

NEEA EVAPORATOR FAN INITIATIVE CASE STUDY

Blue Bird - Peshastin, Washington

Summary

As an energy efficiency measure, a variable frequency drive (VFD) was installed to allow reduced fan speed operation in a controlled atmosphere (CA) room used for storage of boxed D'Anjou pears.

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 113	VFD Room Room 112	Improvement Room 113 - Room 112
Mass Loss (%)	0.00%	2.67%	4.00%	-1.33%
Firmness (psig)	13.3	12.8	13.1	0.3
% Energy Use	N/A	100.0%	33.6%	66.4%

Results from the major test parameters showed:

- Significant more mass loss in the VFD room
- An increase in average fruit firmness in the VFD room.
- Substantial energy savings with the VFD versus 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 VFD Retrofit (15 hp)	Cost Savings per Year			Simple Payback (years)
	Energy	Mass	Total	
\$2,600	\$306	-\$3,652	-\$3,346	N/A

Based on the results from this test, the VFD installation would never pay for itself, as the annual cost savings were negative.

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 an evaporator coil providing refrigeration to a CA storage room. The evaporator coil was equipped with two 5 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 112. Fans ran at 100%

for 18 days after the room was sealed. Fan speed was reduced to 75% for the next 7 days. The VFD then operated at 50% speed until the room was unloaded. In the control room (room 113), full speed, constant fan operation was employed during the entire storage period.

Fruit Selection/Sample Creation

16 boxes of US 90 sized pears were taken off one of the packing lines. The top layer of 22 fruit from each box was individually labeled and weighed. The sample fruit was then repacked into its original box. The sample boxes were then labeled. 32 fruit (two from each box) were sent to a test lab to establish initial fruit conditions.

Sample Placement

Samples were placed in identical locations as the rooms filled. In each test room, two sample boxes were inserted into 4 pallets (48 boxes per pallet). One box was placed with three exposed sides; the other was placed with only one end exposed (See Figure 3). Sample pallets were placed in two cross-sections of the room. Two sample pallets were placed in each cross-section as illustrated in Figure 2. The locations of the two sample cross-sections are illustrated in Figure 1.

Figure 1 - Sample Pallet Locations - Top View

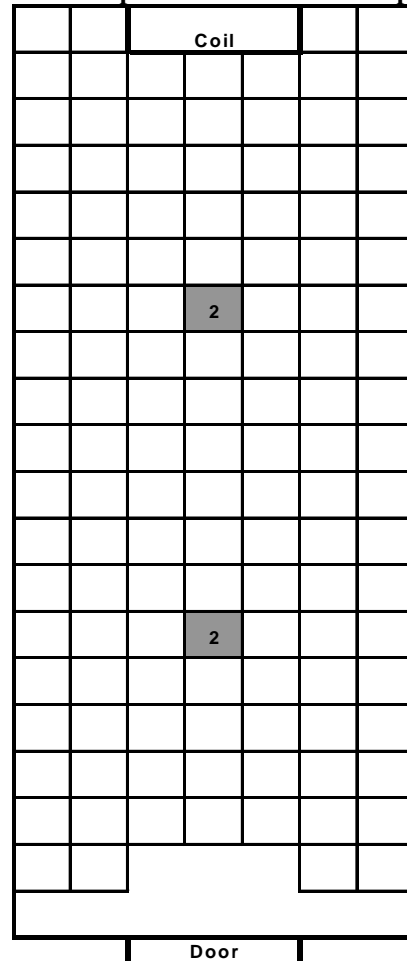


Figure 2 - Sample Pallet Locations - Side View

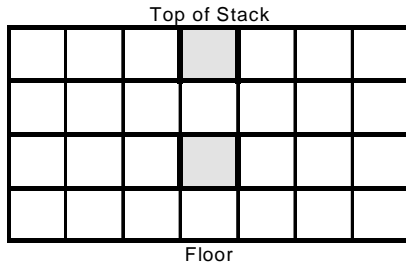
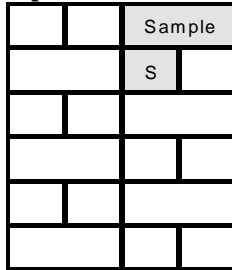


Figure 3 - Sample Boxes on Pallet - Side View



CA Conditions and Room Loading and Unloading

The VFD and control rooms were maintained at similar temperature, O₂ and CO₂ 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)	4	2	2	Control
CA Holding Days	191	200	-9	VFD
Unloading Days (Non-CA)	12	5	7	Control
Total Storage Days	205	205	0	

- The fruit in the VFD room experienced 7 additional days of non-CA storage conditions. This difference puts the VFD fruit at a disadvantage, as product mass loss rates are higher during non-CA storage than CA storage.

Sample Retrieval

Samples boxes were retrieved as the test pallets 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 significantly more mass loss in samples stored in the VFD room.

Table 4 - Mass Loss Summary

Sample Location	Mass Loss (%)		Improvement
	VFD Room	Control	
Evap. End, Upper, 1 Exposure	3.38%	0.68%	-2.69%
Evap. End, Upper, 3 Exposures	3.94%	2.72%	-1.22%
Evap. End, Lower, 1 Exposure	1.92%	2.35%	0.43%
Evap. End, Lower, 3 Exposures	2.60%	3.43%	0.83%
Oppo. Evap., Upper, 1 Exposure	2.34%	1.54%	-0.79%
Oppo. Evap., Upper, 3 Exposures	5.37%	2.82%	-2.55%
Oppo. Evap., Lower, 1 Exposure	5.94%	4.10%	-1.84%
Oppo. Evap., Lower, 3 Exposures	6.35%	3.75%	-2.60%
Total	4.00%	2.67%	-1.33%
Evaporator End (4 Samples)	2.96%	2.29%	-0.67%
Opposite Evaporator (4 Samples)	5.02%	3.04%	-1.98%
Upper (4 Samples)	3.76%	1.94%	-1.82%
Lower (4 Samples)	4.24%	3.41%	-0.83%
1 Exposure (4 Samples)	3.41%	2.16%	-1.25%
3 Exposures (4 Samples)	4.58%	3.18%	-1.40%

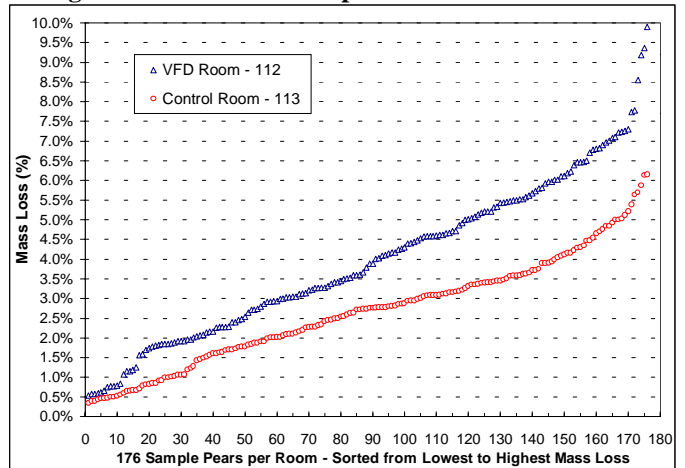
- Mass loss increased 1.33% on average in the VFD room.
- Only 2 of 8 sample sets showed less mass loss in the VFD room.
- The VFD room samples averaged more mass loss in all cross-sections.

The following trends were observed in both rooms.

- Evaporator end samples had less average mass loss than samples located opposite the evaporator.
- Upper pallet samples had less average mass loss than lower pallet samples.
- One exposure samples had less average mass loss than 3 exposure samples.

The following figure shows the mass loss results on an individual fruit basis.

Figure 4 - 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 Location	Firmness (psig)		Improvement
	VFD Room	Control	
Evap. End, Upper, 1 Exposure	12.1	12.7	-0.5
Evap. End, Upper, 3 Exposures	14.0	13.5	0.5
Evap. End, Lower, 1 Exposure	12.4	11.7	0.6
Evap. End, Lower, 3 Exposures	13.9	12.8	1.2
Oppo. Evap., Upper, 1 Exposure	12.3	11.6	0.7
Oppo. Evap., Upper, 3 Exposures	12.8	13.6	-0.8
Oppo. Evap., Lower, 1 Exposure	13.3	13.0	0.3
Oppo. Evap., Lower, 3 Exposures	14.3	13.5	0.8
Total	13.1	12.8	0.3
Evaporator End (4 Samples)	13.1	12.7	0.4
Opposite Evaporator (4 Samples)	13.2	12.9	0.2
Upper (4 Samples)	12.8	12.9	0.0
Lower (4 Samples)	13.5	12.8	0.7
1 Exposure (4 Samples)	12.5	12.3	0.3
3 Exposures (4 Samples)	13.8	13.4	0.4

- Fruit stored in the VFD room tested 0.3 psig higher in firmness on average than that stored in the control room.
- 6 of 8 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 5 - VFD Room Input Power

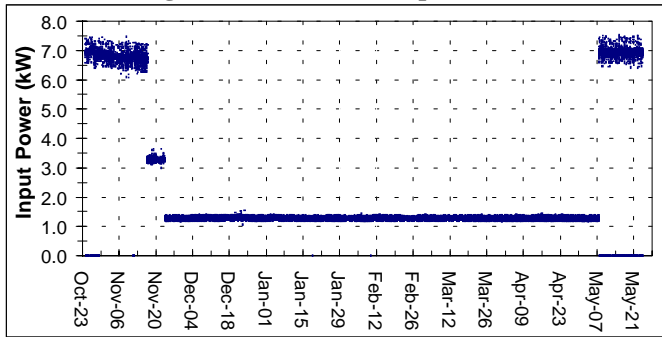


Figure 6 - Control Room Input Power - All Data

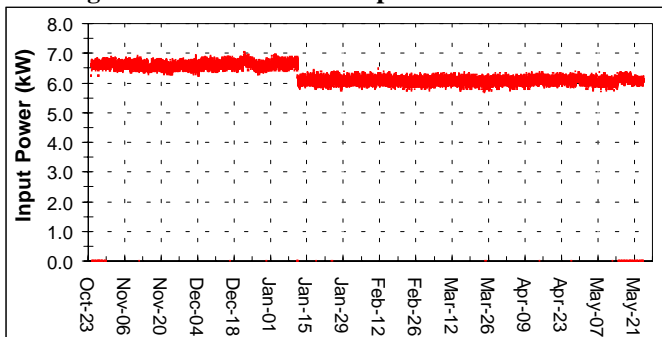
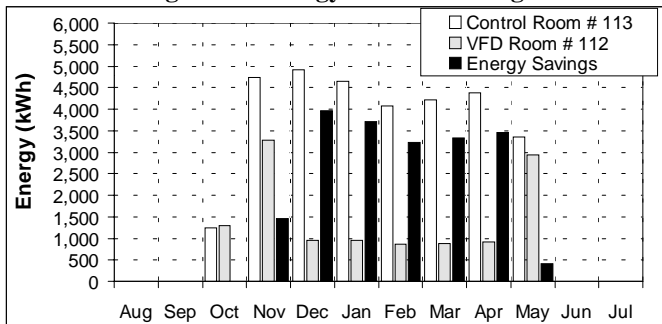


Figure 7 - Energy Use and Savings



- System energy savings of 66.4% were achieved with the VFD.
- VFD input power dropped from ~7.0 kW at 100% speed to 3.3 kW at 75% speed and 1.3 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 113	VFD Room Room 112	Difference Room 113 - Room 112
Soluble Solids	12.6	13.4	13.3	0.1
Titrateable Acid	0.300	0.204	0.189	0.015
Fruit Lightness*	62.1	63.2	61.6	1.5
Color Hue**	107.5	103.3°	102.0°	-1.0°

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

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

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

- Lower in soluble solids.

- Lower in titrateable acid.
- Darker and more yellow in color.

Economic Calculations

The economic calculations are shown in the following table.

Table 7 - Annual Savings Calculations

Pallets per Room	476
Boxes Per Pallet	48
Lbs Per Box	42
Total lbs	959,616
Mass Loss Savings	-1.33%
Product Savings (lbs)	-12,782
Product Savings (boxes)	-304
Product Value (\$/box)	\$12
Product Value Saved	-\$3,652
Energy Savings (kWh)	23,862
*Effective Energy Cost (\$/kWh)	\$0.0128
Energy Savings	\$306
Total Annual Savings	-\$3,346

*Includes Energy and Demand Savings

Given the test results, the VFD technology would not have a simple payback as the value of the lost product mass exceeds the energy savings.

Potential Test Problems/Discrepancies

This was only VFD field trial involving boxed fruit. The mass loss results for this field trial are contrary to those observed in the 10 bin fruit field trials. There was less mass loss in VFD room in all of the 10 bin fruit trials involving 18 separate mass loss tests.

The following sampling and testing methodologies employed in this boxed fruit field trial may have impacted the accuracy of the test results:

- All test fruit was not from a common source. 4 boxes were originally taken from one processing line, another 12 boxes were taken ~ 2 hours later from the same processing line.
- The test rooms were not loaded with the same number of pallets, which directly impacts room airflow. In the VFD room, pallets were only stacked 3 high on one side adjacent to the 4 pallet high test sample located furthest for the evaporator coil.
- The labeling and weighing process involved disturbing the standard box packaging. All boxes were not repacked to identical conditions.
 - All pears had to be individually wrapped and placed back in the box. Great care was not used in this step to insure that all pears were wrapped consistently.
 - The plastic liners were ripped on some boxes when the boxes were opened to get samples. The amount of liner ripping varied from box to box.
 - Great care was not made in ensure that all box liners were repackaged in a consistent manner.
- In the control room, one of the hand holes on each of the four evaporator end sample boxes was taped over with the sample label. This effectively blocked 50% of the direct air to fruit surface area on each box.

