Hine Design: Variable Speed Drive Control of Recirculation Fans for Class 100 Cleanroom

Project Benefits Summary

Annual Energy Savings	372 MWh/y
Annual Energy Cost Savings	$36,000/y
Actual Project Cost	$55,000
Project Payback	1.5 years

Facility Description

Hine Design, a subsidiary of Asyst Technologies, operates a robotics manufacturing facility in Sunnyvale, California. The 45,000-ft^2 building includes 4,000-ft^2 of class 100 cleanroom space, 6,000-ft^2 of combined clean air return chases and class 10,000 assembly areas, with the remaining building space serving as their operations and engineering offices. The facility operates from 8am to 5pm, Monday through Friday, and is closed on weekends and holidays.

All of the clean air provided to both the class 100 and class 10,000 spaces is filtered by 99.99% efficient HEPA (high efficiency particulate air) filters installed in fan powered HEPA units

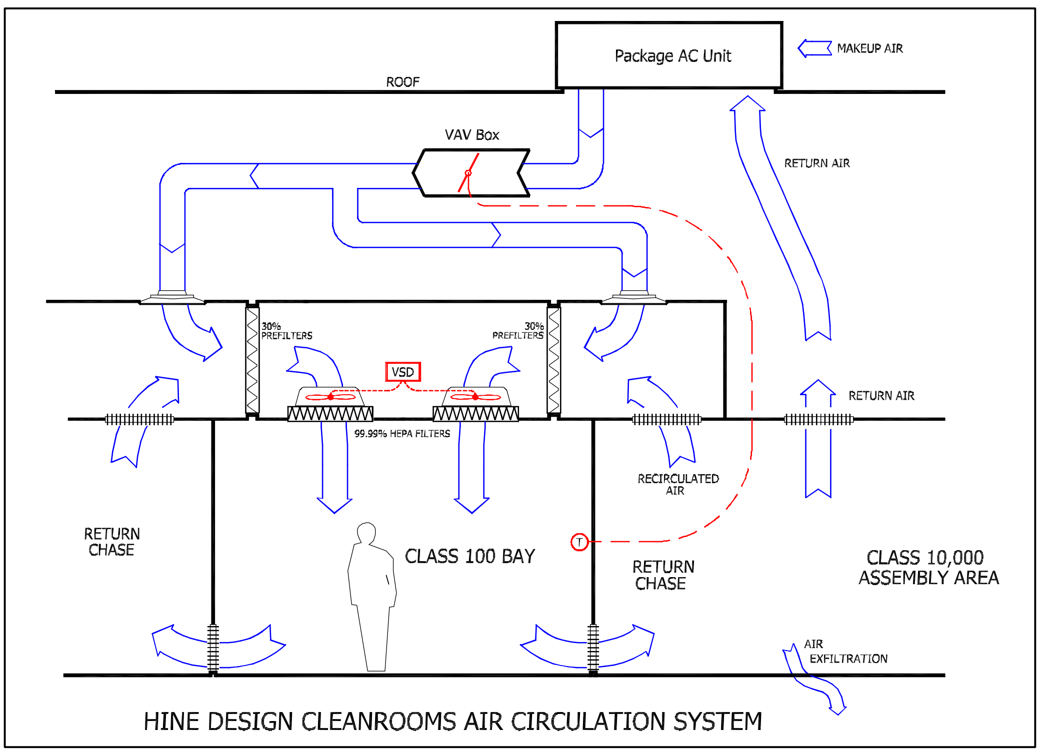


Figure 1

(FPHs). The class 100 space is comprised of 6 individual bays surrounded by return chases and with the large class 10,000 assembly area at the north side of the bays. As shown in Figure 1, air is supplied to the bays by dedicated FPHs and exits through low sidewall returns into the return chases. The FPHs recirculate the air from the chases into mixing plenums where conditioned air is also supplied from two package units located on the roof. The mixed air in the plenum then passes through 30% filters into the ceiling plenum above the FPHs. There is no process exhaust from the bays, but exfiltration from the chases into the office areas requires a small amount of makeup air to keep the cleanroom positively pressurized. Therefore, the rooftop package units primarily condition return air from the class 10,000 assembly area and intake only a small amount of makeup air. Due to the nature of the manufacturing process and the naturally mild Sunnyvale climate, there is no provision for humidity control in the package units.

Project Description

In order to reduce energy use in their cleanrooms, Hine Design hired Northern Pacific Mechanical to design and implement new control logic. Two specific controls were retrofitted onto the system serving the class 100 bays to provide the energy saving benefits:

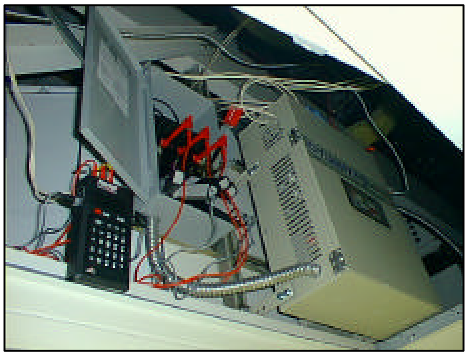
- Variable speed drives (VSDs) on the FPHs serving the class 100 bays (shown in Figure 1)
- A custom control system that schedules the speed of the VSDs based upon occupancy patterns

On normal operating days (M-F), the control system operates the VSDs in the occupied mode from 5am to 5pm, and on weekend days, it operates the VSDs in occupied mode from 6am to 10am. Based upon particle measurements within the bays, it was determined that 60% fan speed is appropriate to maintain cleanliness during operation. At all other times, the control resets the VSDs to 15% speed to maintain positive flow through the HEPA filters and the rooftop package units are shut down. As will be discussed later, when 15% speed is commanded by the control system, the VSDs actually run at 0 Hz (they turn the fans off).

The theory supporting the energy savings associated with this type of system is the "cube law" for fans. This law states that the power required by a fan changes as the cube of the flow induced by it (i.e. power $\propto$ flow^3). This indicates that as the flow through a fan is reduced or increased by a known factor, the power required by the fan is reduced or increased by the same factor cubed. Our measurements confirm savings proportional to the cube law (see the calculations in Appendix A): at 60% speed, fan power is predicted by the cube law to drop by 86%; our measurements show an 82% reduction in fan power.

The energy analysis for this project, including formulas, can be found in Appendix A. The energy cost savings, based upon our measurements, is approximately $36,000 per year. The incremental cost of installing the VSDs and the control system was $55,000, so the simple payback for this project works out to 1.5 years.

Analysis Methodology



To determine the energy savings associated with the VSD control, power measurements were taken in cleanroom bay 6. In order to measure both modes of operation, the system operated over a period of one day. Implied in this measurement is the assumption that the percentage of power saved in this bay is equivalent to the power that is saved in all the bays. A PowerSight true RMS power meter (shown at right measuring VSD power) collected the data at one minute intervals for just over 24 hours. As shown in Figure 2, the power demand during each time interval is essentially constant. Therefore, measurements were taken for only one day, assuming that this data represented the power demand during each mode of operation throughout the year. In order to determine the savings associated with this system, we also measured power demand with the VSD running at full speed for a 15 minute period (the spike at the far right on the Figure 2 shows our measurements at full speed). Without the VSDs and controls, all of the FPHs would run at full speed 24 hours a day, even at night to maintain positive flow through the HEPA filters. These measurements were then used to calculate the annual energy cost savings based upon actual average utility rates for Hine (see Appendix A).

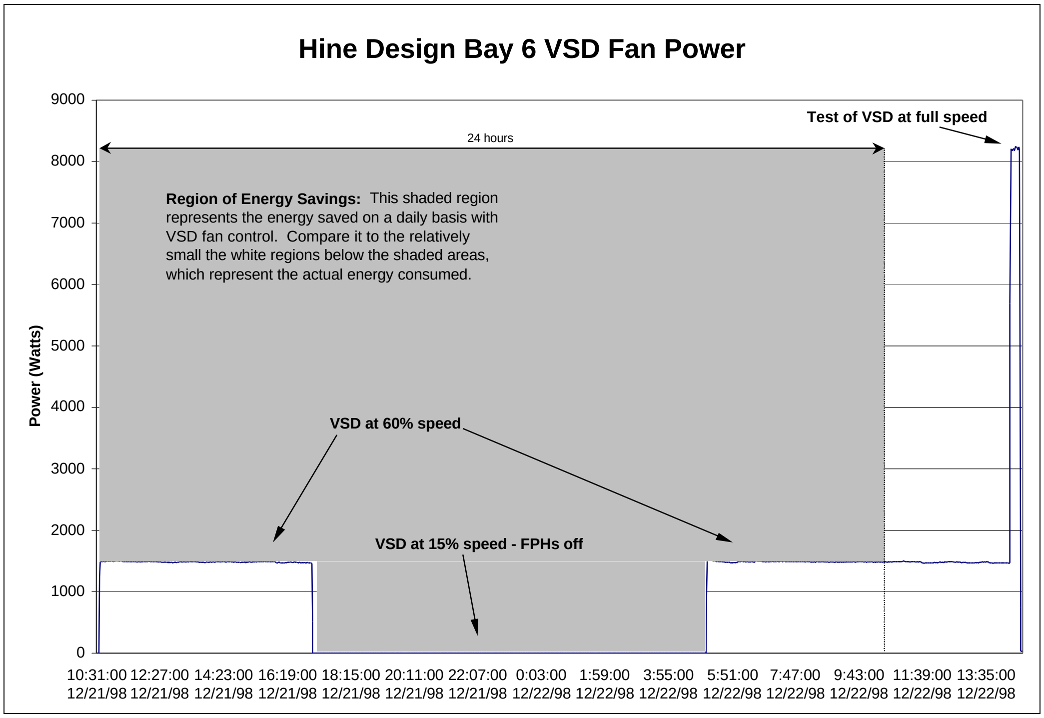


Figure 2

Discussion

The measurements illustrated above show that the fans draw no power at 15% speed. Therefore, the assumption that 15% speed maintains positive flow through the HEPA filters was incorrect. It is likely that the VSDs have been setup with a minimum operating frequency, typically 20 Hz (33% speed), below which they will shut their output to zero power. Our investigation of the VSDs with the manufacturer found that the drives have a low limit parameter that can be set to any frequency (for 15% speed, this minimum needs to be 9 Hz). This discovery will lead to very slightly increased energy use as Hine resets the minimum VSD speed to allow operation at 15% speed and achieve their goal: positive flow through the HEPA filters to prevent particle release. Extrapolating the measured results for the system, we have determined that increasing the fans to 15% speed will increase annual energy use by 1,540 kWh/year [$(0.15)^{2.66}$ x 45.9 kW x 5,214 h/y]. The net annual energy savings would then be reduced from just over 372 MWh/y to about 371 MWh/y – a truly insignificant reduction of 0.4%! The cost impact of this “fix” would be about a $150 increase in annual energy bills.

Furthermore, if Hine does modify the VSDs to actually maintain positive flow through the HEPA filters at all times, they may find that their particle counts drop during normal operating conditions. Based upon this information, the existing normal operating speed of 60% may no longer be necessary to maintain their class 100 rating, at which point they can further reduce their energy use by slowing the fans down even more. This feedback effect should at least offset the meager energy use increase, however it requires that Hine test their particle levels to determine an appropriate fan speed under the potentially cleaner conditions.

One other discovery during our study of the facility was that the 99.99% HEPA filters installed in the FPUs were *used* when they were installed; i.e. they were already at least partly loaded (dirty). This actually improves the efficiency of the filter because, during use, the particles fill the pores in the filter media making it even harder for other particles to pass through. However, loading of the filters also makes it more difficult for the air to pass through them (higher filter pressure drop), increasing the amount of energy needed by the fans to recirculate the air. Another consequence of filter age is that they begin to degrade (common problems are sagging, tears, loose framing, etc.) and release particles from stress points. It may be worth investigating the opportunity to replace the filters with new filters to see how particle counts and fan energy are influenced. We suspect that fan energy and particle levels will be reduced, allowing further reductions in fan speed and related energy use. The flexibility of VSD controls makes all of these options possible.

Many cleanroom operators, including projects we evaluated at Applied Materials, Conductus, Exar, and Lam Research, have installed energy saving controls on their recirculation fan systems that are similar to the Hine system. Some have installed VSDs that run at constant speed without scheduling, allowing them to minimize airflow based upon particle counts, but without the need for independent fan control logic. This type of system works especially well for facilities that operate around the clock, where scheduling is not necessary. Still other facilities, like Applied Materials, are taking the Hine scheduling idea to another level by installing occupancy sensors that control VSD speed based upon the activity in the individual clean areas. Rather than fixed scheduling of fan speed, the occupancy sensors detect whether the space is in use and modulate the fans up and down accordingly. In this way, the fans can be reduced any time the cleanrooms are unoccupied, including during normally occupied times. Another innovation for fan speed control that also expands on the Hine system concept is that of real-time particle counting and control of the fans. This system counts particle levels continually and modulates fan speed to maintain whatever cleanliness level is required for the space supplied by each fan. This idea has the potential of tapping into energy savings that few facilities have achieved[1].

[1] For more about this, see "Energy Savings in Cleanrooms from Demand-Controled Ventilation" by David Faulkner, et. al. in the *Journal of the Institute of Environmental Sciences; Nov/Dec 1996, pages 21-27.*

Figure 3: Hine Design Case Study Data Analysis

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	Descriptions	*Values*	*Formulas*	*Notes*
A	Total Rated Recirculation Fan Power	140 *hp*		*Design data*
B	Bay 6 Rated Recirculation Fan Power	25 *hp*	-	*Design data*
C	Bay 6 VSD Average Power at Full Speed	8.2 *kW*	-	*Measured*
D	Total Recirculation Fan Power at Full Speed	45.9 *kW*	*A x C / B*	*Assuming all fan motors would operate at the same percentage of their rated power as the motors in Bay 6*
E	Annual Hours of Operation at Full Speed without VSD Control	8,760 *h/y*	-	*Fans must run at all times to maintain positive flow through the HEPA filters*
F	Total Annual Recirculation Fan Energy Use without VSD Control	402,259 *kWh/y*	*D x E*	
G	Bay 6 VSD Average Power at 60% Speed (31.5 Hz)	1.5 *kW*	-	*Measured - normal operating fan speed to maintain particle counts*
H	Predicted Fan Power Reduction at 60% Speed (31.5 Hz)	86%	$1 - [(31.5\ Hz) / (60\ Hz)]^3$	*Based on the cubic relationship between fan speed (or flow) and power*
I	Actual Fan Power Reduction at 60% Speed (31.5 Hz)	82%	*1 - (G / C)*	*This result indicates a power 2.66 rather than the power 3.0 (cubic) relationship predicted by the theory*
J	Total Recirculation Fan Power at 60% Speed	8.4 *kW*	*A x G / B*	
K	Annual Hours of Operation at 60% Speed with VSD Control	3,546 *h/y*	*(68 h/w) x (52.14 w/y)*	*Fans scheduled to run from 5am-5pm M-F and 6am-10am S-S, every week; i.e 68 hrs/wk*
L	Total Annual Recirculation Fan Energy Use at 60% Speed	29,782 *kWh/y*	*J x K*	
M	Bay 6 VSD Average Power at 15% Speed (0.0 Hz)	0 *kW*	-	*Measured - night and weekend fan speed intended to maintain positive flow through HEPA filters*
N	Total Annual Recirculation Fan Energy Use with VSD Control	29,782 *kWh/y*	*L*	
O	Annual Energy Savings	372,477 *kWh/y*	*F - N*	
P	Average Cost of Electricity	$0.098 *per kWh*	-	*From Hine Design (PG&E billing data)*
Q	Total Electricity Cost Reduction	$36,435 *per y*	*O x P*	
R	Incremental Cost of VSDs and Control System	$55,000	-	*From Hine Design*
S	Project Payback	1.5 *y*	*R / Q*	