NEEA EVAPORATOR FAN INITIATIVE CASE STUDY
CM Holtzinger Fruit - Yakima, Washington

Summary

As an energy efficiency measure, a variable frequency drive (VFD) was installed to allow reduced fan speed operation in a 2150 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 Results - Primary Test Parameters				
		Conditions at the End of CA Holding		
Test Characteristic	Initial Conditions	Control Room Room 5	VFD Room Room 7	Improvement Room 7 - Room 5
Mass Loss (%)	0.00%	4.14%	3.56%	0.58%
Firmness (psig)	15.4	14.5	13.8	-0.7
% Energy Use	N/A	100.0%	59.2%	40.8%

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 the alternating fan 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	$761	$1,277	$2,038	1.3

Mass savings were based on only 50% of the recorded improvement of 0.58%. The mass loss improvement was reduced to 0.29% to adjust for the VFD fruit being stored for fewer days than the control room fruit.

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 7. Fans ran at 50% speed after fruit pull-down. In the control room (room 5), alternating fan control was employed after fruit pull-down. In the alternating fan control, 2 fans (one on each coil) were operated at full speed while other two fans were shut off. Based on a 50% duty cycle, the control system would start the two fans that had been off while shutting off the two that had been operating.

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 three hour period. 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

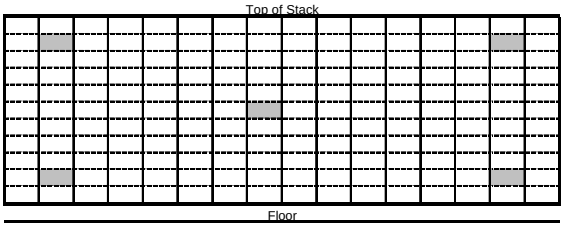
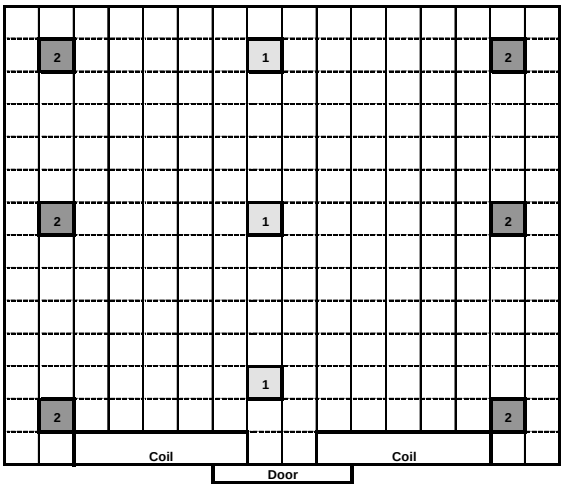


Figure 2 - Sample Location - Top View



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

Room Loading and Unloading Information				
Mode of Operation	VFD Room	Control Room	Difference	Storage Advantage
Loadings Days (Non-CA)	12	5	7	Control
CA Holding Days	183	235	-52	VFD
Unloading Days (Non-CA)	11	11	0	NONE
Total Storage Days	204	249	-45	

- The VFD room fruit was stored for 45 less days than the control fruit.
- The VFD room fruit experienced 7 more day of non-CA conditions during the room loading period of the test.
- The differences in the loading and unloading schedules would be somewhat offsetting.

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.

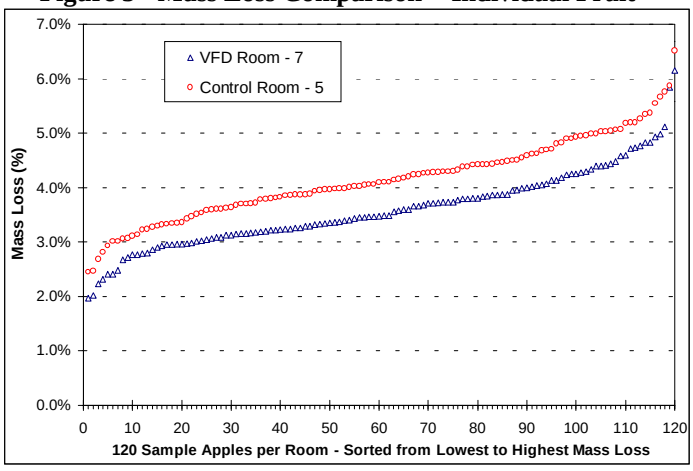
Table 4 - Mass Loss Summary

Sample Location	Mass Loss (%)		
	VFD Room	Control	Improvement
Evaporator End, Lower Left	3.50%	4.77%	1.27%
Evaporator End, Lower Right	4.67%	4.25%	-0.42%
Evaporator End, Middle	3.98%	4.43%	0.45%
Evaporator End, Upper Left	3.41%	4.60%	1.19%
Evaporator End, Upper Right	3.91%	3.43%	-0.48%
Mid-room, Lower Left	3.43%	4.04%	0.61%
Mid-room, Lower Right	3.71%	3.64%	-0.07%
Mid-room, Middle	3.86%	3.96%	0.09%
Mid-room, Upper Left	3.06%	4.37%	1.31%
Mid-room, Upper Right	2.90%	4.03%	1.13%
Opposite Evaporator, Lower Left	3.54%	4.48%	0.94%
Opposite Evaporator, Lower Right	3.32%	4.64%	1.32%
Opposite Evaporator, Middle	3.01%	3.39%	0.38%
Opposite Evaporator, Upper Left	3.71%	4.13%	0.42%
Opposite Evaporator, Upper Right	3.44%	4.06%	0.61%
Total	**3.56%**	**4.14%**	**0.58%**
Evaporator End (5 Samples)	3.88%	4.28%	0.41%
Mid-Room (5 Samples)	3.40%	4.00%	0.60%
Opposite Evaporator (5 Samples)	3.40%	4.13%	0.73%
Upper (6 Samples)	3.40%	4.09%	0.69%
Middle (3 Samples)	3.62%	3.92%	0.29%
Lower (6 Samples)	3.69%	4.30%	0.62%
Left (6 Samples)	3.44%	4.41%	0.97%
Middle (3 Samples)	3.62%	3.92%	0.29%
Right (6 Samples)	3.65%	3.99%	0.34%

- An average mass loss of 0.58% was recorded.
- 12 of 15 sample sets showed less mass loss in the VFD room.
- The VFD room showed mass loss improvements in all cross-sections; front to 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 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 - 7 Firmness (psig)	Control Room - 5 Firmness (psig)	Improvement Firmness (psig)
Evaporator End, Lower Left	13.2	12.8	0.4
Evaporator End, Lower Right	12.8	12.5	0.3
Evaporator End, Middle	12.6	12.6	0.1
Evaporator End, Upper Left	13.1	12.8	0.3
Evaporator End, Upper Right	13.2	12.5	0.7
Mid-room, Lower Left	13.8	13.0	0.7
Mid-room, Lower Right	13.1	12.7	0.4
Mid-room, Middle	13.3	12.4	0.9
Mid-room, Upper Left	13.7	12.6	1.1
Mid-room, Upper Right	13.2	13.2	-0.1
Opposite Evaporator, Lower Left	13.6	12.2	1.4
Opposite Evaporator, Lower Right	12.9	13.4	-0.5
Opposite Evaporator, Middle	13.6	12.2	1.5
Opposite Evaporator, Upper Left	13.1	13.3	-0.2
Opposite Evaporator, Upper Right	13.4	14.1	-0.6
Total	**13.2**	**12.8**	**0.4**
Evaporator End (5 Samples)	13.0	12.6	0.4
Mid-Room (5 samples)	13.4	12.8	0.6
Opposite Evaporator (5 Samples)	13.3	13.0	0.3
Upper (6 Samples)	13.3	13.1	0.2
Middle (3 Samples)	13.2	12.4	0.8
Lower (6 Samples)	13.2	12.8	0.5
Left (6 Samples)	13.4	12.8	0.6
Middle (3 Samples)	13.2	12.4	0.8
Right (6 Samples)	13.1	13.1	0.0

- Fruit stored in the VFD room tested 0.4 psig higher in firmness on average than that stored in the control room.
- 11 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

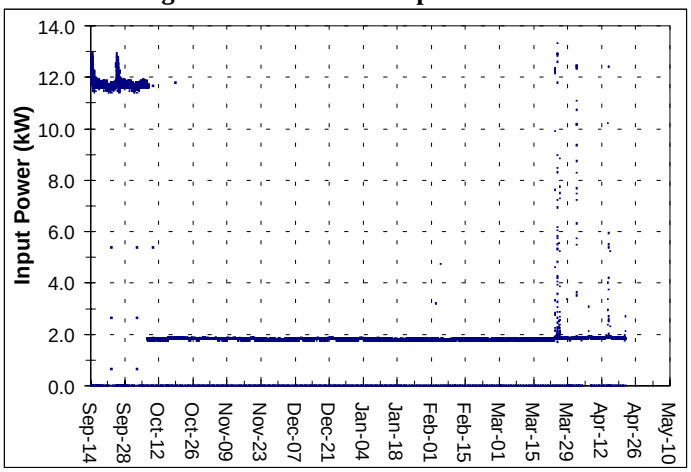


Figure 5 - Control Room Input Power

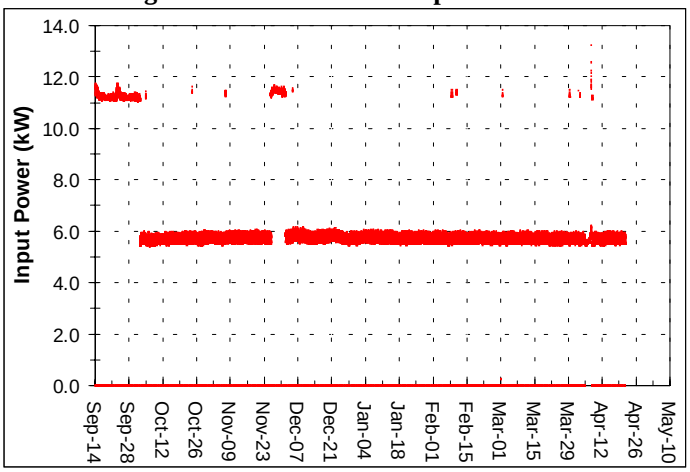
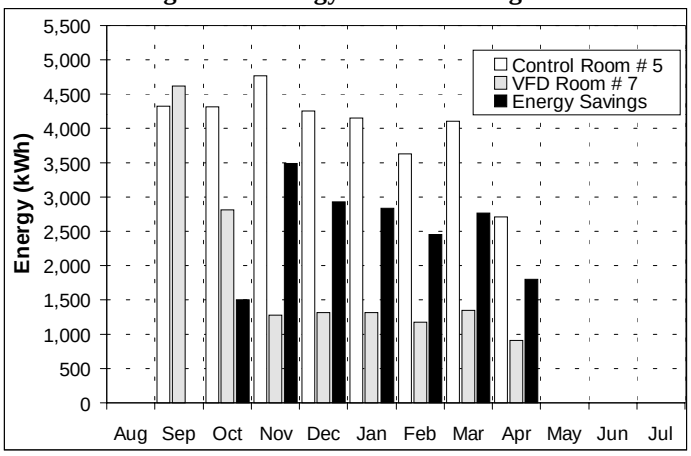


Figure 6 - Energy Use and Savings



- System energy savings of 40.8% were achieved with the VFD.
- VFD input power dropped from ~11.8 kW at 100% speed to 1.8 kW at 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 5	VFD Room Room 7	Difference Room 5 - Room 7
Soluable Solids	13.1	14.1	13.9	0.2
Titratable Acids	0.575	0.421	0.390	0.032

- The fruit in the VFD room had lower levels of soluble solids.
- The fruit in the VFD room had lower levels of titratable acid.

Economic Calculations

The economic calculations are shown in the following table.

Table 7 - Annual Savings Calculations

Bins per Room	2150
lbs. per Bin	900
% Packout	80.0%
Total lbs	1,548,000
Mass Loss Savings	0.29%
Product Savings (lbs)	4,468
Product Savings (boxes)	106
Product Value ($/box)	$12
Product Value Saved	**$1,277**
Energy Savings (kWh)	21,422
*Effective Energy Cost ($/kWh)	$0.0355
Energy Savings	**$761**
Total Annual Savings	**$2,038**

*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 ~ 0.9 years.