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Variable Air Volume Systems: Maximize Energy Efficiency and Profits

Findings and Recommendations
January 1995

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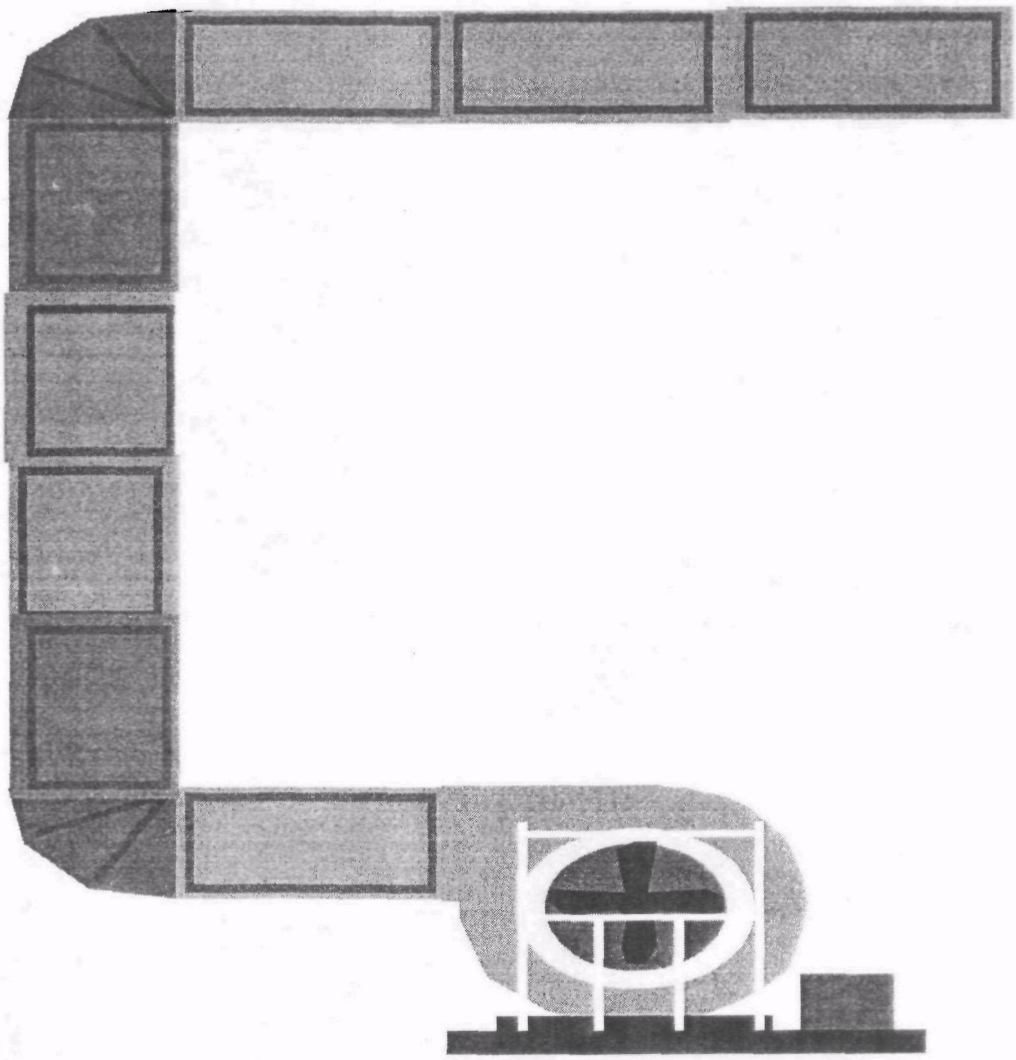

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MAJOR FINDINGS

The U.S. Environmental Protection Agency has researched variable air volume (VAV) systems and identified several low-cost opportunities that can significantly reduce energy consumption and increase fan efficiency. Upgrades to VAV systems can be profitable and, due to decreases in energy consumption, will prevent pollution.

Variable Speed Drive (VSD) Pilot Studies

The EPA has conducted pilot studies of VSDs installed in 10 buildings around the country, yielding the following lessons learned.

- A VSD is almost always profitable, but more so when the fan or motor is oversized.
- The benefits of VSDs diminish if the fan or motor is grossly undersized or always runs at or near full capacity.
- Similarly, the benefits of VSDs diminish if the system on which the VSD is installed suffers from control problems (for example, simultaneous heating and cooling of the same area).
- In most cases, VSDs should be equipped with integral harmonic filters. Where this is not possible, a three-phase AC line reactor should be installed to reduce total current harmonic levels to within five percent.
- Backward-inclined and airfoil fans are the best candidates for VSDs. Forward-curved fans become unstable and are more difficult to control at partial loads.

Commercial HVAC Survey

A total of 211 facility managers responded to the *VSD Field Performance Questionnaire*, giving the following results.

- Most (95 percent) of the respondents indicate that they *would install VSDs again*.
- Reliability is a key factor in VSD application.
- VSDs experience less problems than previous control methods.
- VSDs have become more reliable over time.
- Installed VSDs meet or exceed predicted energy savings.
- VSD power quality/power factor problems are minimal.
- Pulse width modulation converter VSDs have become more popular over time.
- VSDs for water-side applications receive good performance ratings.
- Premature motor burnout is not reported.
- Proper VSD installation ensures against circuit board failure.

Fan Oversizing Study

A study has been conducted by EPA that investigates the prevalence of fan oversizing. Major findings are as follows:

- Oversizing was found to be prevalent in the 26 buildings surveyed;
- More than half of the buildings had air handling units with oversizing greater than 10 percent; and
- Of those oversized greater than 10 percent, the average oversizing was 72 percent.

INTRODUCTION

Improving fans and air distribution is one of the most profitable investments a buildings owner can make when upgrading the performance of a building. EPA analysis estimates that fan and air handling system upgrades can provide rates of return as high as 200%, with simple paybacks often occurring in less than 1 year. Energy reductions due to upgrades have been estimated between 30 and 60%. These savings can be realized by participating in EPA's Energy Star Buildings Program, a voluntary energy-efficiency program for U.S. commercial buildings. Building on the successful Green Lights program, Energy Star Buildings focuses on profitable investment opportunities available in most buildings, using proven technologies. A central component of the program is a step-by-step implementation process that takes advantage of the system interactions, enabling building owners to achieve additional energy savings while lowering capital expenditures.

The five-stage Energy Star Buildings upgrade strategy is shown below in ***Figure 1***. One key advantage of this approach is that it reduces equipment cost. By implementing Green Lights (Stage 1), tuning up the building's systems (Stage 2), and investing in upgrades that reduce heating and cooling loads (Stage 3), building owners can significantly reduce the size and cost of mechanical equipment associated with Stages 4 and 5. Moreover, the program reduces uncertainties about the proper sizing of upgraded cooling equipment (chillers and direct-expansion units), leading to potential equipment downsizing, cost savings, and proper operation of equipment.

Stage 4 of the Energy Star Buildings Program focuses on improved fans and air handling systems. The purpose of this report is to present information to demonstrate the profitable energy savings which are possible by upgrading fan systems, particularly with variable speed drives.

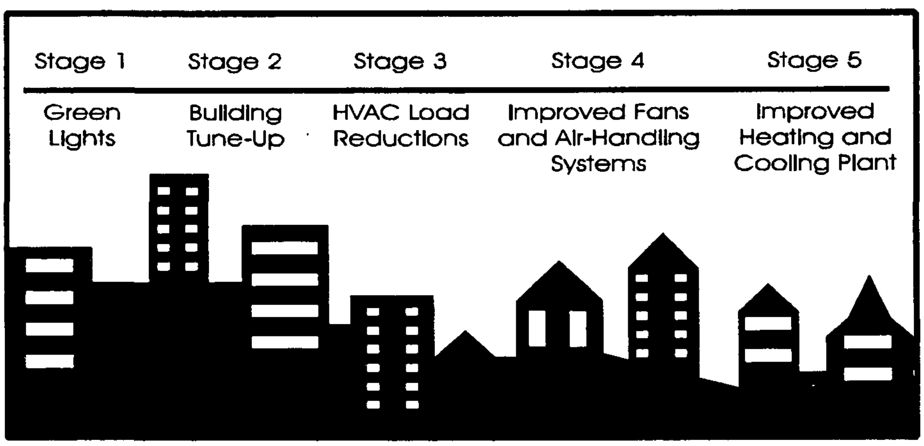


Figure 1. *Five-Stage Energy Star Building Upgrade Strategy*

Section One:

OPPORTUNITIES TO UPGRADE VARIABLE AIR VOLUME SYSTEMS

BEST OPPORTUNITIES

The many different types of air handling systems installed in commercial buildings can generally be classified as constant air volume (CV) or variable air volume (VAV) systems. VAV systems are inherently more efficient than CV systems. This section describes opportunities to further improve the efficiency of variable air volume systems while maintaining indoor air quality. With these options, a fairly low initial investment can result in significant reductions in energy consumption. The three options are as follows:

- *Load Matching*, in which the fans and motors in the air handling unit are sized to operate efficiently at the reduced loads you have realized by implementing Green Lights upgrades; tuning up your building's systems; purchasing Energy Star computers, printers, and monitors; and implementing window and roofing upgrades.

- *Replacing the existing motors* on the air handling unit with new, smaller energy-efficient motors.

- *Installing variable speed drives* that match the speed of the air handling unit's fans to the required variable load.

These options can be profitable in most buildings. You can implement them individually or combine them to provide maximum savings. As you develop your strategy:

- Consider installing properly sized equipment. This usually means you can downsize, which consists of (1) replacing pulleys, (2) adjusting static pressure, and (3) installing smaller energy-efficient motors.

- If you find that downsizing is not appropriate, you still may be able to replace existing motors with energy-efficient motors of the same capacity or smaller.

- Always consider variable speed drives. These are the most energy-efficient and profitable upgrades for variable air volume systems.

Load Matching

As you begin Stage 4 of the Energy Star Buildings program, you have reduced overall loads in your building through some combination of Green Lights upgrades, building tune-ups, Energy Star computer equipment, and window and roofing upgrades. As a result, fans and motors on the air handling units in your building are probably oversized—that is, they are no longer required to operate at previous capacities. Oversized fans and motors waste energy. They are rarely required to run at full capacity, but still use the same amount of energy that full-capacity operation requires. Therefore, you can save a significant amount of money by ensuring that fans and motors operate efficiently at your newly reduced loads.

Energy-Efficient Motors

Energy-efficient motors use improved motor designs, more metal, and high-quality materials to reduce motor losses and therefore improve efficiency. They are more reliable than standard-efficiency motors and generally have longer manufacturer's warranties. These motors reduce operating costs by:

- Lowering energy consumption, which saves money by reducing the monthly electric bill.
- Postponing or eliminating the need to expand the capacity of the electrical supply system in the building in response to changes in building use or installation of additional equipment.
- Reducing downtime, replacement, and maintenance costs.

Energy-efficient motors can be implemented individually or as part of a retrofit that includes downsizing, variable speed drives, or both.

Whenever a motor is operating, some loss in efficiency is incurred. For example, if a motor is 85 percent efficient, 15 percent of the energy input dissipates as heat, which increases motor temperature. This in turn increases wear and wastes energy. Replacing a standard-efficiency motor with an energy-efficient motor reduces those losses and therefore also reduces costs.

Fan motors operate best at 75 to 100 percent of their fully rated load because the efficiency curve peaks between 75 percent and 100 percent. However, a smaller energy-efficient motor can improve efficiency when operating under part-load conditions.

Most savings occur when the motor is properly matched to its load. Thus, motors operating at less than 60 percent of their fully rated loads are excellent candidates for replacement with smaller energy-efficient motors.

When energy-efficient motors are part of a downsizing program, savings increase significantly. For example, downsizing a 75-horsepower standard-efficiency motor to a 40-horsepower energy-efficient motor will result in average energy savings of 15 percent.

Variable Speed Drives

Variable speed drives—an efficient and economical retrofit option—should be seriously considered for all variable air volume systems. These devices, which operate electronically rather than mechanically, continually adjust the speed of the air handling unit's fan motor to match the required load. Thus, the only power consumed is the power required to meet the demand. Because motors used in air handling units can consume up to 20 percent of the energy used in commercial buildings, significant energy savings can result. For example, reducing a fan's speed by 20 percent can reduce its energy requirements by about 50 percent.

Variable speed drives require far less input power than existing methods used to control air-flow in variable air volume systems (such as variable inlet vane control and outlet damper control). In addition, variable speed drives reduce fan speed, resulting in more efficient control of airflow because the motor's speed can then match the motor's load. Because they are controlled electronically, the drives can respond quickly to changing load requirements. They also reduce fan noise and vibration.

Variable speed drives reduce wear by controlling current surge when the motor starts up. This surge of electric current, required to move the motor from its stationary position, is approximately six times the normal operating current in motors with constant speed drives. This produces great stress on the equipment, particularly the windings. Variable speed drives reduce current surge by replacing instantaneous startup with "soft starting," where startup is gradual, over several minutes.

All variable air volume systems should be good candidates for variable speed drives. The drives can be implemented individually or as part of a retrofit that includes downsizing, energy-efficient motors, or both. In retrofit applications, the existing control (an inlet vane or outlet damper) is locked in the fully open position or removed and the variable speed drive controls the amount of discharge air by altering the speed of the fan.

Section Two contains the results of several pilot installations of variable speed drives.

ECONOMIC BENEFITS

You can estimate the expected benefits of a variable air volume system upgrade for your own building by running the EPA QuikFan program. This program provides estimates of the potential for reducing equipment sizes for fan systems, thus saving money and energy. QuikFan software is available to Green Lights and Energy Star Buildings Partners by writing to the EPA Global Change Division, USEPA/OAR (6202-J), 401 M Street SW, Washington, DC, 20460. The software will also be available from the Green Lights bulletin board. Dial 202-775-6671 and follow the instructions on the screen.

How Variable Speed Drives Reduce Operating Costs

- Soft start capabilities allow motor speed to be gradually increased, reducing starting currents and thermal stresses.
- Controlled braking results in quick but safe reductions in motor speed.
- Soft start, controlled braking, and current reductions in response to reduced demand lead to longer equipment life. Belts, pulleys, bearings, motors, and transformers will also last longer.
- Routine maintenance is unnecessary. If service is required, the fan can operate independently (at full speed or under the original controls), which eliminates downtime.

How Variable Speed Drives Save Energy

- The power required to run variable speed drives is proportional to rpm^3. Therefore, a reduction in speed of as little as 10 percent results in a 27 percent drop in power consumption ($100 - 0.9^3$). With a variable speed drive, a fan in a typical variable air volume system runs at 80 percent speed or less 90 to 95 percent of the time. Compare this with a fan running at 100 percent speed 90 to 95 percent of the time.
- The initial power required to start a motor is about 600 percent of rated current when a motor is started at full voltage and frequency. If a motor is started at low voltage and frequency through use of a variable speed drive, it will never need more than 150 percent of its rated current.

Potential Savings

Potential Air-Side Energy Savings From Downsizing, Smaller Energy Efficient	
Motors, and Variable Speed Drives	50-85%
Internal Rate of Return	25-55%

Potential for Downsizing

If You Reduce Loads By	You Probably Can Downsize Airflow (cfm) By
Green Lights Upgrades	15-30%
Energy Star Computers	10-20%
Window and Roofing Upgrades	5-15%
Total Potential for Downsizing	30-65%

Section 2 contains a series of pilot studies conducted by EPA that demonstrate the effectiveness of VSD installation. These studies illustrate the potential energy savings and profitability that can be gained through the use of VSDs.

Section Two:

VARIABLE SPEED DRIVE PILOT STUDIES

One of the Energy Star Buildings Program's first efforts was to conduct pilot studies of variable speed drives (VSDs) installed at 10 buildings around the country. The purpose of these studies was twofold:

- Compare the airflow control provided by VSDs with that of variable inlet vanes (VIVs).
- Verify—through actual installations—the potential of VSD technology to provide profitable energy savings for Energy Star Buildings Partners.

The studies showed that VSDs can greatly reduce the energy used by the same fan operating under similar airflow volumes and static pressure conditions. Overall, VSDs provided average energy savings of 52 percent, average demand savings of 27 percent, and an average simple payback period of 2.5 years.

Major Lessons Learned Over the Course of the Pilot Studies

- A VSD is almost always profitable, but more so when the fan or motor is oversized.
- The benefits of VSDs diminish if the fan or motor is grossly undersized or always runs at or near full capacity.
- Similarly, the benefits of VSDs diminish if the system on which the VSD is installed suffers from control problems (for example, simultaneous heating and cooling of the same area).
- In most cases, VSDs should be equipped with integral harmonic filters. Where this is not possible, a three-phase AC line reactor should be installed to reduce total current harmonic levels to within five percent.
- In most cases, VSDs should be equipped with internal power factor correction capacitors. Where this is not possible, a single capacitor should be installed, either on the main power line serving all VSDs or on the main power line serving a section of the building or the entire building.
- Backward-inclined and airfoil fans are the best candidates for VSDs. Forward-curved fans become unstable and are more difficult to control at partial loads.

SUMMARY OF RESULTS

The two tests employed in the pilot studies, while relatively simple, provide a sound basis for comparing the VSD and VIV of airflow control. The first provides a straightforward comparison of actual energy consumption readings for the two types airflow controls under similar normal operating conditions. The second compares power requirements over a range of airflow rates.

The first test determined ***energy consumption savings on a day of normal operations.*** This test involved recording the VSD's energy consumption (and, where possible, energy demand) hourly during a day of normal operation (when the building was occupied) and comparing it with VIV energy consumption during a similar day of normal operation (the following day). Airflow and outside air temperature were monitored to ensure that both systems were operating under similar conditions. ***Table 1*** provides a summary of the results of this test.

The second test determined ***energy consumption savings for the fan over the range of its operating load.*** For this test, airflow was manipulated so that VIV and VSD energy consumption (and, where possible, demand) could be compared over a range of airflow rates (in this case, increments of 10 percent) simulating the fan's operating load. The measurements were taken during hours when the building was unoccupied. The results of this incremental testing were used to estimate annual energy savings. ***Table 2*** provides a summary of the results of this test.

Table 1. Summary of Observed Energy Savings

Site	VIV Average Airflow (cfm)	VSD Average Airflow (cfm)	VIV One-Day Energy Consumption (kilowatthours)	VSD One-Day Energy Consumption (kilowatthours	Energy Savings with VSD (percent)	VIV Maximum Demand (kilowatts)	VSD Maximum Demand (kilowatts)	Demand Savings with VSD (percent)
American Express (Fifth Floor)	21,157	15,118	183.6	47.1	74.3	N/A	N/A	N/A
American Express (Fourth Floor)	18,103	17,980	N/A	N/A	N/A	14.2	17.3	-21.0
Douglas County, Oregon		22,100	20,220	161.1	54.3	66.3	18.7	8,554.5
Eli Lilly & Company	10,319	10,588	112.8	44.2	60.8	12.6	5.3	54.0
Hewlett-Packard (Colorado)	114,474	114,474	1,867.9	876.2	53.1	N/A	N/A	N/A
Hewlett-Packard (California)	10,225	11,560	170.9	45.6	73.3	13.4	4.0	70.1
IVAC, Incorporated	11,400	13,017	136.8	69.4	50.0	17.1	10.0	41.5
Mattel, Inc.	5,310	5,810	75.9	34.8	54.0	10.2	9.3	8.2
Mobil Corporation	13,800	12,600	149.6	89.4	40.2	16.1	12.1	24.8
New York Telephone	11,300	11,100	91.2	86.8	5.1	7.6	7.4	2.6

Table 2. Annual Energy Savings from VSDs Projected from Incremental Testing

Site	Assumed Annual Hours of Operation	Projected Energy (kilowatthours)	Annual Savings (percent)	Simple Payback Period (years)[1]	Internal Rate of Return (percent)
American Express (Fifth Floor)	3,651	31,000	53	2.3	42
American Express (Fourth Floor)	3,763	18,440	49	3.9	25
Douglas County, Oregon	2,808	26,802	75	2.6	31
Eli Lilly & Company	2,730	25,499	79	7.4	12
Hewlett-Packard (Colorado)	4,680	295,309	73	1.4	69
Hewlett-Packard (California)[1]	2,860	35,000	68	1.5	42
IVAC, Incorporated	4,420	54,000	71	1.3	76
Mattel, Inc.	2,132	18,083	72	4.9	20
Mobil Corporation	2,860	18,430	61	3.0	32
New York Telephone[2]	8,760	7,485	23	3.2	29

[1]Economic data are based on information provided by the building owners. Costs for Douglas County, Eli Lilly, and Mattel are installed costs; costs for American Express, Hewlett Packard, IVAC, and Mobil were estimated.

[2]This system operates 24 hours a day. The projections are estimates of the savings that could be realized if the VSD is installed with appropriate HVAC controls and a properly sized fan.

[3]This system operates 24 hours a day. The projections are estimates of the savings that could be realized if the VSD installed with appropriate HVAC controls and a properly sized fan.

STUDY METHODOLOGY

To conduct the pilot studies, the participants installed submetered VSDs on air handling units at each site. The participants were volunteers who were already Partners in the EPA's Green Lights Program. The VSDs were installed at the following facilities:

- American Express Company, Shearson Plaza, New York City, New York (two VSDs).
- Douglas County Courthouse, Douglas County, Oregon.
- Eli Lilly & Company Corporate Center, Indianapolis, Indiana.
- Hewlett-Packard Corporation, Palo Alto, California (Building 20).
- Hewlett-Packard Corporation, Colorado Springs Division, Colorado Springs, Colorado (Building C).
- IVAC, Incorporated, San Diego, California.
- Mattel, Inc., El Segundo, California.
- Mobil Corporation Research and Development Technical Center, Princeton, New Jersey (Building 16).
- New York Telephone Company, Buffalo, New York (Building B).

The VSDs were used to control the airflow in air handling systems that previously had been using VIVs to control airflow. (VIVs control airflow by restricting air at the inlet vane, with the fan always running at full speed. VSDs control air-flow by adjusting the speed of the fan.) The performance of these two types of airflow control was compared across a range of operating conditions.

EPA and the pilot study participants used the following procedure to estimate the annual energy savings of a VSD system:

1. Measure the input power of the existing system under VIV control at various flow rates (from 100 percent to the lowest possible flow, usually around 40 percent, in increments of 10 percent).

2. After the VSD is installed, measure the input power of the new system at the same airflow rates used in the VIV testing.

3. Establish an assumed yearly load profile that defines hours of use at various airflow rates[1]. The annual operating load profile used in these studies is shown in ***Table 5***.

Table 3. Assumed Load Profile Used in VSD Pilot Studies

Airflow (percent of CFM)	Percentage of Annual Operating Hours
40 or less	21.0
50	22.0
65	22.0
70	15.0
80	10.0
90	7.5
100	2.5

4. Multiply the hours of use at each flow rate by the measured energy savings from VSD installation at that flow rate. Sum these products over the fan's operating range to determine total savings, in kilowatthours, over a given period.

This procedure incorporates many of the elements of approaches described by Stephen Harding, P.E., writing for Bonneville Power Administration[2], and Perigrine White, Jr., at the Fifth National Demand Side Management Conference[3]. It provides a measurement of savings that is unaffected by changes in weather, occupancy, equipment load, or indoor temperature; that is, variables that cannot be reliably measured or controlled for a significant period of time. The objective of these short-term studies is to simply verify savings resulting from VSD installation.

[1]While an assumed profile was used for the purposes of the pilot studies, data can be gathered with a data logger or the trending capabilities of an energy management control system to log the hours of use as a function of flow rate.

[2]Harding, Steve, P.E., with Fred Gordon and Mike Kennedy, *Site Specific Verification Guidelines, report prepared for Bonneville Power Administration*, May 199, pp. 27-29.

[3]White, Peregrine, Jr., "DSM Savings Verification of Varying Loads," in *Building on Experience: Proceedings of the Fifth National Demand-Side Management Conference*, Palo Alto, California: Electric Power Research Institute, July 1991, pp. 103-106.

This type of incremental power monitoring provides an exact comparison of the VSD and VIV at the same points. The differences in power consumption can then be applied to any fan operating load. However, unless the data upon which the load profile is based are collected over several months or a complete year, it is difficult to account for seasonal variations in airflow. This constraint is avoided by using the assumed annual load profile. To improve confidence in the annualized results, operating trend data could be collected in the field.

AMERICAN EXPRESS COMPANY (FIFTH FLOOR)

This study highlighted the importance of weather conditions being similar on the two days of testing.

Test Summary

The test on the fifth floor of American Express Company's facility at Shearson Plaza in New York City was conducted on February 18, 19, and 22, 1993.

System Tested	
Air Handling Unit (AHU 5-3)	Carrier 39EB3B
Motor	U.S. Electric Motor (Emerson) SK386AL223A-R (30 horsepower)
VSD	Asea Brown Boveri Model ACH 500 (40 horsepower)
Airflow Measurement	Cambridge FMS-F
Energy Management System	Landis & Gyr Power System 600
Test Conditions	
Day One (VSD Testing)	OA temperature range: 37.58-45.87° F OA relative humidity range: 67.55-82.21 percent
Day Two (VIV Testing)	OA temperature range: 33.45-39.57° F OA relative humidity range: 98.09-106.6 percent

Note: *Because relative humidity cannot exceed 100 percent, the measurements were assumed to be inaccurate and 100 percent was used.*

Results

Figures 2 and 3 show the results of the tests. These results are summarized below. Energy consumption was 74.3 percent lower with the VSD. However, average airflow was 28.5 percent lower.

At minimum airflow, energy consumption was 87.5 percent lower with the VSD.

At maximum airflow, there was no difference in energy consumption between the VSD and VIV.

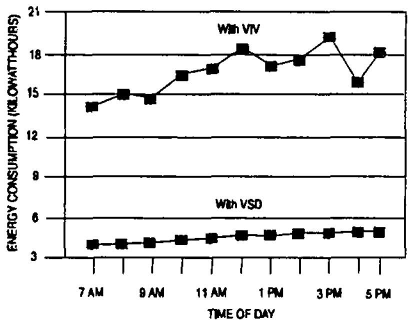


Figure 2. American Express Fifth Floor Test Results

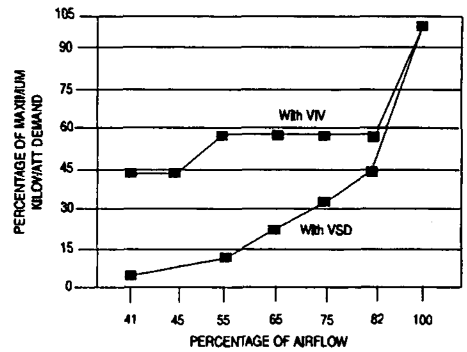


Figure 3. American Express Fifth Floor Test Results

The VSD would reduce annual energy consumption by about 31,000 kilowatthours and demand by 8.4 kilowatts. Using an energy cost of $0.055 per kilowatthour and an equipment cost of $4,000 for the 40-horsepower drive, the simple payback period was determined to be approximately 2.3 years.

Unique Issues for This Study

The tests were performed during the winter, when airflow requirements in New York City are typically less than during the summer. Average airflow during the test was approximately 59.1 percent of peak with the VSD and 82.6 percent with the VIV. In summer, airflow requirements are closer to peak for a few hours on some days.

The large variance in outside air temperatures on the two testing days led to the difference in average airflow. The average airflow would still lead to energy consumption savings between 23 percent (with the VSD normalized to the VIV's average airflow) and 70 percent (with the VIV normalized to the VSD's average airflow).

AMERICAN EXPRESS (FOURTH FLOOR)

This study showed that energy savings can be realized only if the VSD is properly sized to match motor horsepower requirements. The study also showed the importance of having the inverter's line choke and capacitor properly sized for power factor correction.

Test Summary

The test on the fourth floor of American Express Company's facility at Shearson Plaza in New York City was conducted on March 4-5, 1993.

System Tested	
Air Handling Unit (AHU 4-3)	Carrier 39EB36
Motor	U.S. Electric Motor (Emerson) SK386AL223A-R (40 horsepower)
VSD	Asea Brown Boveri Model ACH 500 (40 horsepower)
Airflow Measurement	Cambridge FMS-F
Energy Management System	Landis & Gyr Power System 600
Test Conditions	
Day One (VSD Testing)	OA temperature range: 14.88-24.76° F OA relative humidity range: 45-72-70.93 percent
Day Two (VIV Testing)	OA temperature range: 36-88-40.98° F OA relative humidity range: 101.1-107.4 percent

Note: *Because relative humidity cannot exceed 100 percent, the measurements were assumed to be inaccurate and 100 percent was used.*

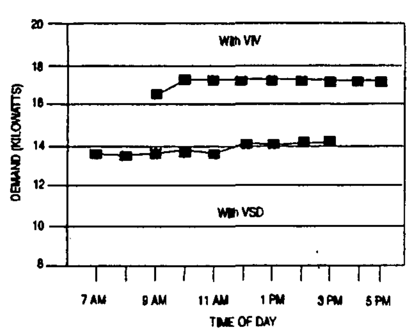


Figure 4. American Express Fourth Floor Test Results

Results

Figure 4 and ***Figure 5*** show the results of the tests.

Due to the type of meter available, energy consumption could not be measured. Hourly readings for demand were used for the analysis.
Demand was 21 percent higher with the VSD while airflow was 0.4 percent higher because an off-the-shelf 40-horsepower

VSD was installed on a 30-horsepower motor; thus, the VSD was over-sized.

At minimum airflow, demand was 78 percent lower with the VSD, which required 73 percent less current.

At maximum airflow, demand was 3.4 percent higher with the VSD, which required 7.9 percent more current.

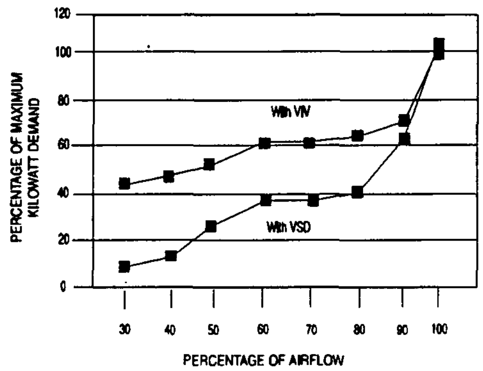


Figure 5. American Express Fourth Floor Test Results

Based on 3,763 hours of operation per year, the VSD would reduce annual energy consumption by approximately 18,440 kilowatthours and demand by 4.5 kilowatts. Using an average energy cost of $0.055 per kilowatthour and an equipment cost of $4,000 for the 40-horsepower drive, the simple payback period was determined to be approximately 3.9 years. The payback period for a 30-horsepower drive, after taking into account the lower initial cost and the higher efficiency, would be approximately 2.7 years.

Unique Issues for This Study

To facilitate test scheduling, the 40-horsepower VSD was bought off-the-shelf. The motor was 30 horsepower. This difference is seen in the relatively higher energy usage of the VSD. A properly sized VSD would be more energy efficient. In addition, the system operated at 91 percent of maximum airflow during normal operation with the VSD. The system should not be operating at such a high airflow during the winter; normal operation would be between 40 and 60 percent of maximum. If the VSD had been operating in this range, demand would have been 69 percent lower with the VSD. With a properly sized VSD, energy savings would be even greater.

AHU 4–3 with the VIV showed a power factor between –0.9 and –0.94. With the VSD, the power factor was between –0.86 and –0.97. The VSD power factor range should normally be between 0.96 and 0.99. Here it is low because the VSD was oversized. In addition, the VSD procured for this test was an off-the-shelf unit and the inverter's line choke and capacitor were not sized properly for the motor's power factor. The negative numbers indicate a capacitive load rather than an inductive load.

DOUGLAS COUNTY, OREGON

This study provided the expected results.

Test Summary

The VSD pilot study at the Douglas County Courthouse was conducted on February 25–26, 1993.

System Tested	
Air Handling Unit (AHU-8)	Backward-inclined fan by PACE
Motor	Lincoln (30 horsepower)
VSD	Asea Brown Boveri Model ACH 500
Airflow Monitoring Station	Paragon/Honeywell
Energy Meter	Dranetz 808
Test Conditions	
Day One **(VSD Testing)**	OA temperature range: 31-54° F OA relative humidity range: 73.8-80.4 percent
Day Two **(VIV Testing)**	OA temperature range: 29-50° F OA relative humidity range: 73.2-86.9 percent

Results

Figure 6 and ***Figure 7*** show the results of the tests. These results are summarized below.

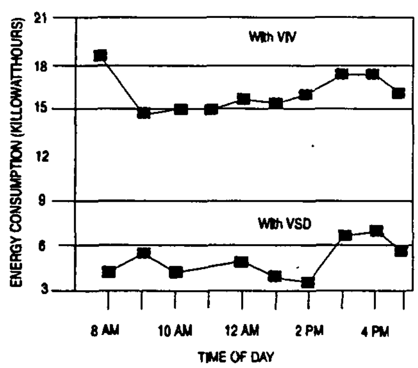


Figure 6. Douglas County, Oregon, Test Results

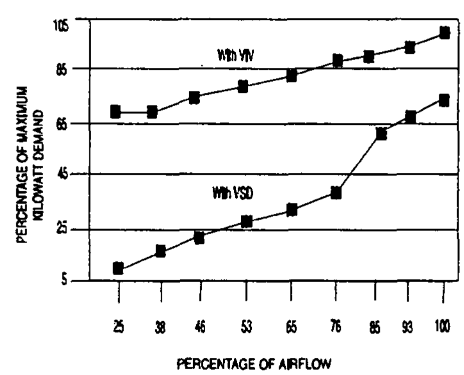


Figure 7. Douglas County, Oregon, Test Results

Energy consumption was an average of 66.3 lower with the VSD.

At minimum airflow, AHU–8 required 86.5 percent less demand with the VSD than with the VIV.

At maximum airflow, AHU–8 required 25.5 per-cent less demand with the VSD than with the VIV.

Using an energy cost of $.0328 per kilowatthour and demand and distribution charges of $2.48 per kilowatt, the $2,850 AHU-8 drive (30 horsepower) would reduce yearly energy consumption by about 26,802 kilowatthours and demand by 7.5 kilowatts. The simple payback period was determined to be approximately 2.6 years.

Unique Issues for This Study

The tests were performed in winter, when airflow requirements in Oregon are typically less than during the summer. Average airflow during the test was approximately 80 percent of peak with the VSD and 87 percent with the VIV. In summer, airflow requirements are closer to peak for a few hours on some days.

Without the VSD, AHU-8 showed a power factor between 0.71 and 0.79. With the VSD, the power factor improved to 0.99 at varying speeds. The VSD installed for this test was provided with an internal power factor correction capacitor that provides automatic power factor correction.

ELI LILLY & COMPANY

This study found that a significant reduction in fan energy consumption does not always mean that a VSD retrofit will be profitable. Although the test confirmed that a VSD brings significant energy savings when applied to variable air volume air handling systems (in this case 81 percent better than the VIV airflow control), the relatively low cost of energy for the facility examined caused a longer payback period.

Test Summary

The VSD pilot study at Eli Lilly & Company's Corporate Center in Indianapolis, Indiana, was conducted on February 11–12, 1993.

System Tested	
Air Handling Unit (AHU 5-3)	Carrier 39ED, size 32, double-width double-inlet (DWDI) airfoil fan
Motor	Marathon MN 284TTDR7026FN-F2 (25 horsepower)
VSD	Allen Bradley Model 1336VTB0235EA-FL1
Airflow Measurement	Tek-Air Vortek airflow monitoring station located in each branch duct
Energy Meters	Esterline PMT3B and Dranetz 658
Energy Management System	Johnson Control System 686
Vibration Meter	Computational Systems Model 2110-4D
Test Conditions	
Day One (VSD Testing)	OA temperature range: 37.2-40.6° F OA relative humidity range: 82.5-98.9 percent
Day Two (VIV Testing)	OA temperature range: 34.5-36.5° F OA relative humidity range: 100 percent

Results

Figure 8 and ***Figure 9*** show the results of the tests. These results are summarized below.

Energy consumption was 60.8 percent lower with the VSD, while airflow was 2.5 percent higher.

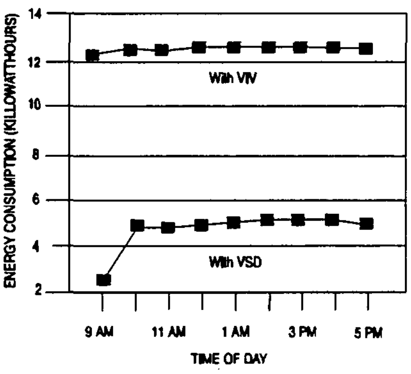


Figure 8. Eli Lilly & Company Test Results

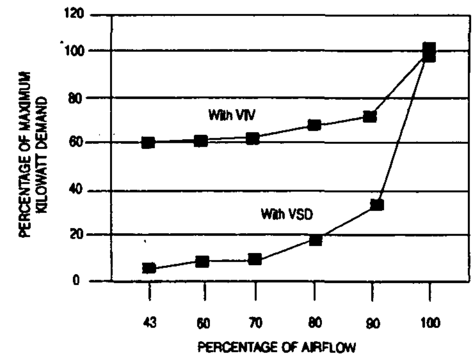


Figure 9. Eli Lilly & Company Test Results

Demand was 54 percent lower with the VSD, while airflow was 3.4 percent higher. At minimum airflow, demand was 91.7 percent lower with the VSD, which required 93.3 percent less current. At maximum airflow, demand was 1.6 percent higher with the VSD, which required 18.2 percent less current.

The VSD would reduce annual energy consumption by about 25,499 kilowatthours and demand by 9 kilowatts. Using an energy cost of $.0368 per kilowatthour and an equipment cost of $6,900 for the 25-horsepower drive, the simple payback period was determined to be approximately 7.4 years.

Unique Issues for This Study

During the incremental testing, the fan became unstable at 43 percent of maximum airflow. No further measurements were possible.

The static pressure setpoint was not maintained during the incremental testing. If static pressure had been maintained during the incremental testing, demand for both the VIV and the VSD would have increased at all intervals. However, the difference in demand between the two would have been close to the results shown.

The tests were performed during the winter, when airflow requirements in Indianapolis are typically less than during the summer. Average airflow during the test was approximately 62 percent of peak. In summer, airflow requirements are closer to peak for a few hours on some days.

AHU–FQ3 with the VIV showed a power factor between 0.658 and 0.755. With the VSD, the power factor improved to 0.99 at varying speeds. The VSD installed for this test is provided with a line choke and a capacitor that provides automatic power factor correction.

HEWLETT-PACKARD CORPORATION (COLORADO)

This study demonstrated the need to have an airflow monitoring station to obtain accurate readings to use in calculating energy savings. Lack of airflow monitoring data necessitated use of manufacturer's data. Because use of this theoretical data conflicted with the methodology, the margin of error for the predicted savings is understandably larger.

Test Summary

The VSD pilot study at Building C of Hewlett-Packard's Colorado Springs complex was conducted on January 25–26, 1993.

System Tested	
Air Handling Unit (AHU 5-2)	Field-erected, size 66, double-width single-inlet (DWSI) airfoil fan by Trane.
Motor	150 horsepower
System	Dual-duct VAV system controlled by outside air temperature *Note: This system does not maintain or monitor static pressure.*
VSD	Graham
Airflow Measurement	Pilot tube located in the cold deck
Energy Meter	BMI
Test Conditions	
Day One (VSD Testing)	OA temperature range: 22.5-49.1° F *Note: No VIV testing was conducted.*

Results

Figure 10 and ***Figure 11*** show the results of the tests. These results are summarized below.

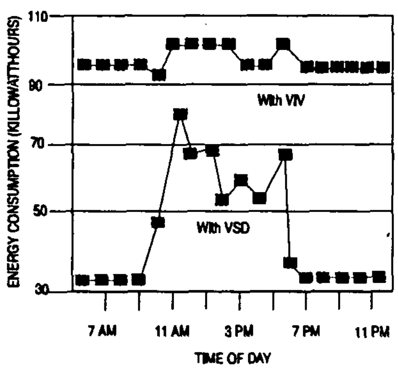


Figure 10. Hewlett-Packard (Colorado) Test Results

Energy consumption was 53.1 percent lower with the VSD at equivalent airflow levels.

At minimum airflow, demand was 92 percent lower with the VSD.

At maximum airflow, demand was 6 percent lower with the VSD.

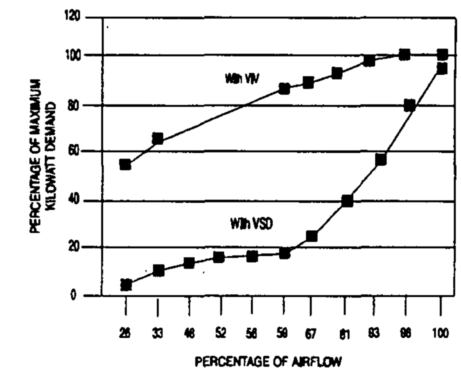


Figure 11: Hewlett-Packard (Colorado) Test Results

The VSD would reduce annual energy consumption by approximately 295,309 kilowatthours. Using an energy cost of $0.043 per kilowatthour and equipment costs of approximately $18,300 for the 150-horsepower drive, the simple payback period was determined to be approximately 1.44 years.

Unique Issues for This Study

This air handling unit does not operate as a normal variable air volume unit in that it does not monitor or maintain static pressure. From 5 a.m. to 6 p.m., the unit operates the VSD between a minimum of 65 percent and a maximum of 95 percent of airflow capacity, depending on the outside air temperature. From 6 p.m. to 11 p.m., the unit operates with the VSD at 65 percent capacity. At 11 p.m., the unit is shut down. Therefore, airflow was measured with a pilot tube only on the day of VSD testing. However, the airflow measurements taken could not be used for the analysis due inaccuracies caused by turbulence conditions. Actual fan performance was used to calculate VSD energy consumption. VIV energy consumption was calculated by using fan performance-curve data from the manufacturer; airflow levels were assumed to be the same as when the VSD was tested.

Because the VIV had no controls, data for the incremental testing could be collected only by manually adjusting the VIV setting and taking readings at different airflows. These readings were then compared to those of the VSD at similar airflows.

The maximum setpoint on the VSD, 95 percent, corresponded to an airflow of 135,000 cfm. The lowest setpoint, 25 percent (set manually), corresponded to an airflow of 35,000 cfm.

The 20-psi maximum setpoint on the VIV corresponded to 95,000 cfm. The 0-psi minimum setpoint on the VIV corresponded to 65,000 cfm (48 percent of the maximum).

HEWLETT-PACKARD CORPORATION (CALIFORNIA)

This study showed that return fans are excellent candidates for VSDs. A system that is oversized when a VSD is installed will have even greater savings because the VSD will operate the system only at the required load.

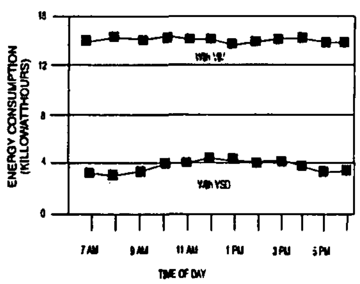
Test Summary

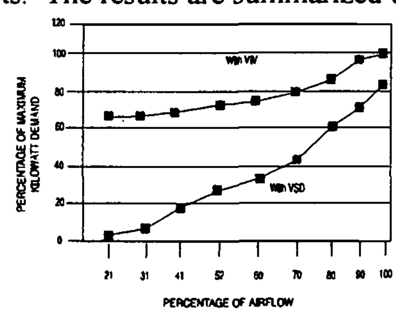
The test at Building 20 of Hewlett-Packard's Palo Alto facility was conducted on January 11–12, 1993. It evaluated energy consumption for both the air handling unit and the return fan.

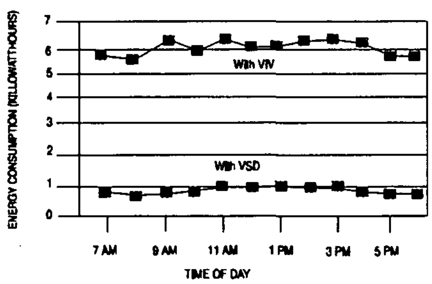
System Tested	
Air Handling Unit (AHU-3)	Field-erected, size 490, single-width single-inlet (SWSI) airfoil fan (Twin City)
Return Fan (RF-3)	SWSI airfoil (Twin City)
Motors	Lincoln (30-horsepower for AHU-3; 15-horsepower for RF-3)
VSD	Asea Brown Boveri
Airflow Monitoring Station	Paragon
Energy Meter	Dranetz 8000
Test Conditions	
Day One (VSD Testing)	OA temperature range: 39-54° F OA relative humidity range: 55-95 percent
Day Two (VIV Testing)	OA temperature range: 41-51° F OA relative humidity range: 87-100 percent

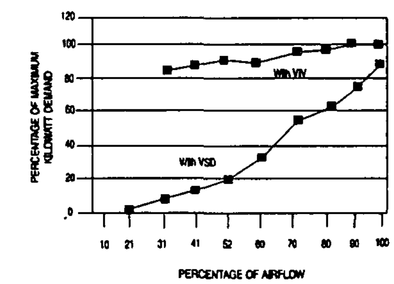
Results

Figure 12 through ***Figure 15*** show the results of the tests. The results are summarized below.









AHU–3 energy consumption was 73.3 percent lower with the VSD, while average airflow was 13.1 percent higher. RF–3 energy consumption was 85.9 percent lower with the VSD, while average airflow was 10.4 percent higher. AHU–3 maximum demand was 70.1 percent lower with the VSD, while maximum airflow was 17.6 percent higher. RF–3 maximum demand was 84.4 percent lower with the VSD, while maximum airflow was 19.3 percent higher.

At minimum airflow: AHU–3 demand was 95.5 percent lower, AHU–3 required 99.5 percent less current, and RF–3 required 99.5 percent less current. At maximum airflow: AHU–3 demand was 16.5 percent lower, AHU–3 required 12.0 percent less current, and RF–3 required 31.2 percent less current.

For the air handling unit, the VSD would reduce annual energy consumption by approximately 35,000 kilowatthours and demand by 9.6 kilowatts. Using an energy cost of $0.06 per kilowatthour, demand and distribution charges of $10 per kilowatt, and equipment costs of $5,000 for the 30-horsepower drive, the simple payback period was determined to be approximately 1.5 years.

For the return fan, the VSD would reduce annual energy consumption by approximately 17,500 kilowatthours and demand by 5.0 kilowatts. Using an energy cost of $0.06 per kilowatthour, demand and distribution charges of $10 per kilowatt, and equipment costs of $3,500 for the 15-horsepower drive, the simple payback period would be approximately 2.1 years.

Unique Issues for This Study

The tests at Hewlett-Packard were conducted in the winter, when cooling load requirements in the San Francisco area typically are lower than in the summer. Thus, average airflow during the test was around 40 percent of peak. In summer, airflow requirements are closer to peak for a few hours on some days.

The large difference in peak demand at maximum airflow found in these tests (16.5 percent) was a result of oversizing. This oversizing also allowed the VSD to consume much less energy.

IVAC, INCORPORATED

This study showed that VSDs provide significant energy savings even if the system operates with higher average airflow.

Test Summary

The test at IVAC, Incorporated, a subsidiary of Eli Lilly & Company in San Diego, California, was conducted on March 10–12, 1993.

System Tested	
Air Handling Unit (AHU-4)	Backward-inclined fan by Trane (CLCH-35)
Motor	Gould Century (30 horsepower)
VSD	Magnetek GPD 503
Airflow Monitoring Station	Air Monitor
Energy Meter	BMI 3030
Energy Management System	Trane Tracer
Test Conditions	
Day One **(VSD Testing)**	OA temperature range: 53-65.0° F OA relative humidity range: 76.1-89.5 percent
Day Two **(VIV Testing)**	OA temperature range: 64.1-81.4° F OA relative humidity range: 72.7-90.4 percent

Results

Figure 16 and ***Figure 17*** show the results of the tests. These results are summarized below.

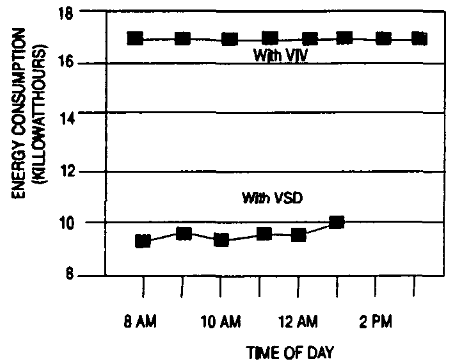


Figure 16. IVAC Incorporated Test Results

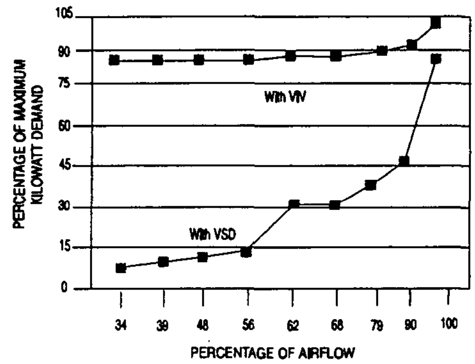


Figure 17. IVAC Incorporated Test Results

Energy consumption was 50 percent lower with the VSD, while airflow was 10 percent higher.

At minimum airflow, demand was 92.9 percent lower with the VSD.

At maximum airflow, demand was 14 percent lower with the VSD.

The VSD would reduce annual energy consumption by about 54,000 kilowatthours, summer demand by 2.7 kilowatts, and winter demand by 10.7 kilowatts. Using an energy cost of $.03332 to $.07201 per kilowatthour and demand and distribution charges of $7.02 to $20.47 per kilowatt, and an equipment cost of $5,000 for the 30-horsepower drive, the simple payback period was determined to be approximately 1.3 years.

Unique Issues for This Study

Average airflow during the test was around 72.7 percent of peak with the VSD and 65.8 percent of peak with the VIV. The VSD still consumed less energy than the VIV, even though it was operating at airflow that on average was 10 percent higher and an average outside air temperature 14.6° F. higher. The large difference indicated here could be due to motor oversizing.

Without the VSD, AHU–4 showed a low power factor of 0.75, which indicates that the motor is inefficient. With the VSD, the power factor gradually improved from a low reading of 0.6 at low speed to 0.89 at the full 60 Hz speed. Without replacing the motor, the VSD provided a remarkable power factor improvement.

MATTEL, INC.

This study provided the expected results.

Test Summary

The test at Mattel, Inc., in El Segundo, California, was conducted on March 24–26, 1993.

System Tested	
Air Handling Unit (AHU-5)	Forward-curved fan
Motor	20 horsepower
VSD	Graham 1700
Airflow Monitoring Station	Tek-Air
Energy Meter	Dranetz 8000
Energy Management System	Teletrol Control System
Test Conditions	
Not available.	

Results

Figure 18 and ***Figure 19*** show the results of the tests. These results are summarized below.

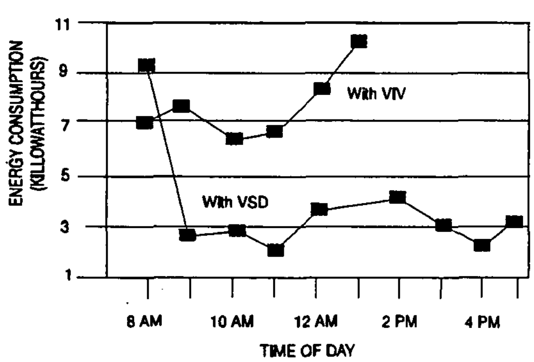


Figure 18. Mattel Inc. Test Results

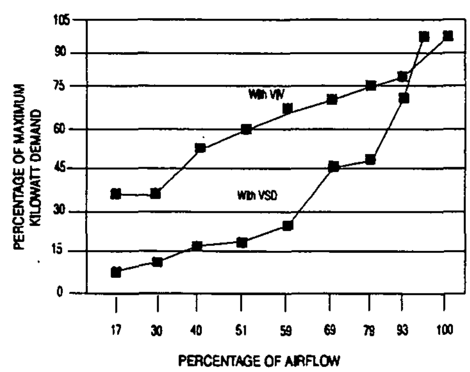


Figure 19. Mattel Inc. Test Results

Energy consumption was 54 percent lower with the VSD, while airflow was 4.3 percent higher.

At minimum airflow, demand was 83.3 percent lower with the VSD.

At maximum airflow, demand was 8.5 percent higher with the VSD.

The VSD would reduce annual energy consumption by approximately 18,083 kilowatthours and demand by 1.5 kilowatts. Using an energy cost of $0.13784 per kilowatthour during the summer on-peak hours and $0.05675 per kilowatthour during all other hours, $19.45 per maximum demand and $3.65 for demand ratchet, and an equipment cost of $8,742, the simple payback period was determined to be approximately 4.9 years.

Unique Issues for This Study

Average airflow during the test was approximately 33.8 percent of peak with the VSD and 30.8 percent with the VIV. In summer, airflow requirements are closer to peak for a few hours on some days. VSDs may require slightly more energy at peak airflow than VIVs.

When VSD testing began, the drive was operating the fan at 68 percent of maximum airflow, causing the higher initial energy consumption for the VSD shown in ***Figure 26.*** More typical percentages of maximum airflow were recorded during the remainder of the test.

The VSD used for this study was more expensive than comparable drives of its size, even when installation is included. This caused the longer payback period, with a IRR of 20 percent.

With the VIV, AHU–5 showed a power factor between 0.675 and 0.869. This indicates that the motor is inefficient. With the VSD, the power factor ranged between –0.21 and –0.77. The VSD installed for this test was not equipped with power factor correction capability (indicated by the low power factor reading). The negative number indicates the measured load is capacitive.

MOBIL CORPORATION

This study provided an example of what can happen when cooling and heating systems are not properly coordinated. This coordination could be achieved by connecting perimeter heating valves to the thermostats that control the VAV boxes. If this were done, the VAV boxes would modulate the airflow down to the minimum position before allowing the heating valves to open when there is demand for heating. On the other hand, the heating valves would close completely before allowing the VAV boxes to open when there is demand for cooling.

Test Summary

The test at Building 16 of Mobil's Princeton, New Jersey, complex was conducted on April 13 and 15, 1993.

System Tested	
Air Handling Unit (FNS-4)	Trane Climate Changer (CLCH) with a single-width single-inlet (SWSI) backward-inclined fan
Motor	Magnetek 25 horsepower
VSD	Asea Brown Boveri model 501 ACH
Airflow Monitoring Station	Multi-tube, multi-hole station built on site by Mobile's Facilities staff, a pilot tube, and a pressure differential gauge
Energy Meter	Dranetz 8000
Test Conditions	
Day One (VIV) Testing	OA temperature range: 40-61°F
Day Two (VSD Testing)	OA temperature range: 51-65°F

Results

Figure 20 and ***Figure 21*** show the results of the tests. These results are summarized below.

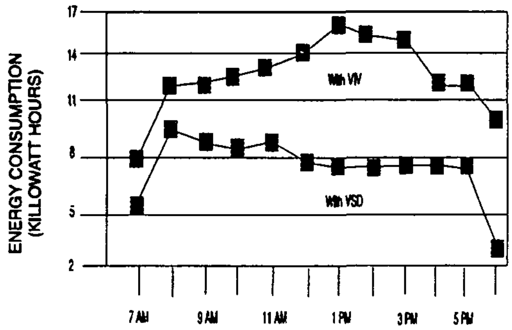


Figure 20. Mobil Corporation Test Results

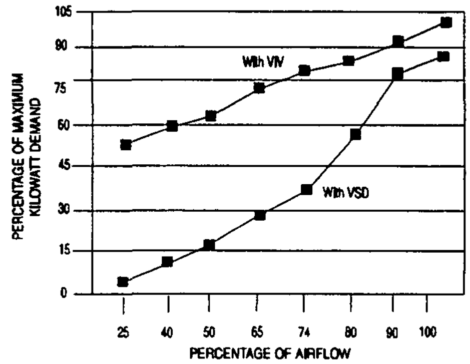


Figure 21. Mobil Corporation Test Results

Energy consumption was 40.2 percent lower with the VSD. However, average airflow was 9.2 percent lower.

At minimum airflow, demand was 92.3 percent lower with the VSD, which required 89.6 percent less current.

At maximum airflow, demand was 15.5 percent lower with the VSD, which required 15.3 percent less current.

The VSD would reduce annual energy consumption by about 18,430 kilowatthours. Using an average energy cost of $0.07 per kilowatthour and a VSD cost of $4,000, the simple payback period was determined to be approximately 3 years. This figure is based on a load ratio that varies during the year according to the heating and cooling load.

Unique Issues for This Study

The tests were performed in early spring, when airflow requirements in Princeton are typically 40 percent to 70 percent of peak. Average airflow during the tests was approximately 86 to 87 per-cent of peak, a figure more comparable with summer airflow. This high airflow was a result of cooling demand caused by excessive heat from perimeter heating, which is controlled by outside air temperature (airflow is controlled by space thermostats). This setting causes the airflow to run high to remove the heat from the space.

With the VIV, AHU FNS–4 showed a power factor of 0.9, which indicates that the motor is efficient. With the VSD, the power factor remained in the 90 percent and above range. The VSD installed for this test was provided with power factor correction capability.

NEW YORK TELEPHONE

This study provided another example of what can happen when cooling and heating systems are not properly coordinated. This coordination could be achieved by connecting perimeter heating valves to the thermostats that control the VAV boxes. If this were done, the VAV boxes would modulate the airflow down to the minimum position before allowing the heating valves to open when there is demand for heating. On the other hand, the heating valves would close completely before allowing the VAV boxes to open when there is demand for cooling.

Test Summary

The test at New York Telephone was conducted at Building B of the company's Buffalo complex on March 17–19, 1993.

System Tested	
Air Handling Unit (AHU-7B)	Packaged, size 31, single-width single-inlet (SWSI) airfoil fan (Climate Changer by Trane)
Motors	(15 horsepower for AHU-7B; 5 horsepower for RF-7)
VSD	ASEA Brown Boveri model ACS 501
Airflow Monitoring Station	Tek-Air Vortek
Energy Meter	Dranetz 808
Energy Management System	Johnson Control Systems DSC 8540 and DSC 8500
Test Conditions	
Day One (VSD Testing)	OA temperature range: 16-24°F OA relative humidity range: 42-45 percent
Day Two (VIV Testing)	OA temperature range: 12-26°F OA relative humidity range: 41-48 percent

Results

Figure 22 and ***Figure 23*** show the results of the tests. These results are summarized below.

Energy consumption was 5.1 percent lower with the VSD. However, average airflow was 1.8 percent lower. Demand was 2.6 percent lower with the VSD, while average airflow was 1.8 percent lower. At 20 percent of maximum airflow, demand was 62 percent lower with the VSD, which required 55 percent less current. At maximum airflow, demand was 0.6 percent higher with the VSD, which required 7.2 percent more current.

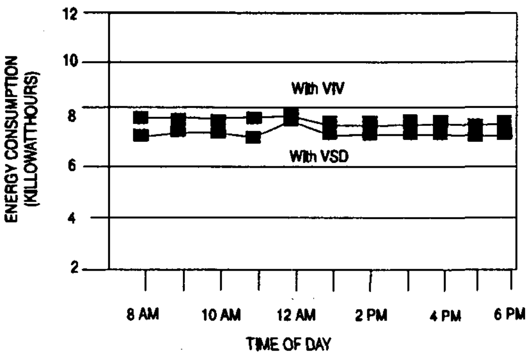


Figure 22. New York Telephone Test Results

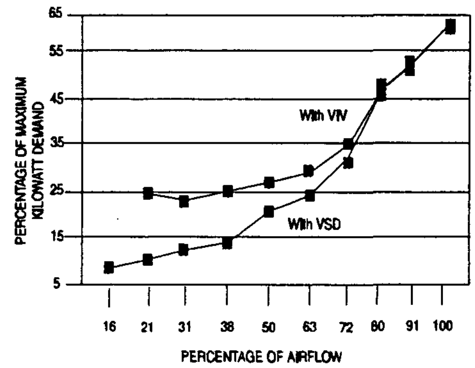


Figure 23. New York Telephone Test Results

because the system was operating at peak airflow at all times with the VSD as well as with the VIV, energy savings from using the VSD could only be estimated. If the control problem is corrected and the fan is sized properly, the VSD would reduce annual energy consumption by about 7,485 kilowatthours. Using an energy cost of $0.095 per kilowatthour and an equipment cost of $2,300 for the 15-horsepower drive, the simple payback period was determined to be approximately 3.2 years.

Unique Issues for This Study

Due to the lack of a second energy meter and an additional airflow monitoring station in the return air ductwork, airflow, demand, energy consumption, power factor, and harmonics data were not obtained during the incremental testing.

AHU–7B was adjusted during the incremental testing, while RF–7B tracked AHU–7B. The lowest frequency setpoint on AHU–7B and RF–7B with the VSD was 10 Hz. That setpoint coincided with an AHU–7B airflow of 1,820 cfm (16 percent of the maximum airflow). Using the VIV with dampers set at the maximum closed position, AHU–7B airflow was 1,360 cfm (10 percent of the maximum airflow).

The design of the existing HVAC system had a major effect on this test. The building is heated by individually controlled radiators that operate independently of cooling system controls. Therefore, as long as the room is being heated, the room thermostat will call for cooling. This results in VAV boxes being constantly in a full open position. Since the VAV system was run at maximum airflow, the test showed only minor differences between VSD and VIV operation. Nevertheless, when airflow was adjusted manually, a significant reduction in energy consumption was observed.

Section Three:

VSD PERFORMANCE AND RELIABILITY STUDY

VSD COMMERCIAL HVAC STUDY

Motors account for up to 50 percent of total electric energy use. They convert electricity to mechanical energy for operation of equipment such as fans, blowers, pumps, and compressors. The output of the equipment is typically adjusted by various means (clutches, brakes, valves, and dampers) to satisfy dynamic system requirements; however, these adjustments waste energy to varying degrees. A variable speed drive (VSD) saves significant energy by modulating the output of the motor to satisfy changing system requirements.

VSDs offer much more than energy savings, however. Less maintenance is one benefit since electronic speed control replaces a mechanical transmission system. The mechanical stresses on machine bearings and shafts are lower which prolongs the service life of equipment. Because of the low starting current, the thermal stress on the machine itself and the electrical stress on the power supply are substantially reduced. All these factors contribute to higher reliability and reduced downtime of the equipment.

In order to obtain a better understanding of VSD performance and reliability in commercial heating, ventilating and air-conditioning system applications, The Alliance to Save Energy (ASE) performed a survey of facility managers' experience with installed VSDs. Data obtained from the survey was shared with the Global Change Division of the U.S. Environmental Protection Agency (EPA). A technical assessment of the survey data was performed by Enviro-Management and Research, Inc. (EMR).

Findings

A total of 211 facility managers responded to the *VSD Field Performance Questionnaire*, representing a 8.8 percent rate of response. The survey response included information on more than 200 separate facilities and 3,000 VSDs representing 36 manufacturer product lines. The major findings of this survey are briefly detailed below.

Energy and Operating Cost Savings Are Very Important

More than three quarters (80 percent) of the respondents indicate that *potential energy savings*, *improved efficiency*, or *reduced operating expenses* are very important factors that led them to consider installing VSDs.

Reliability Is A Key Factor In VSD Application

Although not the most important factor in VSD application, *reliability* is one of the key factors in decision-making with regards to the installation of VSDs. The majority of facility managers also consider *independent documentation of reliability* as being *very critical* in decision-making with regards to the application of VSDs in facilities.

VSDs Experience Less Problems Than Previous Control Methods

The majority of facility managers (59 percent) indicate that the frequency of problems with VSDs is *less* or *far less than* problems experienced with previous control methods (*e.g.*, outlet dampers and inlet vanes).

VSDs Have Become More Reliable Over Time

The facility managers who report encountering more frequent problems than with previous control systems had typically installed VSDs with older technology (average installation date: 1986) than facility managers reporting less frequent problems (average installation date: 1988). This data suggests that the reliability of VSDs has improved over time.

Most Facility Managers Would Install VSDs Again

Nearly all facility managers (95 percent) who returned a survey questionnaire indicate that they *would install VSDs again* (***Figure 24***). About two-thirds of these managers are *very satisfied* with the performance of currently installed VSDs since initial start-up (***Figure 25***). Some of the major factors leading to their high satisfaction are:

- *Energy savings*—due to significant kWh reductions
- *Flexibility*—superior control in operating equipment
- *Product quality*—basically trouble-free, reliable, no environmental complaints

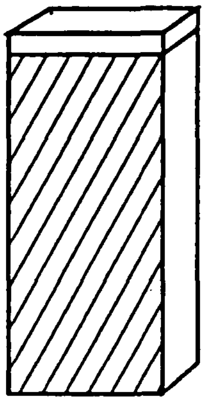


Figure 24. Install VSDs Again

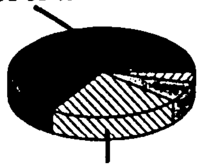


Figure 25. Level of Satisfaction with VSDs

Of the facility managers who expressed dissatisfaction with VSDs, 69 percent reported they *would install VSDs again.* In addition, many facility managers who used VSDs for certain applications *are considering installing VSDs* for other applications in the near future.

Installed VSDs Meet or Exceed Predicted Energy Savings

The majority of facility managers indicate that annual energy savings after installation of VSDs *are equal to or greater than* predicted energy savings. In fact, one in three respondents indicate that their VSDs have produced *greater* energy savings than they had predicted before installation.

VSD Power Quality/Power Factor Problems Are Minimal

Of the facility managers providing information on both power quality and power factor problems, more than 80 percent indicated that they *did not experience any power quality problems* and 95 percent indicated that they *did not experience any low power factor problems.* Of the minority that did experience these problems, many resolved them by installing harmonic filters, isolation transformers, and power factor correction capacitors or by adjusting the set-points.

PWM VSDs Have Become More Popular Over Time

Three types of variable speed drives are currently available in the marketplace. These are: variable voltage inverter (VVI), current source inverter (CSI), and pulse width modulation converter (PWM). According to survey results, facility managers *are opting for PWM VSDs over VVI VSDs* at a rate of 2 to 1, while *opting for PWM VSDs over CSI VSDs* at a rate of 11 to 1. Furthermore, facility managers report having to service their PWM VSDs *less frequently* than other VSD types.

VSDs for Water-Side Applications Receive Good Performance Ratings

Although the majority of VSDs have been installed in air-side applications, facility managers indicate *very favorable* results for VSDs installed in water-side applications. For example, few managers report that they have experienced *more or far more problems* in using VSDs as compared to previous control systems when utilized in chilled water/hot water pumps, chillers, and cooling tower fans.

Premature Motor Burnout Is Not Reported

Results of the survey contain *no evidence that VSDs cause pre-mature motor burn-out.* In fact, of the 59 facility managers that report experiencing performance problems with VSDs, not one reported motor burn-out. In addition, only four managers report having experienced motor overheating.

Proper VSD Installation Ensures Against Circuit Board Failure

Thirty of the 59 facility managers (50 percent) that report experiencing performance problems with VSDs cite circuit board failure as a common performance problem. This problem can be avoided by ensuring the VSD is installed correctly by the manufacturer's distributor or electrical contractor. Contacting the manufacturer is recommended if there are any questions that arise before, during or after the installation.

Methodology

The specific objectives of this project were to:

1. Obtain data/information on facility managers' experience with installed VSDs.
2. Assess the performance and reliability of VSD technology on the basis of the data/information obtained from a survey.

The Alliance to Save Energy initiated the project by developing the *VSD Field Performance Questionnaire*. The questionnaire requested data/information on:

1. Manager's decision-making process when considering installation of VSDs in their facility.
2. Existing VSDs, including name of manufacturer, HP range, type of VSD, date installed, and application.
3. Level of user satisfaction with the performance of VSDs.
4. Importance of various factors (cost, flexibility, efficiency, utility rebate, energy savings, reliability, etc.) relating to the installation of VSDs.
5. Types of start-up problems experienced and the amount of time it takes to correct them.
6. Frequency of problems.
7. Type of service contract, the annual cost of the contract, contract scope, service frequency, and response time.
8. Measures that have been implemented to correct power quality problems and low power factor problems.
9. Amount of energy savings due to the installation of VSDs.
10. Likelihood of additional VSD installations in the facility.

Once the questionnaire was finalized, ASE mailed copies of the questionnaire to approximately 2,400 facility managers using 11 different mailing lists. The data collected by ASE was then analyzed by EMR using the following methodology:

1. Reviewed questionnaires for completeness of response.
2. Compiled data/information in Paradox 4.0 Relational Data Base.
3. Analyzed data/information for specific trends.

Section Four:

FAN OVERSIZING STUDY

The EPA has investigated the prevalence of supply fan oversizing. The purpose of the study was to quantify the percentage of buildings with oversized fans and to encourage downsizing as a viable option of reducing upgrade costs while further increasing energy efficiency.

The study consisted of a cross section of 47 air handling units (AHUs) located in 26 commercial buildings throughout the continental U.S. Data were collected in Indianapolis, IN; New York, NY; Pennington, NJ; Los Angeles, CA; Seattle, WA; Weston, MA; Washington, DC, and Fairfax, VA. The study was conducted in July, August, and September 1993.

Air flow rates were measured with air flow monitoring stations at outside air temperatures near or above the 2.5 percent design temperature for each location. These measurements were compared to the design air flow from the building specifications. .

Due to the nature of the study (traveling from city to city as heat waves moved from region to region) and the lack of time to carefully calibrate all equipment, errors of plus or minus 15 percent were expected for each AHU. Although no single measurement can be taken as exact, the average of all 47 AHUs clearly leads to one conclusion.

Over half of the 26 buildings had AHUs with oversizing greater than 10 percent. Of those buildings, the average percent oversizing was 72 percent! Fan energy reductions of 50 percent would be expected simply by reducing the oversizing from 72 percent to 10 percent.

Summary Of Results

	Percentage with Oversizing > 10 percent	* Average Oversizing	** Average Oversizing
Buildings Surveyed	58 percent	38 percent	72%

*includes all 26 buildings
** only includes those that are oversized greater than 10 percent

Oversizing was found to be prevalent in the 26 buildings surveyed. This conclusion agrees with the opinion of those involved in the building industry. Any attempt to conserve fan energy must therefore begin by investigating oversizing that may exist.

Oversizing not only wastes energy but also leads to greater wear on equipment. Thus, reducing oversizing will reduce maintenance costs. Care should be taken to measure and reduce oversizing when upgrading fan motors or adding variable speed drives. Smaller motors and VSDs will also costs less to purchase.

The following table lists buildings included in the study and the average oversizing.

Table 4. Buildings Studied and Average Oversizing

Building	Oversizing
Statenet Building, Indianapolis, IN	38%
American United Life, Indianapolis, IN	88%
54 Monument Circle, Indianapolis, IN	8%
Eli Lilly Corporation Center #73, Indianapolis, IN	28%
Eli Lilly Corporation Center #76, Indianapolis IN	-12%
Eli Lilly Corporation Center #75, Indianapolis IN	-11%
Methodist Hospital, Indianapolis, IN	-11%
Mobil Research and Development Corp. #16, Pennington, NJ	-33%
Mobil Research and Development Corp. #19, Pennington, NJ	62%
Mobil Research and Development Corp. #17, Pennington, NJ	-2%
American Express Tower, New York, NY	13%
Liberty Mutual Building, Weston, MA	-14%
UCLA Medical Plaza 200, Los Angeles CA	15%
UCLA Medical Plaza 300, Los Angeles, CA	34%
Kaiser Imperial Medical Office, Los Angeles, CA	15%
Children's Hospital of L.A., Los Angeles, CA	0%
Boeing Building #40-03, Seattle, WA	88%
Boeing Building #40-04, Seattle, WA	422%
Boeing Building #40-23, Seattle, WA	113%
Boeing Building #40-22, Seattle, WA	11%
Boeing Building, #87, Seattle, WA	27%
Boeing Building, #40-83, Seattle, WA	86%
Boeing Building, #88, Seattle, WA	33%
International Square, 1825 I St., Washington, D.C.	1%
International Square, 1850 K St., Washington, D.C.	6%
International Square, 1875 I St., Washington, D.C.	-21%