NEEA EVAPORATOR FAN INITIATIVE CASE STUDY
Valley Fruit - Wapato, Washington

Summary

As an energy efficiency measure, a variable frequency drive (VFD) was installed to allow reduced fan speed operation in an 1806 bin controlled atmosphere (CA) room used for storage of red delicious apples.

The impact of VFD operations during a storage season was monitored on three sets of test fruit; premium size 80's, fancy size 80's, and apples that were not sprayed with "ReTain". The major test parameters are summarized in Tables 1-4.

Table 1 - Test Energy Savings

Test Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 16	VFD Room Room 14	Improvement Room 14 - Room 16
% Energy Use	N/A	100.0%	21.6%	78.4%

- Substantial energy savings were realized with the VFD versus the constant fan operation control room.

Table 2 - Fruit Testing - Premium 80's

Test Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 16	VFD Room Room 14	Improvement Room 14 - Room 16
Mass Loss (%)	0.00%	2.24%	1.99%	0.25%
Firmness (psig)	15.1	12.5	14.0	1.4

Table 3 - Fruit Testing - Fancy 80's

Test Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 16	VFD Room Room 14	Improvement Room 14 - Room 16
Mass Loss (%)	0.00%	2.12%	2.06%	0.06%
Firmness (psig)	15.1	12.8	12.4	-0.4

Table 4 - Fruit Testing - No ReTain

Test Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 16	VFD Room Room 14	Improvement Room 14 - Room 16
Mass Loss (%)	0.00%	2.62%	2.39%	0.24%
Firmness (psig)	14.8	12.4	10.7	-1.7

Results from the fruit testing showed:

- Less mass loss in the VFD room for all three sample groups.
- An increase in average fruit firmness in the VFD room for the premium 80's.
- A decrease in average fruit firmness in the VFD room for the Fancy 80's and no ReTain apples.

Economics for a full-scale VFD retrofit project are estimated in Table 5. Installation costs are anticipated to be considerably lower for a full-scale retrofit as compared to the field trial installation.

Table 5 - Economics for Full-Scale VFD Retrofit Project

Project Cost	Cost Savings per Year			Simple
VFD Retrofit (15 hp)	Energy	Mass*	Total	Payback (years)
$2,600	$1,654	$686	$2,340	1.1

*Mass savings based on the average from the three sample groups.

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 five 2 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 14. Fans ran at 50% speed after a 40 day fruit pull-down period. In the control room (room 16), full speed fan operation was employed during the entire storage season.

Fruit Selection/Sample Creation

Samples were created from a single bin representing each of the three fruit test groups. Sample fruit were individually weighed and labeled. Weights were recorded to 1/100th of a gram. For each of the three sets of test fruit, 15 sample bags, each containing 6 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 90 samples were created during a single day. Samples were stored in covered boxes 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 respective rooms filled. Sample bags were placed in the center of a bin covered by a layer of fruit. Samples were place in three cross-sections of the room. Five sample locations were selected 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

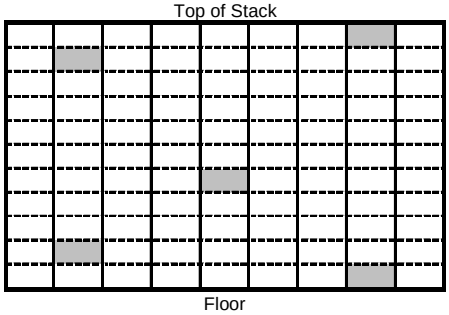
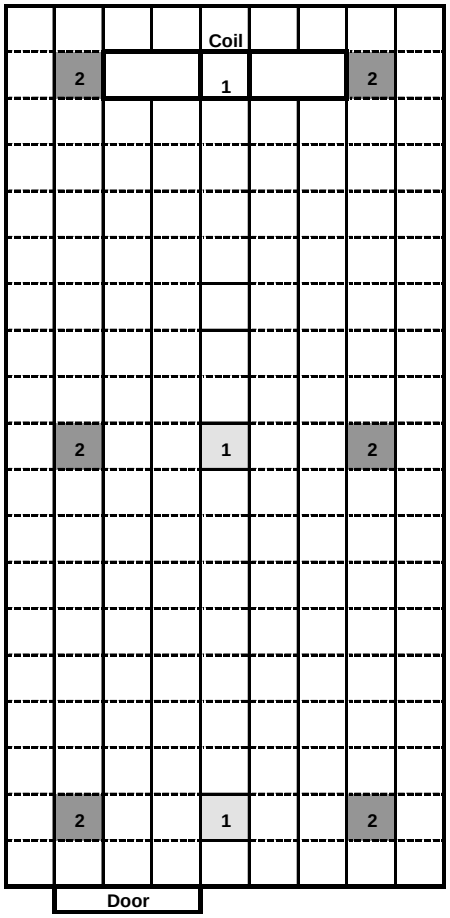


Figure 2 - Sample Location - Top View



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 6 - Room Loading and Unloading

Mode of Operation	VFD Room	Control Room	Difference	Storage Advantage
Loadings Days (Non-CA)	11	11	0	NONE
CA Holding Days	235	225	10	Control
Unloading Days (Non-CA)	2	3	-1	VFD
Total Storage Days	246	237	9	

- The loading, storage and unloading schedules were very similar providing no distinct advantage to either test room.

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 an overall improvement for samples stored in the VFD room.

Table 7 - Mass Loss Summary - Premium 80's

Sample Location	Mass Loss (%) VFD Room	Control	Improvement
Evaporator End, Lower Left	1.93%	2.42%	0.50%
Evaporator End, Lower Right	2.36%	2.06%	-0.29%
Evaporator End, Middle	2.07%	2.13%	0.05%
Evaporator End, Upper Left	2.12%	1.98%	-0.14%
Evaporator End, Upper Right	1.65%	2.00%	0.35%
Mid-room, Lower Left	1.85%	2.17%	0.32%
Mid-room, Lower Right	2.14%	2.34%	0.20%
Mid-room, Middle	1.75%	2.18%	0.44%
Mid-room, Upper Left	2.11%	2.30%	0.19%
Mid-room, Upper Right	1.91%	1.97%	0.06%
Opposite Evaporator, Lower Left	1.97%	2.36%	0.39%
Opposite Evaporator, Lower Right	2.04%	2.90%	0.86%
Opposite Evaporator, Middle	1.53%	2.06%	0.53%
Opposite Evaporator, Upper Left	2.12%	2.18%	0.06%
Opposite Evaporator, Upper Right	2.25%	2.52%	0.27%
Total	1.99%	2.24%	0.25%
Evaporator End (5 Samples)	2.03%	2.12%	0.09%
Mid-Room (5 Samples)	1.95%	2.19%	0.24%
Opposite Evaporator (5 Samples)	1.98%	2.42%	0.43%
Upper (6 Samples)	2.02%	2.16%	0.13%
Middle (3 Samples)	1.75%	2.13%	0.38%
Lower (6 Samples)	2.05%	2.38%	0.33%
Left (6 Samples)	2.02%	2.23%	0.22%
Middle (3 Samples)	1.75%	2.13%	0.38%
Right (6 Samples)	2.06%	2.30%	0.24%

- An average mass loss improvement of 0.25% was recorded.
- 13 of 15 sample sets showed less mass loss with the VFD.

Table 8 - Mass Loss Summary - Fancy 80's

Sample Location	Mass Loss (%) VFD Room	Control	Improvement
Evaporator End, Lower Left	2.01%	1.96%	-0.05%
Evaporator End, Lower Right	2.54%	2.11%	-0.43%
Evaporator End, Middle	2.13%	2.07%	-0.05%
Evaporator End, Upper Left	1.72%	1.85%	0.13%
Evaporator End, Upper Right	2.11%	2.03%	-0.08%
Mid-room, Lower Left	1.80%	2.06%	0.26%
Mid-room, Lower Right	2.12%	2.37%	0.25%
Mid-room, Middle	1.81%	2.09%	0.28%
Mid-room, Upper Left	2.02%	1.92%	-0.10%
Mid-room, Upper Right	1.90%	2.33%	0.43%
Opposite Evaporator, Lower Left	2.47%	2.51%	0.04%
Opposite Evaporator, Lower Right	2.59%	2.22%	-0.37%
Opposite Evaporator, Middle	1.78%	1.84%	0.06%
Opposite Evaporator, Upper Left	2.07%	2.02%	-0.05%
Opposite Evaporator, Upper Right	1.83%	2.43%	0.59%
Total	2.06%	2.12%	0.06%
Evaporator End (5 Samples)	2.09%	2.00%	-0.09%
Mid-Room (5 Samples)	1.93%	2.16%	0.23%
Opposite Evaporator (5 Samples)	2.15%	2.20%	0.05%
Upper (6 Samples)	1.94%	2.10%	0.16%
Middle (3 Samples)	1.90%	1.99%	0.09%
Lower (6 Samples)	2.25%	2.20%	-0.05%
Left (6 Samples)	2.02%	2.05%	0.04%
Middle (3 Samples)	1.90%	1.99%	0.09%
Right (6 Samples)	2.18%	2.25%	0.07%

- An average mass loss improvement of 0.06% was recorded.
- 8 of 15 sample sets showed less mass loss with the VFD.

Table 9 - Mass Loss Summary - No ReTain

Sample Location	Mass Loss (%) VFD Room	Control	Improvement
Evaporator End, Lower Left	2.74%	2.47%	-0.27%
Evaporator End, Lower Right	3.42%	2.81%	-0.60%
Evaporator End, Middle	2.30%	2.29%	0.00%
Evaporator End, Upper Left	2.22%	2.31%	0.09%
Evaporator End, Upper Right	2.63%	2.44%	-0.19%
Mid-room, Lower Left	2.19%	2.90%	0.71%
Mid-room, Lower Right	2.40%	2.62%	0.22%
Mid-room, Middle	2.30%	3.03%	0.74%
Mid-room, Upper Left	2.05%	2.85%	0.80%
Mid-room, Upper Right	2.37%	2.62%	0.25%
Opposite Evaporator, Lower Left	2.05%	2.76%	0.72%
Opposite Evaporator, Lower Right	2.65%	2.63%	-0.02%
Opposite Evaporator, Middle	1.85%	2.33%	0.47%
Opposite Evaporator, Upper Left	2.33%	2.49%	0.16%
Opposite Evaporator, Upper Right	2.53%	2.87%	0.34%
Total	2.39%	2.62%	0.24%
Evaporator End (5 Samples)	2.65%	2.46%	-0.19%
Mid-Room (5 Samples)	2.26%	2.81%	0.55%
Opposite Evaporator (5 Samples)	2.28%	2.62%	0.34%
Upper (6 Samples)	2.36%	2.59%	0.22%
Middle (3 Samples)	2.13%	2.54%	0.40%
Lower (6 Samples)	2.55%	2.70%	0.15%
Left (6 Samples)	2.25%	2.62%	0.37%
Middle (3 Samples)	2.13%	2.54%	0.40%
Right (6 Samples)	2.65%	2.67%	0.02%

- An average mass loss improvement of 0.24% was recorded.
- 10 of 15 sample sets showed less mass loss with the VFD.

The following figures show the mass loss improvement with the VFD on an individual fruit basis.

Figure 3 - Mass Loss - Individual Fruit - Premium 80's

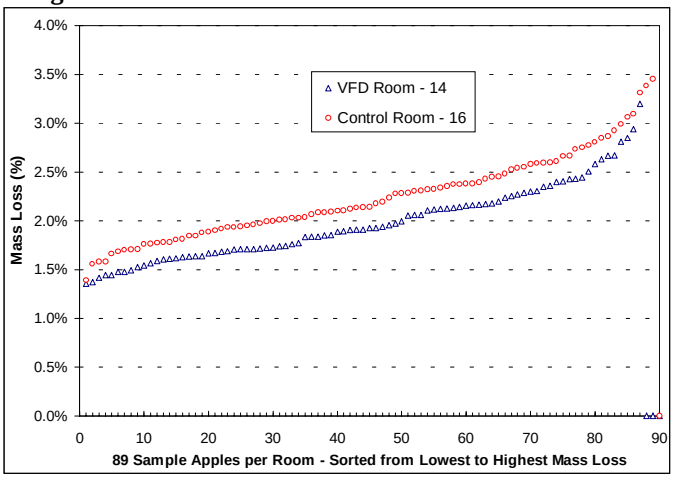


Figure 4 - Mass Loss - Individual Fruit - Fancy 80's

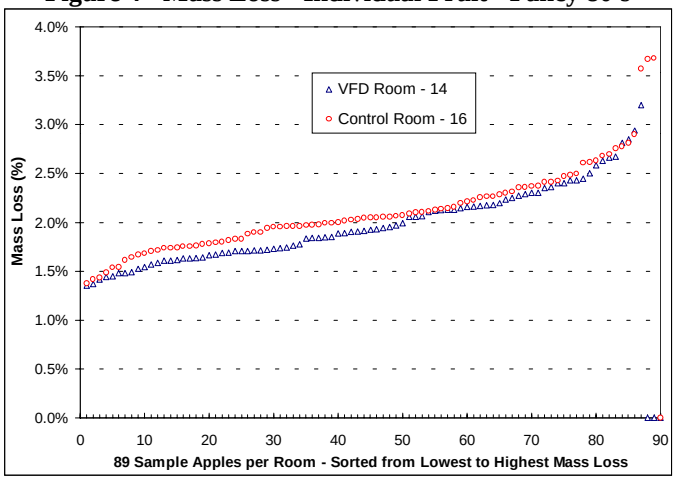
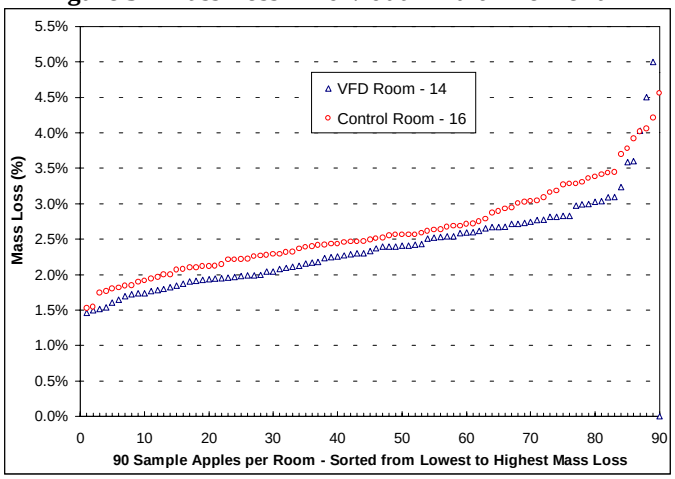


Figure 5 - Mass Loss - Individual Fruit - No ReTain



Fruit Firmness Test Results

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

Table 10 – Fruit Firmness Results -Premium 80's

Sample ID Name	VFD Room Firmness (psig)	Control Room Firmness (psig)	Improvement Firmness (psig)
Evaporator End, Lower Left	14.4	13.2	1.2
Evaporator End, Lower Right	14.0	13.8	0.2
Evaporator End, Middle	13.6	12.7	0.9
Evaporator End, Upper Left	13.2	12.8	0.4
Evaporator End, Upper Right	14.3	12.8	1.5
Mid-room, Lower Left	14.1	12.7	1.4
Mid-room, Lower Right	14.4	12.6	1.8
Mid-room, Middle	14.2	13.0	1.3
Mid-room, Upper Left	13.6	12.7	0.8
Mid-room, Upper Right	13.5	12.3	1.2
Opposite Evaporator, Lower Left	13.7	11.8	1.8
Opposite Evaporator, Lower Right	13.4	10.8	2.6
Opposite Evaporator, Middle	14.8	12.6	2.2
Opposite Evaporator, Upper Left	14.2	11.8	2.4
Opposite Evaporator, Upper Right	14.2	12.5	1.6
Total	14.0	12.5	1.4
Evaporator End (5 Samples)	13.9	13.1	0.8
Mid-Room (5 samples)	13.9	12.6	1.3
Opposite Evaporator (5 Samples)	14.0	11.9	2.1
Upper (6 Samples)	13.8	12.5	1.3
Middle (3 Samples)	14.2	12.7	1.5
Lower (6 Samples)	14.0	12.5	1.5
Left (6 Samples)	13.9	12.5	1.4
Middle (3 Samples)	14.2	12.7	1.5
Right (6 Samples)	13.9	12.5	1.5

- Fruit stored in the VFD room tested 1.4 psig higher in firmness on average than that stored in the control room.
- All sample sets tested higher for firmness in the VFD room.

Table 11 – Fruit Firmness Results -Fancy 80's

Sample ID Name	VFD Room Pressure (psig)	Control Room Pressure (psig)	Improvement Pressure (psig)
Evaporator End, Lower Left	12.7	13.6	-0.9
Evaporator End, Lower Right	13.1	14.1	-1.0
Evaporator End, Middle	13.2	13.1	0.1
Evaporator End, Upper Left	12.1	11.5	0.6
Evaporator End, Upper Right	12.1	13.3	-1.2
Mid-room, Lower Left	11.4	12.6	-1.2
Mid-room, Lower Right	13.3	12.0	1.2
Mid-room, Middle	12.7	12.7	0.0
Mid-room, Upper Left	12.1	13.4	-1.3
Mid-room, Upper Right	12.1	12.9	-0.7
Opposite Evaporator, Lower Left	11.7	12.4	-0.6
Opposite Evaporator, Lower Right	11.6	12.8	-1.2
Opposite Evaporator, Middle	11.9	13.2	-1.2
Opposite Evaporator, Upper Left	13.3	12.4	0.9
Opposite Evaporator, Upper Right	13.1	12.7	0.3
Total	12.4	12.8	-0.4
Evaporator End (5 Samples)	12.6	13.1	-0.5
Mid-Room (5 samples)	12.3	12.7	-0.4
Opposite Evaporator (5 Samples)	12.3	12.7	-0.4
Upper (6 Samples)	12.5	12.7	-0.2
Middle (3 Samples)	12.6	13.0	-0.4
Lower (6 Samples)	12.3	12.9	-0.6
Left (6 Samples)	12.2	12.6	-0.4
Middle (3 Samples)	12.6	13.0	-0.4
Right (6 Samples)	12.5	13.0	-0.4

- Fruit stored in the VFD room tested 0.4 psig lower in firmness on average than that stored in the control room.
- 5 of 15 sample sets tested higher for firmness in the VFD room.

Table 12 – Fruit Firmness Results -No ReTain

Sample ID Name	VFD Room Pressure (psig)	Control Room Pressure (psig)	Improvement Pressure (psig)
Evaporator End, Lower Left	10.2	13.5	-3.3
Evaporator End, Lower Right	9.9	12.3	-2.4
Evaporator End, Middle	10.6	11.9	-1.3
Evaporator End, Upper Left	11.0	11.8	-0.8
Evaporator End, Upper Right	11.1	12.6	-1.5
Mid-room, Lower Left	10.4	12.3	-2.0
Mid-room, Lower Right	10.8	11.6	-0.8
Mid-room, Middle	11.0	12.0	-1.0
Mid-room, Upper Left	10.0	12.6	-2.6
Mid-room, Upper Right	11.0	13.5	-2.6
Opposite Evaporator, Lower Left	11.8	12.6	-0.9
Opposite Evaporator, Lower Right	11.3	11.9	-0.6
Opposite Evaporator, Middle	10.3	12.7	-2.4
Opposite Evaporator, Upper Left	10.9	12.5	-1.6
Opposite Evaporator, Upper Right	11.1	12.6	-1.5
Total	10.7	12.4	-1.7
Evaporator End (5 Samples)	10.6	12.4	-1.9
Mid-Room (5 samples)	10.6	12.4	-1.8
Opposite Evaporator (5 Samples)	11.1	12.5	-1.4
Upper (6 Samples)	10.8	12.6	-1.8
Middle (3 Samples)	10.6	12.2	-1.5
Lower (6 Samples)	10.7	12.4	-1.7
Left (6 Samples)	10.7	12.6	-1.9
Middle (3 Samples)	10.6	12.2	-1.5
Right (6 Samples)	10.8	12.4	-1.6

- Fruit stored in the VFD room tested 1.7 psig lower in firmness on average than that stored in the control room.
- All sample sets tested lower 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 6 - VFD Room Input Power

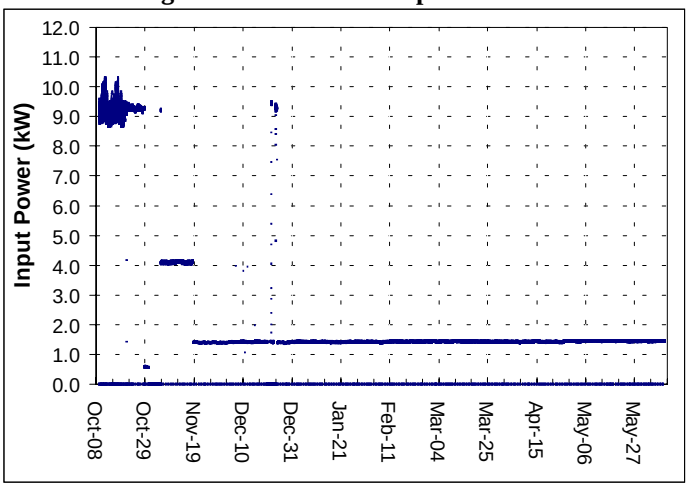


Figure 7 - Control Room Input Power

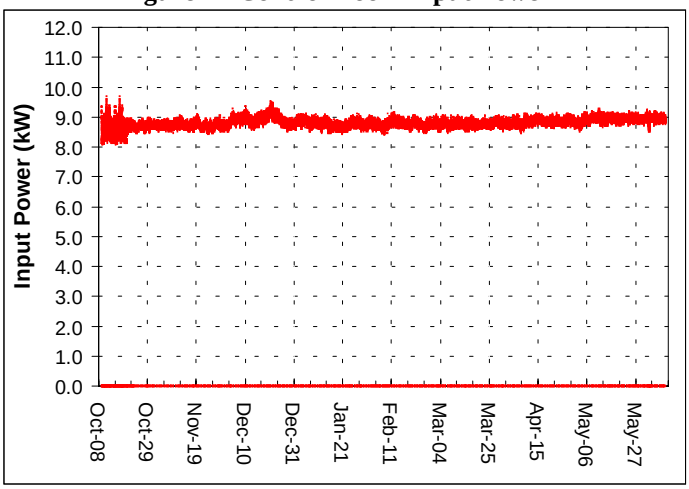
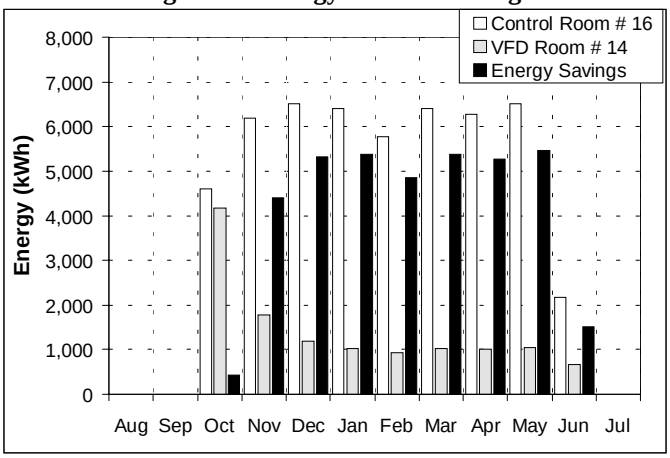


Figure 8 - Energy Use and Savings



- System energy savings of 78.4% were achieved with the VFD.
- VFD input power dropped from ~9.3 kW at 100% speed to ~4.0 kW at 75% speed and then to ~1.4 kW at 50% speed.

Additional Fruit Lab Test Results

Table 13 - Lab Test Results -Premium 80's

Fruit Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 16	VFD Room Room 14	Difference Room 16 - Room 14
Soluble Sugar	10.8	12.5	12.9	-0.4
Titratable Acid	0.228	0.154	0.174	-0.020

Table 14 - Lab Test Results -Fancy 80's

Fruit Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 16	VFD Room Room 14	Difference Room 16 - Room 14
Soluble Sugar	10.9	12.0	12.6	-0.6
Titratable Acid	0.254	0.185	0.169	0.016

Table 15 - Lab Test Results -No ReTain

Fruit Characteristic	Initial Conditions	Conditions at the End of CA Holding		
		Control Room Room 16	VFD Room Room 14	Difference Room 16 - Room 14
Soluble Sugar	11.2	12.3	12.7	-0.5
Titratable Acid	0.250	0.184	0.170	0.014

- The fruit in the VFD room had higher levels of soluble solids in all three fruit sets.
- The fruit in the VFD room had lower levels of titratable acid in 2 of 3 of the fruit sample sets (the higher level was in the premium 80's).

Economic Calculations

The economic calculations are shown in the following table.

Table 16 - Annual Savings Calculations

Product Savings	
Bins per Room	1806
lbs. per Bin	900
% Packout	80.0%
Total lbs	1,300,320
Mass Loss Savings	0.18%
Product Savings (lbs)	2,401
Product Savings (boxes)	57
Product Value ($/box)	$12
Product Value Saved	**$686**
Energy Savings (kWh)	46,564
*Effective Energy Cost ($/kWh)	$0.0355
Energy Savings	**$1,654**
Total Annual Savings	**$2,340**

*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 ~ 0.7 years.