NEEA EVAPORATOR FAN INITIATIVE CASE STUDY
Blue Star Growers, Cashmere Washington

Summary

As an energy efficiency measure, a variable frequency drive (VFD) was installed to regulated refrigeration capacity in a 1420 bin controlled atmosphere (CA) room used for pear storage.

The impact of VFD operations during a storage season was monitored. The major test parameters are summarized in Table 1.

Table 1 - Major Test Parameters

Test Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 39	VFD Room Room 40	Improvement Room 39 - Room 40
Mass Loss (%)	0.00%	2.45%	2.18%	0.27%
Firmness (psig)	12.7	12.5	12.1	-0.4
% Energy Use	N/A	100.0%	42.6%	57.4%

Results from the major test parameters showed:

- Less mass loss in the VFD room
- Lower average fruit firmness in the VFD room.
- Substantial energy savings with the VFD versus the full speed constant operation control room.

Economics for a full-scale VFD retrofit project are estimated in Table 2. Installation costs are anticipated to be considerably lower for a full-scale retrofit compared to the field trial installation.

Table 2 - Economics for Full-Scale VFD Retrofit Project

Project Cost	Cost Savings per Year			Simple
VFD Retrofit (20 hp)	Energy	Mass	Total	Payback (years)
$2,900	$134	$869	$1,003	2.9

The economics were based on only 52 days of reduced speed operation with the VFD. The simple payback would improve as the storage duration increased.

Field Trial Description and Purpose

The VFD installation was performed through the "Evaporator Fan VFD Initiative" a market transformation program sponsored by the Northwest Energy Efficiency Alliance (NEEA) and operated by Cascade Energy Engineering to promote the use of VFDs in refrigerated warehouses.

The purpose of the VFD installation was to demonstrate the energy efficiency of the VFD technology and to determine the impact of reduced airflow operation on the commodity in storage. Pending a positive outcome of the field trail, the technology could then be safely and profitably installed on a full-scale basis.

Field Trial VFD Installation

A 20 hp VFD was installed to regulate fan speed on an evaporator coil providing refrigeration to a CA storage room. The evaporator coil was equipped with five 3 hp fan motors. An input line reactor and a dV/dT output filter were added to provide harmonic and motor protection.

VFD versus Control Room

Two identical rooms were selected for comparison. VFD speed control was employed in room 40. Fans ran at 50% speed after a fruit pull-down period of 32 days. In the control room (room 39), full speed, constant fan operation was employed with refrigerant back pressure regulation.

Fruit Selection/Sample Creation

Fruit from a single bin was used to create all test samples. Sample fruit were individually weighed and labeled. Weights were recorded to $1/100^{th}$ of a gram. 15 sample bags, each containing 8 fruit, were created for each test room. Mesh plastic bags with ~1/2 inch openings were used to minimize the impact on air or moisture flow. 25 fruit were sent to a test lab to establish initial fruit conditions.

Sample Placement

Samples were placed in identical locations as the rooms filled. Each sample bag was placed in the center of a bin covered by a layer of fruit. Samples were place in three cross-sections of the room. Five samples were placed in each cross-section as illustrated in Figure 1. The locations of the three cross-sections are illustrated in Figure 2.

Figure 1 - Sample Locations - Front View

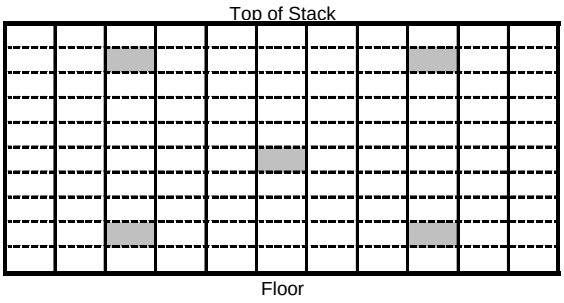
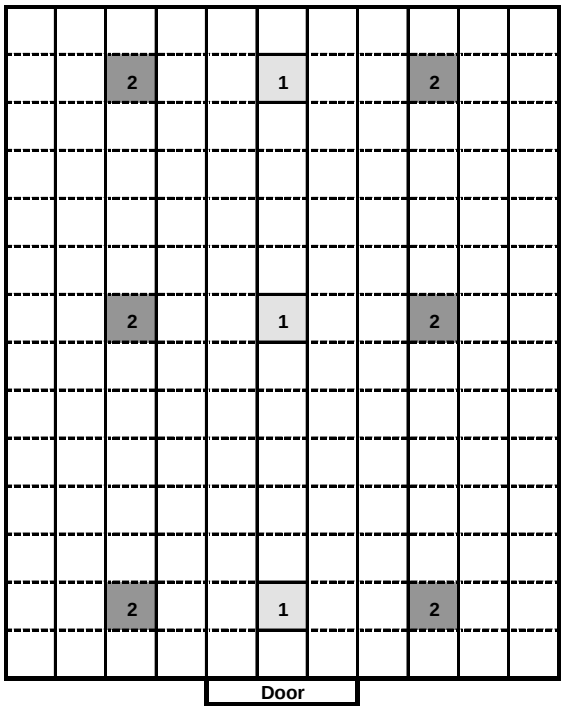


Figure 2 - Sample Location - Top View



CA Conditions and Room Loading and Unloading

The VFD and control rooms were maintained at similar temperature, O_2 and CO_2 conditions throughout the storage period. Both rooms experienced similar loading, holding and unloading schedules.

Table 3 - Room Loading and Unloading

Mode of Operation	VFD Room	Control Room	Difference	Storage Advantage
Loadings Days (Non-CA)	3	3	0	NONE
CA Holding Days	62	62	0	NONE
Unloading Days (Non-CA)	12	12	0	NONE
Total Storage Days	75	75	0	

Sample Retrieval

Test samples were retrieved from test bins as the bins were removed from storage. Individual fruit were reweighed. All samples were then delivered to a lab for further testing.

Mass Loss Results

Evaluation of the mass loss results showed a consistent improvement for samples stored in the VFD room.

Table 4 - Mass Loss Summary

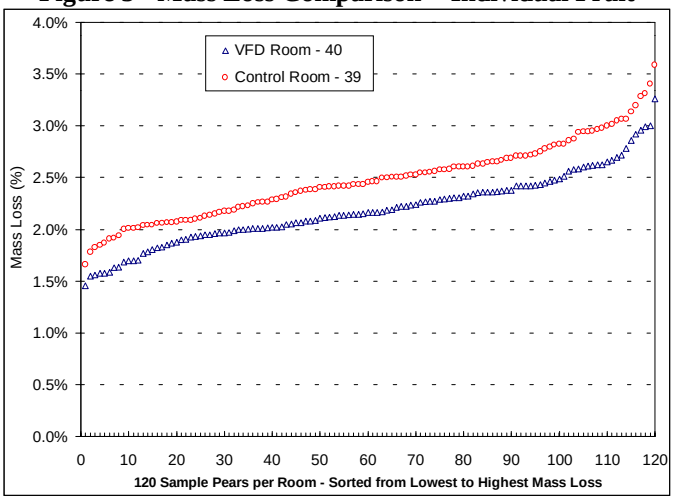
Sample Location	Mass Loss (%)		Improvement
	VFD Room	Control	
Evaporator End, Lower Left	2.36%	2.56%	0.21%
Evaporator End, Lower Right	2.03%	2.52%	0.49%
Evaporator End, Middle	2.39%	2.42%	0.03%
Evaporator End, Upper Left	2.40%	2.54%	0.14%
Evaporator End, Upper Right	2.34%	2.42%	0.08%
Mid-room, Lower Left	2.08%	2.21%	0.12%
Mid-room, Lower Right	2.15%	2.36%	0.21%
Mid-room, Middle	2.48%	2.90%	0.42%
Mid-room, Upper Left	1.83%	2.43%	0.60%
Mid-room, Upper Right	1.86%	2.60%	0.74%
Opposite Evaporator, Lower Left	2.24%	2.48%	0.24%
Opposite Evaporator, Lower Right	1.96%	2.55%	0.60%
Opposite Evaporator, Middle	2.36%	2.21%	-0.16%
Opposite Evaporator, Upper Left	1.89%	2.30%	0.41%
Opposite Evaporator, Upper Right	2.39%	2.39%	0.00%
Total	2.18%	2.45%	0.27%
Evaporator End (5 Samples)	2.31%	2.50%	0.19%
Mid-Room (5 Samples)	2.07%	2.49%	0.41%
Opposite Evaporator (5 Samples)	2.16%	2.38%	0.22%
Upper (6 Samples)	2.10%	2.44%	0.34%
Middle (3 Samples)	2.41%	2.49%	0.08%
Lower (6 Samples)	2.14%	2.44%	0.30%
Left (6 Samples)	2.13%	2.42%	0.29%
Middle (3 Samples)	2.41%	2.49%	0.08%
Right (6 Samples)	2.11%	2.47%	0.36%

The following results were found in the VFD room:

- An average mass loss improvement of 0.27%.
- 13 of 15 sample sets showed less mass loss.
- Average mass loss improvements in all cross-sections.

The following figure shows the mass loss improvement for the VFD room on an individual fruit basis.

Figure 3 - Mass Loss Comparison - Individual Fruit



Fruit Firmness Test Results

Results from firmness testing done at the conclusion of CA storage of the test rooms are presented in the following table.

Table 5 – Fruit Firmness Test Results

Sample ID Name	VFD Room - 40 Firmness (psig)	Control Room - 39 Firmness (psig)	Improvement Firmness (psig)
Evaporator End, Lower Left	12.1	12.2	-0.1
Evaporator End, Lower Right	12.2	12.3	-0.2
Evaporator End, Middle	11.7	12.5	-0.8
Evaporator End, Upper Left	12.7	12.2	0.6
Evaporator End, Upper Right	12.5	13.1	-0.7
Mid-room, Lower Left	11.7	13.2	-1.4
Mid-room, Lower Right	12.1	12.1	0.0
Mid-room, Middle	12.7	11.6	1.2
Mid-room, Upper Left	11.5	12.6	-1.1
Mid-room, Upper Right	11.3	13.0	-1.7
Opposite Evaporator, Lower Left	12.4	12.5	-0.2
Opposite Evaporator, Lower Right	11.5	12.7	-1.2
Opposite Evaporator, Middle	12.4	12.9	-0.5
Opposite Evaporator, Upper Left	11.5	13.0	-1.5
Opposite Evaporator, Upper Right	12.8	11.8	0.9
Total	12.1	12.5	-0.4
Evaporator End (5 Samples)	12.2	12.5	-0.2
Mid-Room (5 samples)	11.9	12.5	-0.6
Opposite Evaporator (5 Samples)	12.1	12.6	-0.5
Upper (6 Samples)	12.1	12.6	-0.6
Middle (3 Samples)	12.3	12.3	0.0
Lower (6 Samples)	12.0	12.5	-0.5
Left (6 Samples)	12.0	12.6	-0.6
Middle (3 Samples)	12.3	12.3	0.0
Right (6 Samples)	12.1	12.5	-0.5

- Fruit stored in the VFD room tested 0.4 psig lower in firmness on average than that stored in the control room.
- 11 of 15 sample sets tested lower for firmness in the VFD room.
- The VFD fruit test at equal or lower firmness on average for all cross-sections.

Energy Savings

Motor current and input power were monitored on the control and VFD room evaporator fans respectively. Energy savings were calculated based on the monitored data.

Figure 4 - VFD Room Input Power

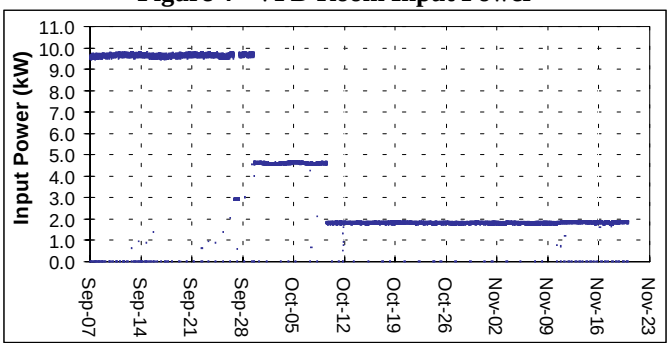


Figure 5 - Control Room Input Power

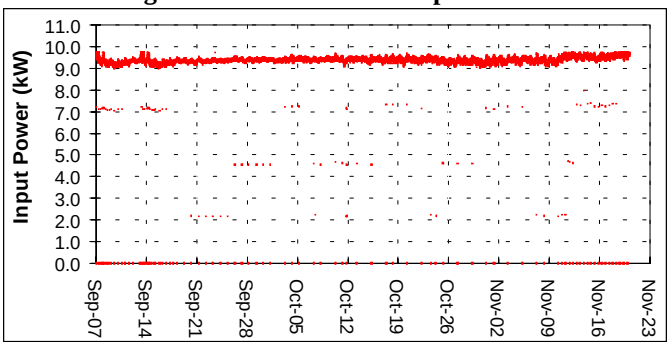
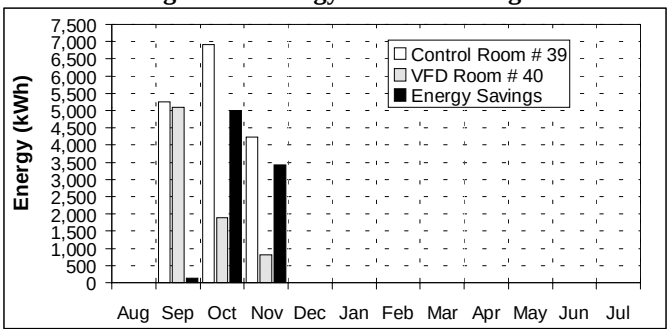


Figure 6 - Energy Use and Savings



- System energy savings of 57.4% were achieved with the VFD installation
- VFD input power decreased from ~9.7 kW at 100% speed to 4.6 kW at 75% speed and 1.8 kW at 50% speed.

Temperature Monitoring

In each test room, a temperature probe was placed at the wall opposite the evaporator near the floor.

Figure 7 - Control Room - Lower, Back Wall - Opp. Evap

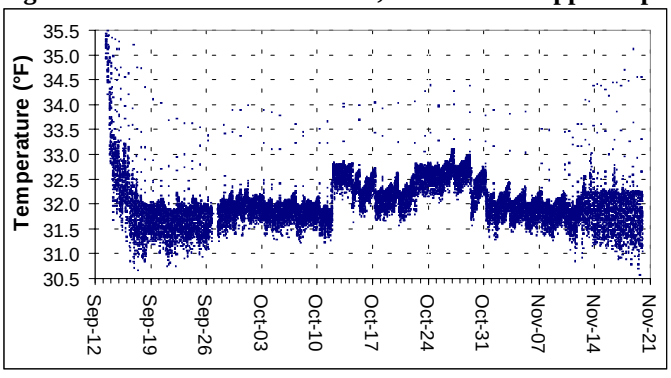
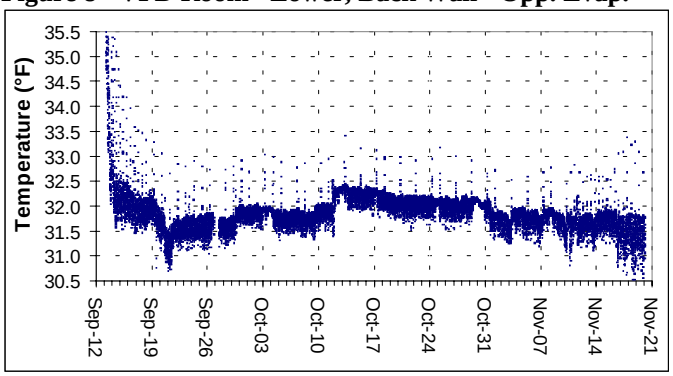


Figure 8 - VFD Room - Lower, Back Wall - Opp. Evap.



- Temperature monitoring revealed that reducing airflow with the VFD did not adversely temperature control.

Fruit Lab Test Results

The fruit samples were lab tested for the following characteristics.

Table 6 - Lab Test Results

Fruit Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 39	VFD Room Room 40	Difference Room 39 - Room 40
Soluble Solids	12.6	13.0	13.0	-0.1
Titratable Acid	0.343	0.319	0.299	0.020
Fruit Lightness*	65.9	60.1	63.7	-3.6
Color Hue**	109.5	105.7°	106.9°	-1.0°

*Fruit Lightness (Black = 0, White = 100)

**'Color Hue (Yellow = 90°, Green = 180°)

Relative to the control room, fruit in the VFD room was tested to be:

- Higher in soluble solids.
- Lower in titratable acid.
- Lighter in shade and greener in color.

Economic Calculations

The economic calculations are shown in the following table.

Table 7 - Annual Savings Calculations

Bins per Room	1420
lbs. per Bin	900
% Packout	80.0%
Total lbs	1,022,400
Mass Loss Savings	0.27%
Product Savings (lbs)	2,806
Product Savings (boxes)	67
Product Value ($/box)	$13
Product Value Saved	**$869**
Energy Savings (kWh)	10,502
*Effective Energy Cost ($/kWh)	$0.0128
Energy Savings	**$134**
Total Annual Savings	**$1,003**

*Includes Energy and Demand Savings

The VFD installation cost was based on a retrofit project. A new construction VFD installation project would cost ~ 2/3 that of a retrofit project. The simple payback on a similar sized new construction VFD installation would be ~ 1.9 years