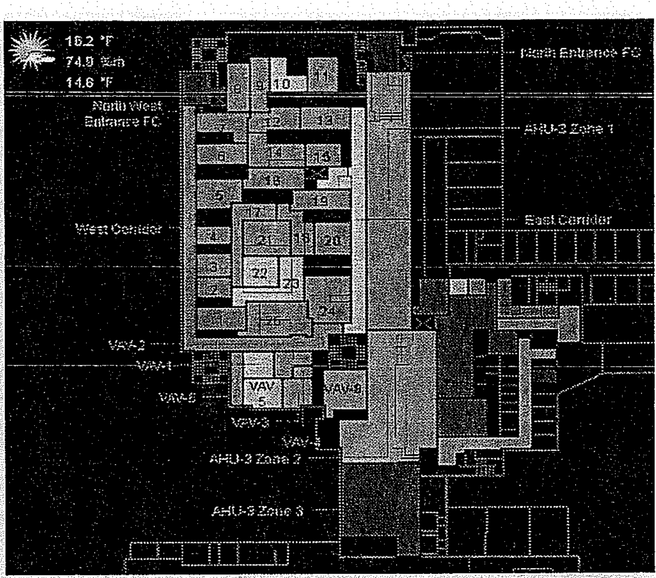


Figure 2 *Cleanroom layout.*

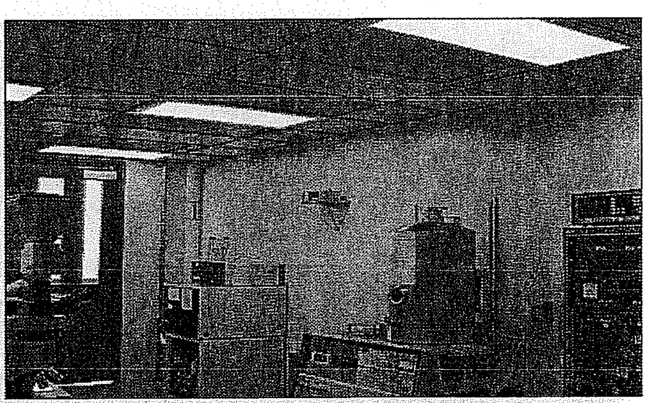


Figure 3 *Particle counter mounted on wall.*

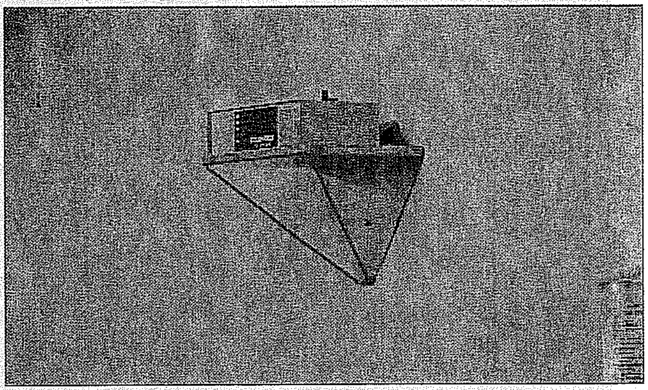


Figure 4 *Particle counter.*

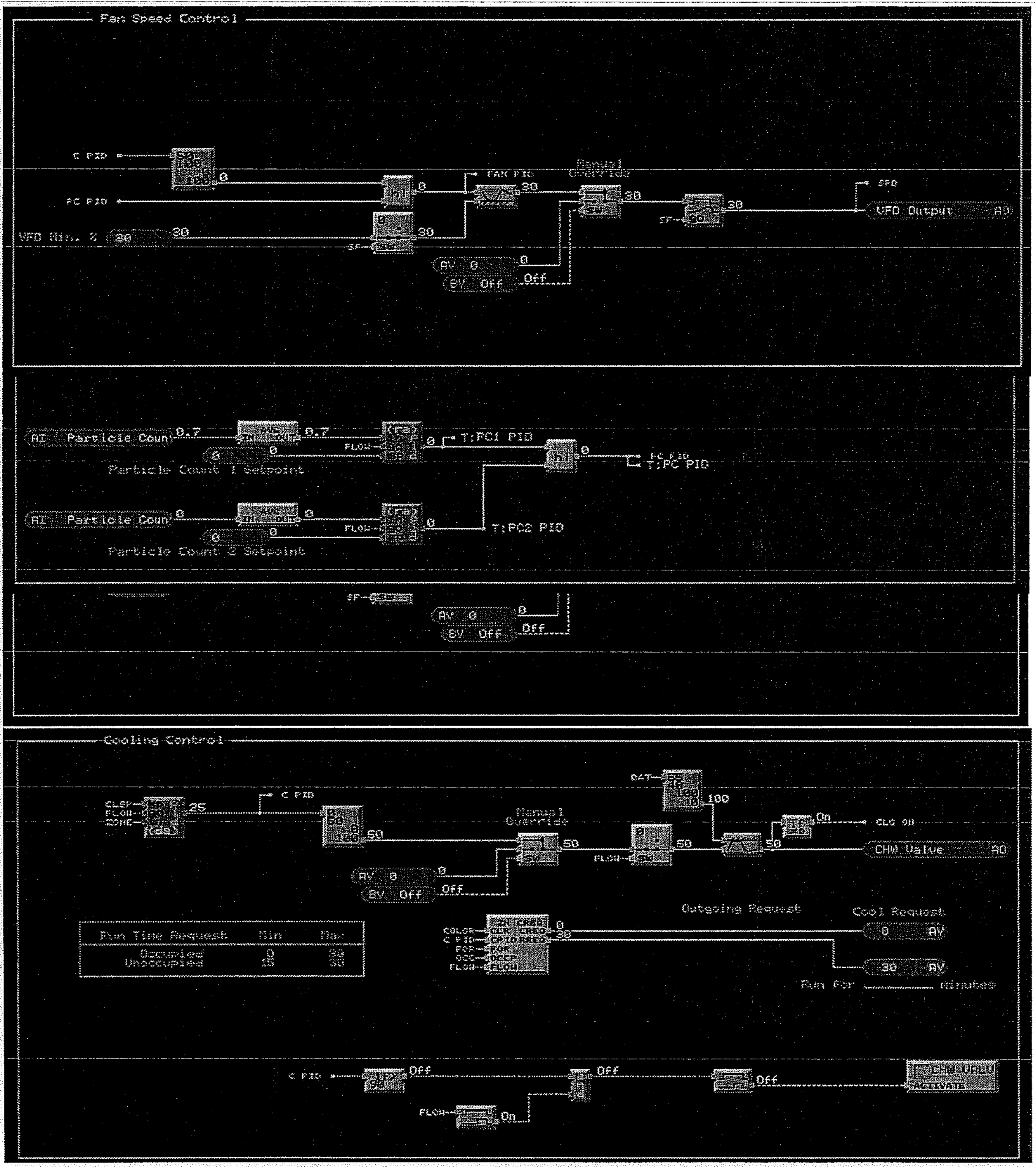
In addition to particle monitors and control logic, the demand-controlled filtration system also includes a DDC/ EMC communication system. The communication system enables the cleanroom's RAHUs to be monitored, controlled, and trended via password-protected, Web-accessed software. The particle monitors are connected to the RAHU control modules, the control modules are, in turn, connected to the main control module hub through the building's DDC system, and the hub is connected to the building's dedicated server through the university's centralized EMC system. Figure 6 shows the DDC/EMC communication system configuration.

As indicated above, the particle counter logic will not be enabled until the acceptance phase has been completed. However, during the acceptance phase, the communication system has been configured to enable real-time data to be monitored and trended. Likewise, a temporary summary screen has also been configured to view instantaneous space temperature, particle count, fan speed, and chilled water valve position data for each of the RAHUs.

The data will be used to calibrate the "single location" particle count data values (obtained from the wall-mounted particle monitors) to "multiple location" particle count data values (obtained from a portable hand-held particle monitor). The data will also be used to verify the performance of the cooling control logic and document the relationship between the fan speed control variables (i.e., space temperature and particle count). For example, the data for RAHU#1 (below) demonstrate that the space temperature setpoint of 68°F (note: setpoints are not shown on the temporary summary screen) is being maintained with particle count #1 = 1 p/cfa, particle count #2 = 0 p/cfa, fan speed = 85%, and chilled water valve position = 48% maximum. Since the particle counts are well below the 1,000 p/cfa threshold for this class 1,000 space (i.e., scanning electron microscope lab), it preliminarily appears that the fan speed could be reduced to some lesser incremental value while maintaining space temperature setpoint and classification level. The exact value of the reduced fan speed will be determined during the acceptance phase. Figure 7 shows instantaneous data for RAHU#1-#25 (Cleanroom Data Summary Screen) and Figure 8 shows trended data for RAHU#1 (Seven-Day Plot of Particle Count Data for RAHU#1).

UNIVERSITY PROJECT CONCLUSIONS

The university's demand-controlled filtration project will be completed in four phases of development: design construction, acceptance, measurement, and verification phases. The design and construction phases have been completed. The acceptance phase is pending and will be completed within 12 months. The measurement and verification phase will commence immediately following



Run Time Request	Min	Max
Occupied	0	30
Unoccupied	15	30

Figure 5 *Fan speed, cooling, and particle counter control logic.*

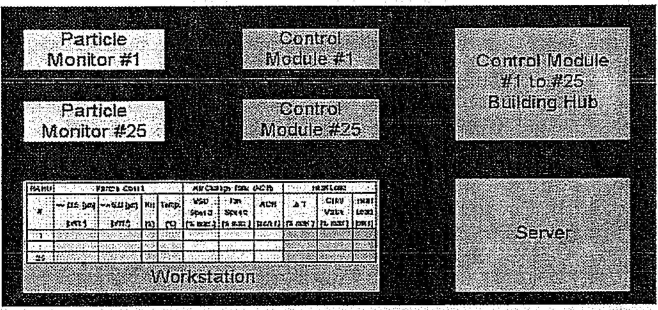
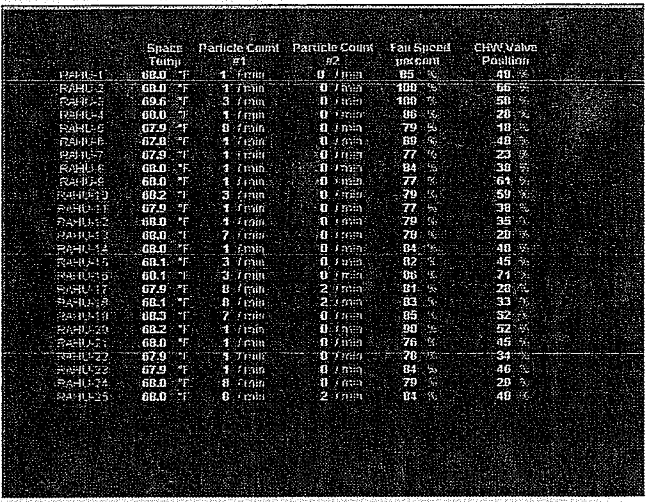


Figure 6 *Communication system configuration.*

completion of the acceptance phase and will be completed within the next 12-month period.

The acceptance phase will include measuring and trending fan speed control variable data, calibrating the "single location" particle count data values to the "multiple location" particle count data values, finalizing the control algorithm, manually controlling several noncritical test RAHUs (i.e., storage room, instrument room, togging room, etc.), and monitoring the RAHUs' performance, automatically controlling the same RAHUs, and finally automatically controlling the cleanroom's remaining RAHUs.

The measurement and verification phase will include monitoring the system's performance, measuring and trending the cleanroom's electrical energy use, analyzing the trended energy use data, and preparing energy analysis reports for further review and discussion. Once the measurement and verification phase is complete, the prefunctional checklists, discrepancy and corrective action reports, functional performance tests, and energy use analysis reports will be archived in an on-line database for use by cleanroom management to schedule routine, planned, preventative maintenance work. By implementing demand-controlled filtration, the university expects to substantially reduce energy use while maintaining the cleanroom's exact space conditions and classification level.



	Space Temp		Particle Count #1		Particle Count #2		Fan Speed percent		CHW Valve Position	
RAHU-1	68.0	°F	1	/min	0	/min	85	%	40	%
RAHU-2	68.0	°F	1	/min	0	/min	100	%	66	%
RAHU-3	69.6	°F	3	/min	0	/min	100	%	50	%
RAHU-4	68.0	°F	1	/min	0	/min	86	%	20	%
RAHU-5	67.9	°F	0	/min	0	/min	79	%	18	%
RAHU-6	67.8	°F	1	/min	0	/min	89	%	48	%
RAHU-7	67.9	°F	1	/min	0	/min	77	%	23	%
RAHU-8	68.0	°F	1	/min	0	/min	84	%	38	%
RAHU-9	68.0	°F	1	/min	0	/min	77	%	61	%
RAHU-10	68.2	°F	3	/min	0	/min	79	%	59	%
RAHU-11	67.9	°F	1	/min	0	/min	77	%	38	%
RAHU-12	68.0	°F	1	/min	0	/min	79	%	35	%
RAHU-13	68.0	°F	7	/min	0	/min	79	%	20	%
RAHU-14	68.0	°F	1	/min	0	/min	84	%	40	%
RAHU-15	68.1	°F	3	/min	0	/min	82	%	45	%
RAHU-16	68.1	°F	3	/min	0	/min	86	%	71	%
RAHU-17	67.9	°F	8	/min	2	/min	81	%	28	%
RAHU-18	68.1	°F	8	/min	2	/min	83	%	33	%
RAHU-19	68.3	°F	7	/min	0	/min	85	%	52	%
RAHU-20	68.2	°F	1	/min	0	/min	90	%	52	%
RAHU-21	68.0	°F	1	/min	0	/min	76	%	45	%
RAHU-22	67.9	°F	1	/min	0	/min	78	%	34	%
RAHU-23	67.9	°F	1	/min	0	/min	84	%	46	%
RAHU-24	68.0	°F	8	/min	0	/min	79	%	29	%
RAHU-25	68.0	°F	0	/min	2	/min	84	%	40	%

Figure 7 *Cleanroom data summary screen.*

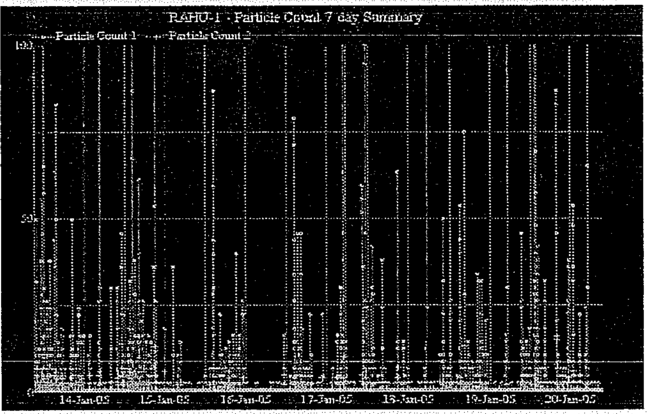


Figure 8 *Seven-day plot of particle count data for RAHU#1.*

CASE STUDY—RECIRCULATION SETBACK

Two operating cleanrooms in a specialized semiconductor type facility were benchmarked as part of a national laboratory study. The cleanrooms were not occupied 24 hours a day and, as such, the facility engineers elected to reduce cleanroom airflow during the non-working hours on the assumption that people were the main source of contamination introduced in the cleanroom. The majority of the employees work from 8 a.m. to 5 p.m., Monday through Friday, although the environmental systems serving the cleanrooms run 8,760 hours a year in order to maintain conditions. During non-working periods, the makeup and recirculation air handlers serving the cleanrooms are set to provide less airflow and, thus, run at a lower fan speed. As a result, fan energy is lowered during the non-working hours. This setback is achieved through use of timers. Figure 9 illustrates the measured power savings during the setback.

The recirculation air handler control is very energy efficient, with recirculation airflow reduced when the rooms are unoccupied. For one measured air handler, the reduction in fan speed was about 30% at night, when the space was unoccupied, and this resulted in a reduction of measured power consumption of 72% (64 kW during the day and 18 kW at night). When recirculation for the entire cleanroom is considered, a significant energy savings is obtained. Table 2 illustrates the metrics and savings as a result of the setback in airflow.

This case study illustrates that significant energy savings are possible by reducing cleanroom airflow. But, more impor-

Table 2. Recirculation Air System—Metrics and Savings

Description		Cleanroom 1	Cleanroom 2
		Class 100	Class 10,000
Recirculation air power, setback	kW	34.2	8.7
Recirculation air handler volume, setback*	cfm	128,000	28,000
Recirculation air setback efficiency	cfm/kW	3,740	3,200
Recirculation air changes per hour, setback	ACH	371	50
Sitewide Savings			
Recirculation air annual energy savings†	kWh	1,250,000	
Recirculation air annual cost savings†	$/yr	$138,000	

* Estimated using fan laws to scale flow and measured power data.

† Extrapolated for full site including three identical but unmeasured recirculation units, average assumed electricity cost $0.11/kWh confirmed with electric utility.

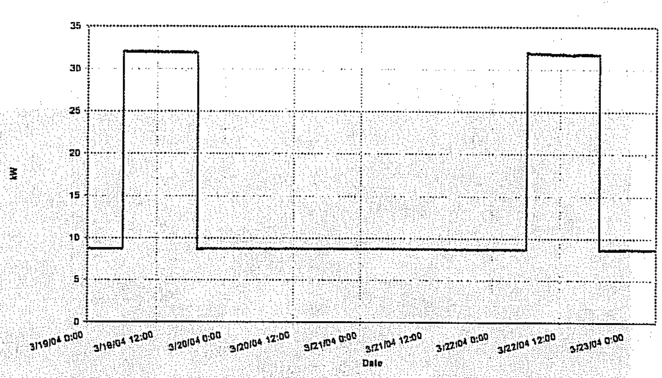


Figure 9 *Measured power savings.*

tantly, this savings was obtained without any adverse effect on the cleanliness of the cleanroom or the production in the cleanroom. This reinforces that control strategies such as demand-controlled filtration may be able to help optimize cleanroom airflow.

CONCLUSIONS

Improvement in energy efficiency can be attained in cleanroom air systems without adversely affecting contamination control. A number of strategies can be used to lower airflow to match the contamination control problem. Control strategies can be simple, such as use of timers or occupancy sensors to take advantage of periods when contamination is not being introduced to the space. The concept of controlling airflow based upon real-time particle monitoring is also promising. This technology may enable cleanroom air systems to optimize airflow to maintain desired cleanliness levels.

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