NEEA EVAPORATOR FAN INITIATIVE CASE STUDY
McDougall & Sons Fruit - East Wenatchee, Washington

Summary

As an energy efficiency measure, a variable frequency drive (VFD) was installed to allow reduced fan speed operation in a 1816 bin controlled atmosphere (CA) room used for storage of golden 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 24	VFD Room Room 25	Improvement Room 24 - Room 25
Mass Loss (%)	0.00%	3.88%	3.53%	0.35%
Firmness (psig)	14.9	12.7	12.6	-0.1
% Energy Use	N/A	100.0%	46.3%	53.7%

Results from the major test parameters showed:

- Less mass loss in the VFD room
- A decrease in average fruit firmness in the VFD room.
- Substantial energy savings with the VFD versus on demand fan cycling in the 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 VFD Retrofit (15 hp)	Cost Savings per Year			Simple Payback (years)
	Energy	Mass	Total	
$2,600	$210	$1,312	$1,523	1.7

Mass savings were conservatively based on the difference between the VFD room and the control room. The VFD room fruit was stored for 34 days longer the control room fruit. If the control room fruit been stored as long as the VFD room fruit, the mass loss savings would have been larger.

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 two evaporator coils providing refrigeration to a CA storage room. The two evaporator coils were each equipped with two 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 25. Fans ran at 50% speed after fruit pull-down. In the control room (room 24), fan cycling was employed. Over the holding season, the control room averaged a 31% 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. 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

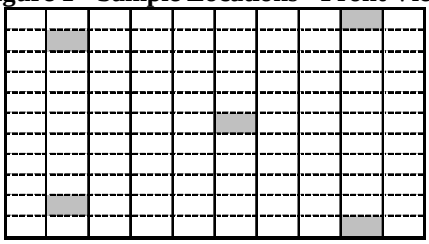
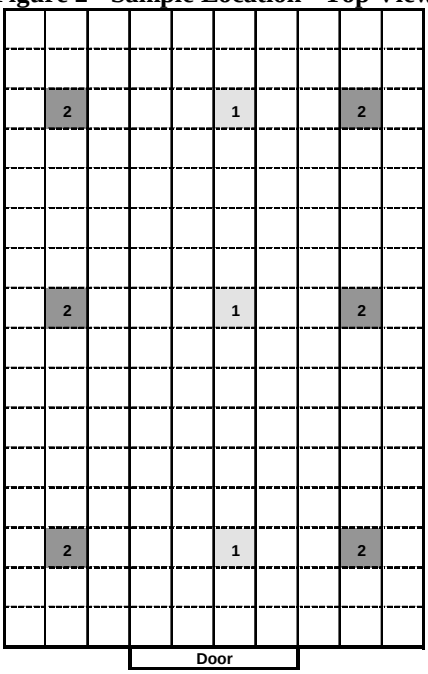


Figure 2 - Sample Location - Top View



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)	9	10	-1	VFD
CA Holding Days	252	217	35	Control
Unloading Days (Non-CA)	11	11	0	NONE
Total Storage Days	270	236	34	

- The VFD room fruit was stored for 34 more days than the control fruit.
- The VFD room fruit experienced 1 less day of non-CA conditions during the room loading period of the test.
- The differences in the loading and unloading schedules favored the control room. The mass loss improvement realized in the VFD room would have been greater had control room fruit been stored as long as the VFD room fruit.

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.

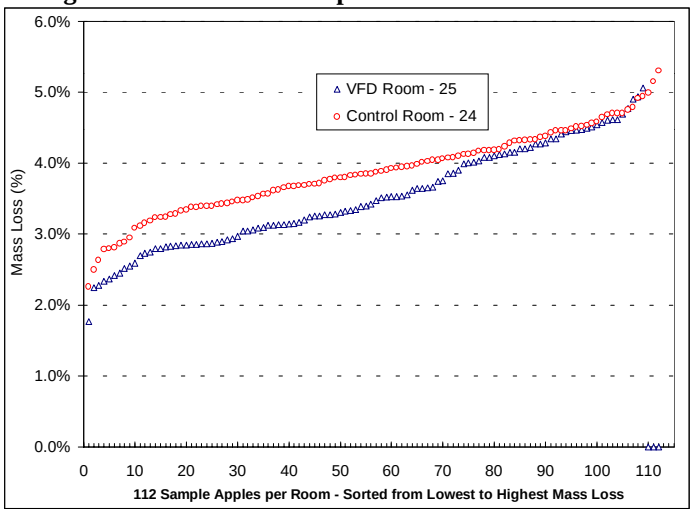
Table 4 - Mass Loss Summary

Sample Location	Mass Loss (%)		Improvement
	VFD Room	Control	
Evaporator End, Lower Left	3.85%	4.00%	0.15%
Evaporator End, Lower Right	3.49%	4.40%	0.91%
Evaporator End, Middle	4.46%	3.82%	-0.64%
Evaporator End, Upper Left	3.01%	3.72%	0.71%
Evaporator End, Upper Right	2.81%	4.23%	1.41%
Mid-room, Lower Left	3.90%	3.81%	-0.08%
Mid-room, Lower Right	3.74%	3.74%	0.00%
Mid-room, Middle	4.33%	3.55%	-0.77%
Mid-room, Upper Left	2.89%	3.72%	0.83%
Mid-room, Upper Right	2.90%	4.03%	1.13%
Opposite Evaporator, Lower Left	3.38%	3.84%	0.46%
Opposite Evaporator, Lower Right	3.44%	4.19%	0.76%
Opposite Evaporator, Middle	3.93%	3.70%	-0.23%
Opposite Evaporator, Upper Left	2.97%	3.71%	0.74%
Opposite Evaporator, Upper Right	3.42%	3.67%	0.25%
Total	3.53%	3.88%	0.35%
Evaporator End (5 Samples)	3.59%	4.04%	0.45%
Mid-Room (5 Samples)	3.58%	3.78%	0.21%
Opposite Evaporator (5 Samples)	3.43%	3.83%	0.40%
Upper (6 Samples)	2.99%	3.84%	0.86%
Middle (3 Samples)	4.23%	3.70%	-0.53%
Lower (6 Samples)	3.63%	4.00%	0.36%
Left (6 Samples)	3.34%	3.79%	0.45%
Middle (3 Samples)	4.23%	3.70%	-0.53%
Right (6 Samples)	3.34%	4.04%	0.70%

- An average mass loss of 0.35% was recorded.
- 10 of 15 sample sets showed less mass loss in the VFD room.
- The VFD room showed mass loss improvements in all cross-sections with exception of the middle cross-section.

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 - 25 Firmness (psig)	Control Room - 24 Firmness (psig)	Improvement Firmness (psig)
Evaporator End, Lower Left	13.1	12.5	0.6
Evaporator End, Lower Right	12.8	12.8	0.0
Evaporator End, Middle	13.1	13.4	-0.3
Evaporator End, Upper Left	12.3	12.2	0.0
Evaporator End, Upper Right	11.0	13.3	-2.3
Mid-room, Lower Left	13.2	12.9	0.3
Mid-room, Lower Right	12.0	12.6	-0.6
Mid-room, Middle	12.2	12.9	-0.6
Mid-room, Upper Left	12.4	12.2	0.3
Mid-room, Upper Right	13.0	12.9	0.2
Opposite Evaporator, Lower Left	12.6	12.5	0.0
Opposite Evaporator, Lower Right	13.0	12.3	0.8
Opposite Evaporator, Middle	12.6	12.5	0.1
Opposite Evaporator, Upper Left	13.0	13.1	-0.1
Opposite Evaporator, Upper Right	13.0	12.5	0.5
Total	12.6	12.7	-0.1
Evaporator End (5 Samples)	12.4	12.8	-0.4
Mid-Room (5 samples)	12.6	12.7	-0.1
Opposite Evaporator (5 Samples)	12.8	12.6	0.3
Upper (6 Samples)	12.5	12.7	-0.2
Middle (3 Samples)	12.6	12.9	-0.3
Lower (6 Samples)	12.8	12.6	0.2
Left (6 Samples)	12.8	12.6	0.2
Middle (3 Samples)	12.6	12.9	-0.3
Right (6 Samples)	12.5	12.7	-0.2

- Fruit stored in the VFD room tested 0.1 psig lower in firmness on average than that stored in the control room.
- 7 of 15 sample sets tested higher for firmness in the VFD room.

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

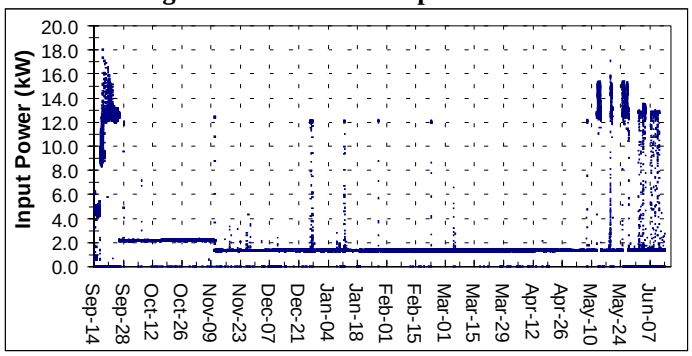
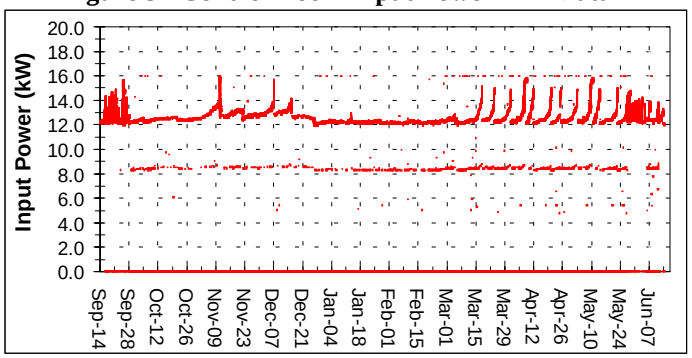


Figure 5 - Control Room Input Power - All Data



The fan cycling pattern is not evident in Figure 5. Figure 6 shows the fan cycling pattern over a two-day period.

Figure 6 - Control Room - Fan Cycling

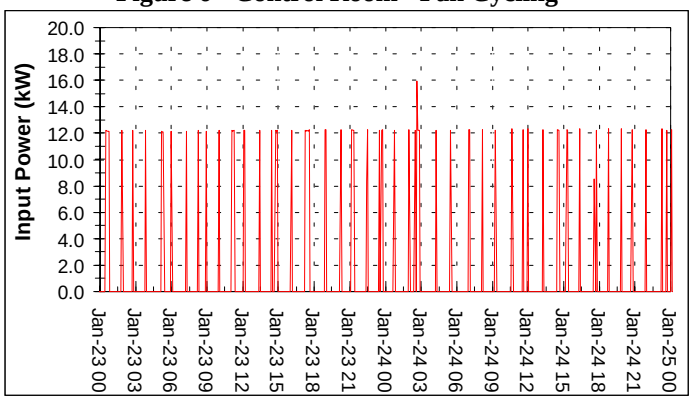
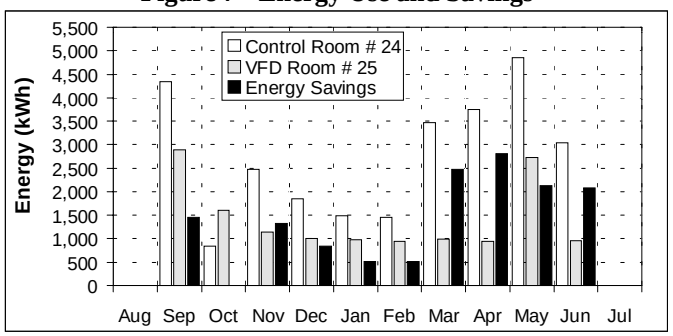


Figure 7 - Energy Use and Savings



The VFD installation resulted in system energy savings of 53.7%.

Gas Concentration Testing

The gas concentration monitoring revealed that reducing air flow with the VFD did not adversely impact gas concentration.

In each test room, concentrations of CO_2 and O_2 were monitored near the evaporator (high air movement location) and in a bin in the back lower portion of the room (low air movement location). The gas concentrations were nearly identical in the high and low air flow locations in the VFD room. Gas concentrations are shown in the following figures.

Figure 8 - CO_2 Concentrations in VFD Room - 50% Speed

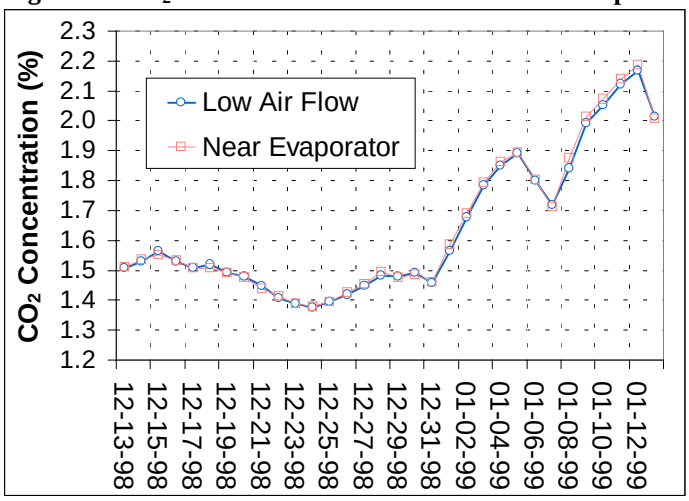
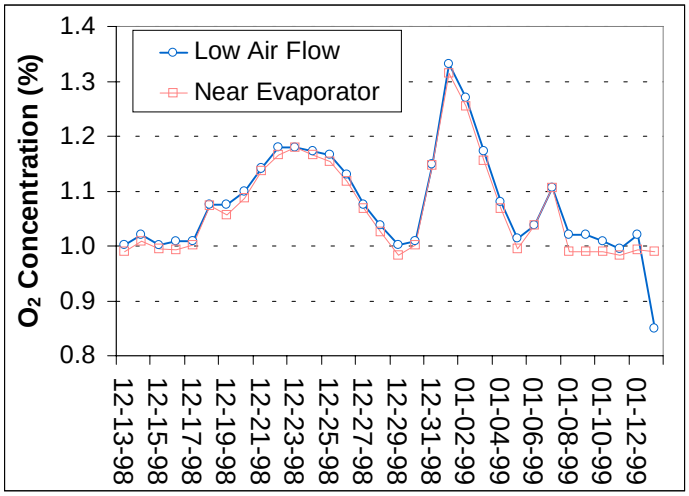


Figure 9 - O_2 Concentrations in VFD Room - 50% Speed



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 24	VFD Room Room 25	Difference Room 24 - Room 25
Soluable Solids	11.9	12.8	13.0	-0.2
Triatable Acid	0.398	0.431	0.389	0.042
Fruit Lightness	71.7	68.9	72.9	-3.9
Color Hue**	103.6	98.7°	99.7°	-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 and greener in color.

Economic Calculations

The economic calculations are shown in the following table.

Table 7 - Annual Savings Calculations

Bins per Room	1816
lbs. per Bin	900
% Packout	80.0%
Total lbs	1,307,520
Mass Loss Savings	0.35%
Product Savings (lbs)	4,594
Product Savings (boxes)	109
Product Value ($/box)	$12
Product Value Saved	**$1,312**
Energy Savings (kWh)	16,424
*Effective Energy Cost ($/kWh)	$0.0128
Energy Savings	**$210**
Total Annual Savings	**$1,523**

*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 ~ 1.1 years.