NEEA EVAPORATOR FAN INITIATIVE CASE STUDY
Olympic Fruit - Moxee, Washington

Summary

As an energy efficiency measure, a variable frequency drive (VFD) was installed to allow reduced fan speed operation in an 1825 bin controlled atmosphere (CA) room used for storage of red delicious apples.

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 16	VFD Room Room 6	Improvement Room 6 - Room 16
Mass Loss (%)	0.00%	1.95%	1.66%	0.29%
Firmness (psig)	15.5	14.9	14.8	-0.1
% Energy Use	N/A	100.0%	75.5%	24.5%

Results from the major test parameters showed:

- Less mass loss in the VFD room
- A slight decrease in average fruit pressure in the VFD room.
- Moderate energy savings with the VFD versus the fan-cycling 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 Economics for Full-Scale Retrofit Project				
Project Cost	Cost Savings per Year			Simple
VFD Retrofit (15 hp)	Energy	Mass	Total	Payback (years)
$2,600	$173	$1,097	$1,270	2.0

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 15 hp VFD was installed to regulate fan speed on a single evaporator coil providing refrigeration to a CA storage room. The evaporator coil was equipped with four 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 6. Fans ran at 50% speed after fruit pull-down. In the control room (room 16), fan cycling was employed. Over the holding season, the control room averaged a 43% fan duty cycle.

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.

All 30 samples were created during a single day. Samples were stored in a covered bin under refrigeration until placed in the proper test location. 30 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

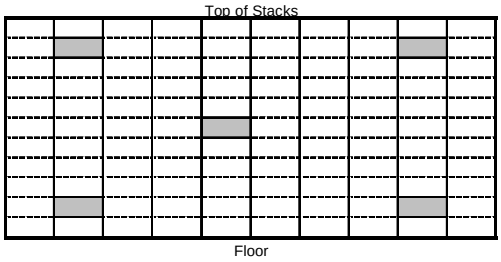
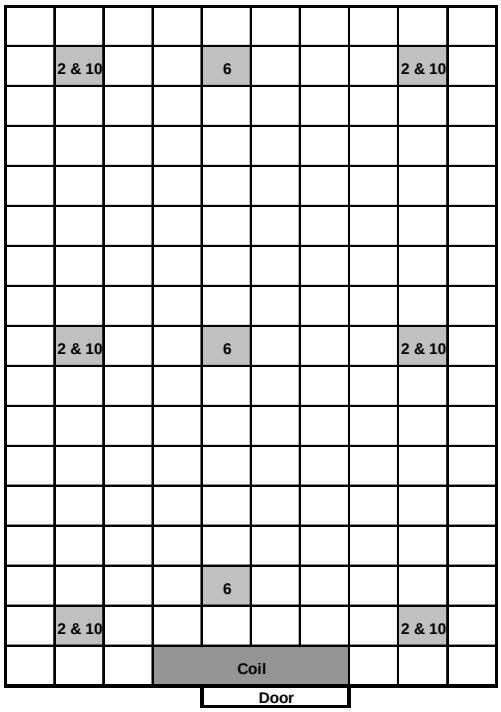


Figure 2 - Sample Location - Top View


2 & 10
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2 & 10
2 & 10
Coil
Door

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.

Table 3 - Room Loading and Unloading

Mode of Operation	VFD Room	Control Room	Difference	Storage Advantage
Loadings Days (Non-CA)	11	5	6	Control
CA Holding Days	206	228	-22	VFD
Unloading Days (Non-CA)	6	3	3	Control
Total Storage Days	221	234	-13	

- The VFD room fruit was stored for 13 fewer days than the control fruit.
- The VFD room fruit experienced 9 additional days of non-CA conditions during the test.
- The differences in the overall room loading and unloading probably favored the control room towards less mass loss.

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.

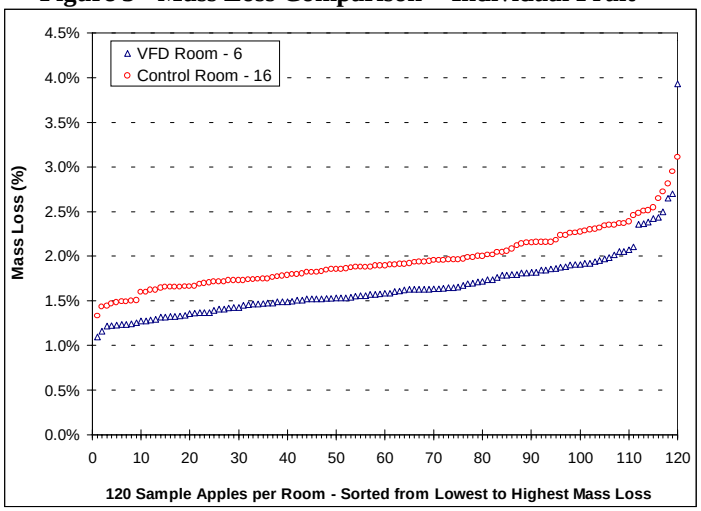
Table 4 - Mass Loss Summary

Sample Location	Mass Loss (%)		Improvement
	VFD Room	Control	
Evaporator End, Lower Left	1.85%	2.54%	0.69%
Evaporator End, Lower Right	1.47%	2.20%	0.73%
Evaporator End, Middle	1.43%	1.76%	0.32%
Evaporator End, Upper Left	1.97%	1.83%	-0.14%
Evaporator End, Upper Right	1.48%	2.03%	0.56%
Mid-room, Lower Left	1.72%	2.06%	0.34%
Mid-room, Lower Right	1.64%	1.97%	0.33%
Mid-room, Middle	1.81%	1.74%	-0.07%
Mid-room, Upper Left	1.36%	1.81%	0.45%
Mid-room, Upper Right	1.43%	1.94%	0.51%
Opposite Evaporator, Lower Left	1.91%	1.79%	-0.12%
Opposite Evaporator, Lower Right	1.79%	2.00%	0.21%
Opposite Evaporator, Middle	1.66%	1.94%	0.27%
Opposite Evaporator, Upper Left	1.85%	1.78%	-0.07%
Opposite Evaporator, Upper Right	1.51%	1.93%	0.42%
Total	**1.66%**	**1.95%**	**0.29%**
Evaporator End (5 Samples)	1.64%	2.07%	0.44%
Mid-Room (5 Samples)	1.59%	1.91%	0.32%
Opposite Evaporator (5 Samples)	1.75%	1.89%	0.14%
Upper (6 Samples)	1.60%	1.89%	0.28%
Middle (3 Samples)	1.63%	1.82%	0.19%
Lower (6 Samples)	1.74%	2.09%	0.36%
Left (6 Samples)	1.78%	1.97%	0.19%
Middle (3 Samples)	1.63%	1.82%	0.19%
Right (6 Samples)	1.56%	2.01%	0.45%

- An average mass loss of 0.29% was recorded.
- 11 of 15 sample sets showed less mass loss in the VFD room.
- The VFD room showed consistent mass loss improvements from the front to the back, top to bottom, and side to side.

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

Table 5 – Fruit Firmness Test Results

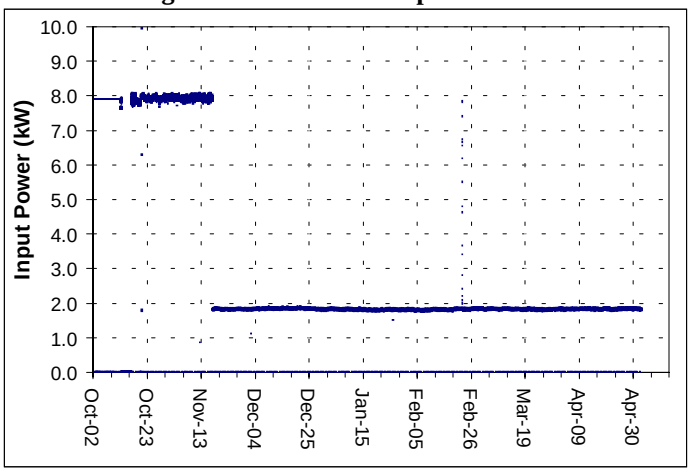
Sample ID Name	VFD Room Pressure (psig)	Control Room Pressure (psig)	Improvement Pressure (psig)
Evaporator End, Lower Left	14.9	14.7	0.2
Evaporator End, Lower Right	15.1	14.8	0.3
Evaporator End, Middle	14.5	15.1	-0.6
Evaporator End, Upper Left	15.4	14.8	0.6
Evaporator End, Upper Right	14.7	15.0	-0.3
Mid-room, Lower Left	15.0	14.7	0.3
Mid-room, Lower Right	14.5	14.8	-0.3
Mid-room, Middle	14.7	15.0	-0.3
Mid-room, Upper Left	14.3	14.6	-0.3
Mid-room, Upper Right	14.9	14.7	0.2
Opposite Evaporator, Lower Left	14.9	15.3	-0.4
Opposite Evaporator, Lower Right	15.1	15.0	0.0
Opposite Evaporator, Middle	14.8	15.3	-0.5
Opposite Evaporator, Upper Left	14.6	15.1	-0.5
Opposite Evaporator, Upper Right	15.2	15.0	0.2
Total	**14.8**	**14.9**	**-0.1**
Evaporator End (5 Samples)	14.9	14.9	0.0
Mid-Room (5 samples)	14.7	14.8	-0.1
Opposite Evaporator (5 Samples)	14.9	15.1	-0.2
Upper (6 Samples)	14.8	14.9	0.0
Middle (3 Samples)	14.7	15.1	-0.5
Lower (6 Samples)	14.9	14.9	0.0
Left (6 Samples)	14.9	14.9	0.0
Middle (3 Samples)	14.7	15.1	-0.5
Right (6 Samples)	14.9	14.9	0.0

- Product stored in the VFD room pressure tested 0.1 psig less on average than that stored in the control room.
- Only 6 of 15 sample sets showed higher pressure in the VFD room.
- The middle samples showed slightly lower pressures in the VFD rooms.

Energy Savings

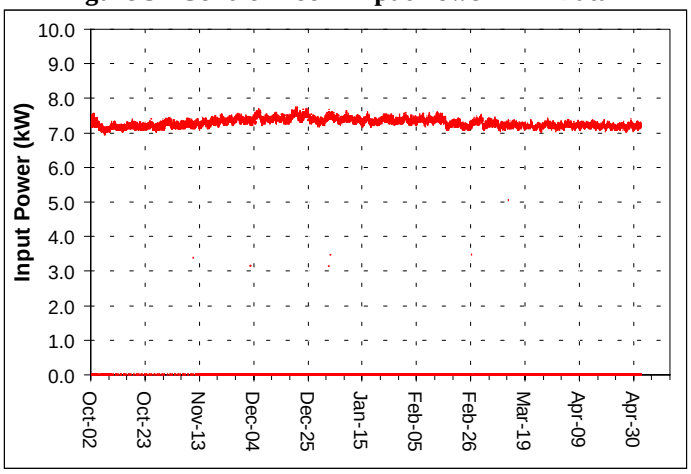
Motor current and input power were monitored on the control and VFD room evaporator fans respectively. Energy savings were calculated based on the monitored data.

Figure 4 - VFD Room Input Power



- VFD input power dropped from ~ 7.9 kW at 100% speed to 1.8 kW at 50% speed (a 77% reduction in power).

Figure 5 - Control Room Input Power - All Data



The fan cycling pattern is not evident in the Figure 5 as the resolution of the figure is not great enough to show the cycling. The following figure shows the fan cycling pattern over a two day period.

Figure 6 - Control Room Input Power-Typical Fan Cycling

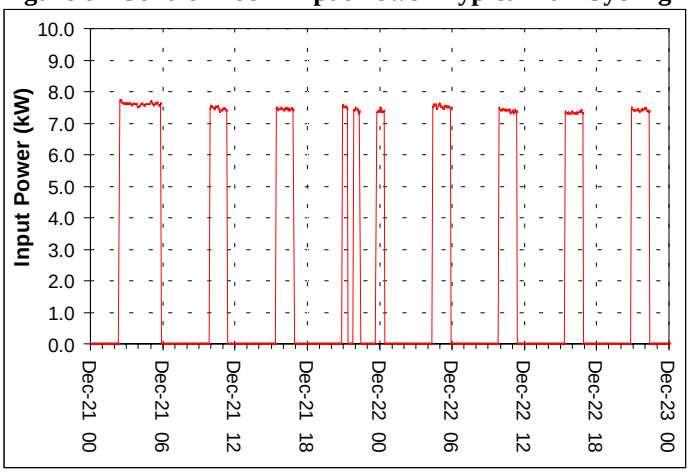
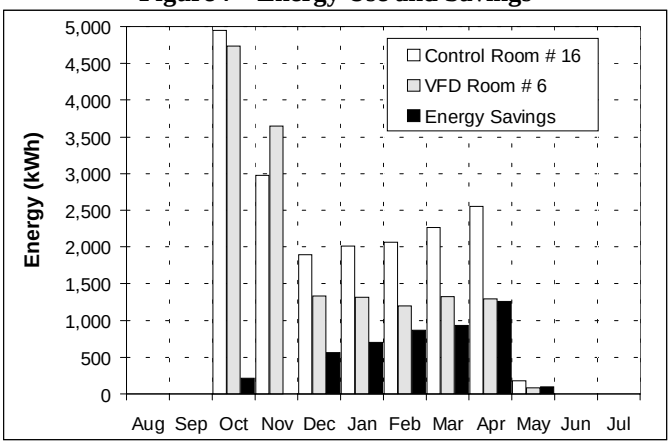


Figure 7 - Energy Use and Savings



Fans were cycled off less as ambient temperature increased during the year. As a result, the energy use of the control room was the lowest in December and the highest in April.

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 16	VFD Room Room 6	Difference Room 16 - Room 6
Soluable Solids	10.4	12.4	12.6	-0.2
Triatable Acid	0.228	0.215	0.201	0.013
Fruit Lightness	NA	41.0	42.4	-1.4
Color Hue**	NA	10.0°	10.7°	-0.7°

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

**'Color Hue (Red = 0°, Green = 90°)

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

- Higher in soluble solids.
- Lower in titratable acid.
- Lighter in shade.
- Less red in color.

Economic Calculations

The following values were used in the calculations.

Table 7 - Annual Savings Calculations

Bins per Room	1825
lbs. per Bin	900
% Packout	80.0%
Total lbs	1,314,000
Mass Loss Savings	0.29%
Product Savings (lbs)	3,840
Product Savings (boxes)	91
Product Value ($/box)	$12
Product Value Saved	**$1,097**
Energy Savings (kWh)	4,857
*Effective Energy Cost ($/kWh)	$0.0355
Energy Savings	**$173**
Total Annual Savings	**$1,270**

*Includes Energy and Demand Savings

The VFD installation cost was based on a retrofit. A new construction VFD installation would cost ~ 2/3 that of a retrofit. The simple payback on a similar sized new construction VFD installation would be ~ 1.3 years.