

NEEA EVAPORATOR FAN INITIATIVE CASE STUDY

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Summary

As an energy efficiency measure, a variable frequency drive (VFD) was installed to allow reduced fan speed operation in a 2300 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. The information presented represents the results at the end of the storage period for each room.

Table 1 - Major Test Parameters - Unadjusted

| Test Characteristic | Initial Conditions | Conditions at the End of CA Holding | | |
|---------------------|--------------------|-------------------------------------|------------------|-------------------------------|
| | | Control Room Room 19 | VFD Room Room 14 | Improvement Room 19 - Room 14 |
| Mass Loss (%) | 0.00% | 4.54% | 2.69% | 1.86% |
| Firmness (psig) | 15.2 | 11.0 | 11.3 | 0.3 |
| % Energy Use | N/A | 100.0% | 32.7% | 67.3% |

The VFD room opened 100 days earlier than the control room. The following table shows the test parameters normalized for an equal storage period.

Table 2 - Major Test Parameters - Adjusted

| Test Characteristic | Initial Conditions | Conditions at the End of CA Holding | | |
|---------------------|--------------------|-------------------------------------|------------------|-------------------------------|
| | | Control Room Room 19 | VFD Room Room 14 | Improvement Room 19 - Room 14 |
| Mass Loss (%) | 0.00% | 3.12% | 2.69% | 0.44% |
| Firmness (psig) | 15.2 | 12.5 | 11.3 | -1.2 |
| % Energy Use | N/A | 100.0% | 33.0% | 67.0% |

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 100% fan operation control room.

Economics for a full-scale VFD retrofit project are estimated in Table 3. Installation costs are anticipated to be considerably lower for a full-scale retrofit compared to the field trial installation.

Table 3 - 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 | \$733 | \$1,558 | \$2,316 | 1.1 |

*Claims only 75% of the adjusted mass savings.

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 trial, 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 fruit pull-down. In the control room (room 19), full speed fan operation was employed during the entire storage season.

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 1/100th 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 on 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 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 placed 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

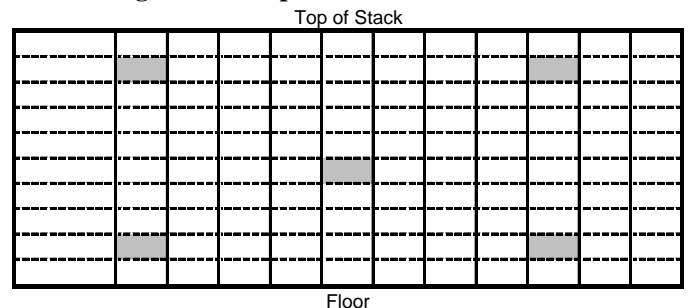
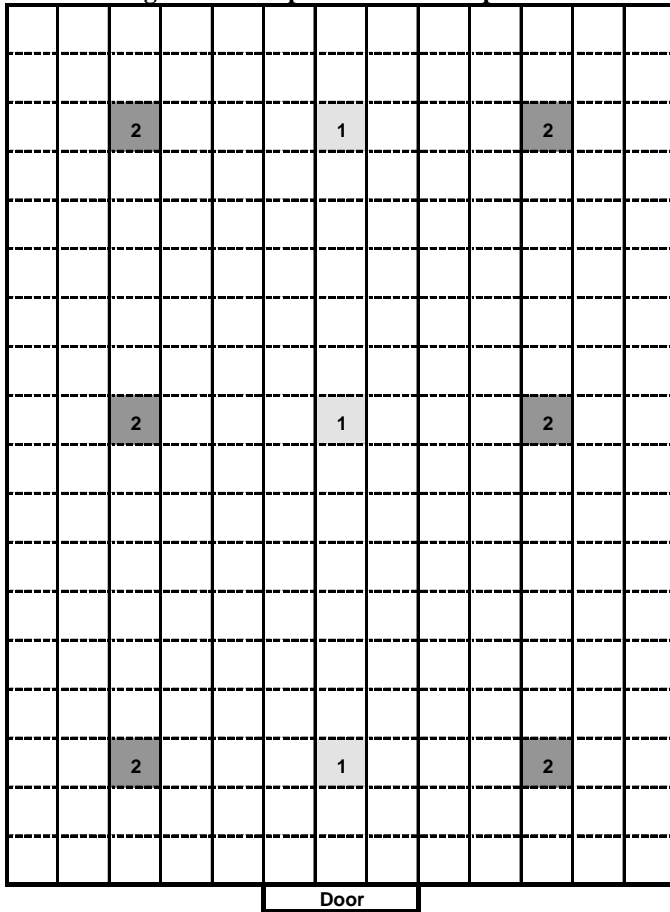


Figure 2 - Sample Location - Top View



CA Conditions and Room Loading and Unloading

The VFD and control rooms were maintained at similar temperature, O₂ and CO₂ conditions throughout the storage period.

Table 4 - Room Loading and Unloading

| Mode of Operation | VFD Room | Control Room | Difference | Storage Advantage |
|-------------------------|----------|--------------|------------|-------------------|
| Loadings Days (Non-CA) | 5 | 5 | 0 | NONE |
| CA Holding Days | 172 | 272 | -100 | VFD |
| Unloading Days (Non-CA) | 3 | 3 | 0 | NONE |
| Total Storage Days | 178 | 278 | -100 | |

- The unloading schedule strongly favored the VFD room. The fruit in the VFD room was stored for 100 days less than the control room fruit.
- Test results were adjusted, to account for the difference in fruit storage duration, in order to make meaningful comparisons.

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 normalized mass loss results showed an overall improvement for samples stored in the VFD room.

Table 5 - Mass Loss Summary

| Sample Location | Mass Loss (%) | | Improvement |
|----------------------------------|---------------|---------|-------------|
| | VFD Room | Control | |
| Evaporator End, Lower Left | 2.84% | 3.47% | 0.63% |
| Evaporator End, Lower Right | 2.78% | 3.11% | 0.33% |
| Evaporator End, Middle | 2.67% | 2.96% | 0.29% |
| Evaporator End, Upper Left | 2.28% | 3.01% | 0.73% |
| Evaporator End, Upper Right | 2.42% | 3.11% | 0.68% |
| Mid-room, Lower Left | 3.05% | 3.24% | 0.19% |
| Mid-room, Lower Right | 2.66% | 3.18% | 0.52% |
| Mid-room, Middle | 2.68% | 3.35% | 0.67% |
| Mid-room, Upper Left | 2.83% | 3.14% | 0.31% |
| Mid-room, Upper Right | 2.89% | NA | NA |
| Opposite Evaporator, Lower Left | 2.88% | 3.14% | 0.27% |
| Opposite Evaporator, Lower Right | 2.83% | 2.87% | 0.03% |
| Opposite Evaporator, Middle | 2.57% | 3.36% | 0.79% |
| Opposite Evaporator, Upper Left | 2.47% | 2.83% | 0.36% |
| Opposite Evaporator, Upper Right | 2.44% | 3.00% | 0.57% |
| Total | 2.69% | 3.12% | 0.44% |
| Evaporator End (5 Samples) | 2.60% | 3.13% | 0.53% |
| Mid-Room (5 Samples) | 2.82% | 3.23% | 0.40% |
| Opposite Evaporator (5 Samples) | 2.64% | 3.04% | 0.40% |
| Upper (6 Samples) | 2.56% | 3.02% | 0.46% |
| Middle (3 Samples) | 2.64% | 3.22% | 0.58% |
| Lower (6 Samples) | 2.84% | 3.17% | 0.33% |
| Left (6 Samples) | 2.72% | 3.14% | 0.41% |
| Middle (3 Samples) | 2.64% | 3.22% | 0.58% |
| Right (6 Samples) | 2.67% | 3.05% | 0.38% |

- The control room mass loss was adjusted to normalize to a storage period equal to the VFD room. The presented values are estimates of mass loss on 3-24-99 and equal 0.68 times the mass loss values recorded on 7-2-99. The 0.68 scaling factor was based on results from load cells located in the test rooms that provided real-time mass loss readings.
- A total mass loss improvement of 0.44% was calculated.
- All sample sets showed less mass loss in the VFD room.
- No sample was placed in the Mid-Room upper right position in the control room.

The following figure shows the mass loss improvement for the VFD room on an individual fruit basis.

Figure 3 - Adjusted Mass Loss Comparison - Individual Fruit

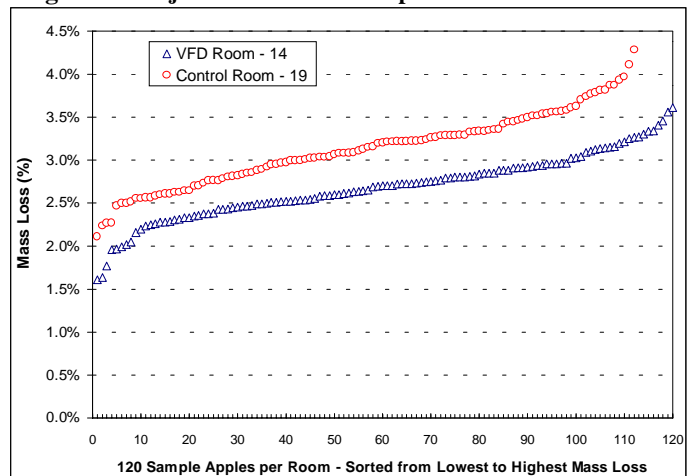
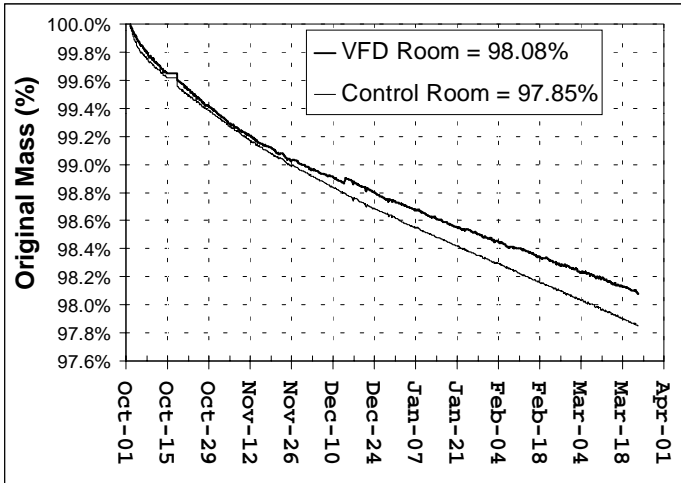


Figure 4 - Real-Time Mass Loss from Load Cells



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. The results were normalized for an equal storage period using a linear extrapolation of fruit firmness.

Table 6 – Fruit Firmness Test Results

| Sample ID Name | VFD Room - 14 Firmness (psig) | Control Room - 19 Firmness (psig)* | Improvement Firmness (psig) |
|----------------------------------|-------------------------------|------------------------------------|-----------------------------|
| Evaporator End, Lower Left | 11.2 | 12.7 | -1.5 |
| Evaporator End, Lower Right | 11.9 | 12.0 | -0.1 |
| Evaporator End, Middle | 11.5 | 12.6 | -1.1 |
| Evaporator End, Upper Left | 11.1 | 12.3 | -1.2 |
| Evaporator End, Upper Right | 12.0 | 12.5 | -0.5 |
| Mid-room, Lower Left | 11.4 | 12.6 | -1.2 |
| Mid-room, Lower Right | 10.9 | 12.8 | -1.9 |
| Mid-room, Middle | 10.9 | 12.7 | -1.8 |
| Mid-room, Upper Left | 10.8 | 12.3 | -1.5 |
| Mid-room, Upper Right | 11.0 | NA | NA |
| Opposite Evaporator, Lower Left | 11.2 | 12.8 | -1.6 |
| Opposite Evaporator, Lower Right | 11.4 | 12.2 | -0.8 |
| Opposite Evaporator, Middle | 10.8 | 12.3 | -1.5 |
| Opposite Evaporator, Upper Left | 11.2 | 12.6 | -1.4 |
| Opposite Evaporator, Upper Right | 11.7 | 12.5 | -0.8 |
| Total | 11.3 | 12.5 | -1.2 |
| Evaporator End (5 Samples) | 11.5 | 12.4 | -0.9 |
| Mid-Room (5 samples) | 11.0 | 12.6 | -1.6 |
| Opposite Evaporator (5 Samples) | 11.3 | 12.5 | -1.2 |
| Upper (6 Samples) | 11.3 | 12.5 | -1.1 |
| Middle (3 Samples) | 11.1 | 12.5 | -1.4 |
| Lower (6 Samples) | 11.3 | 12.5 | -1.2 |
| Left (6 Samples) | 11.2 | 12.6 | -1.4 |
| Middle (3 Samples) | 11.1 | 12.5 | -1.4 |
| Right (6 Samples) | 11.5 | 12.4 | -0.9 |

* Adjusted assuming a linear decrease in firmness as a function of time.

- Samples stored in the VFD room were calculated to be 1.2 psig lower in firmness on average relative to the control room samples.
- All sample sets were calculated to be lower in 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

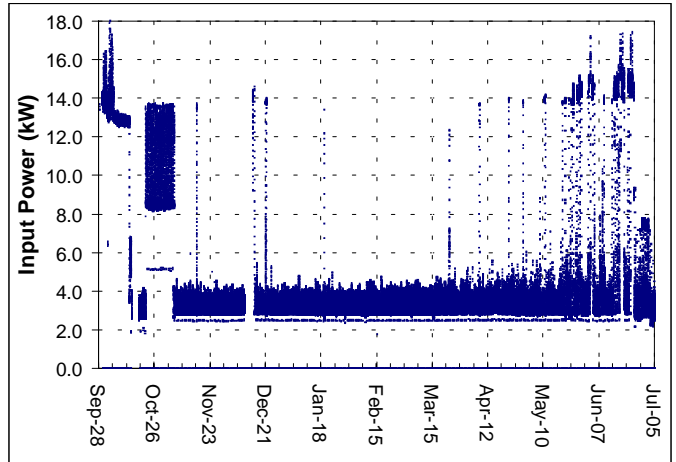


Figure 6 - Control Room Input Power

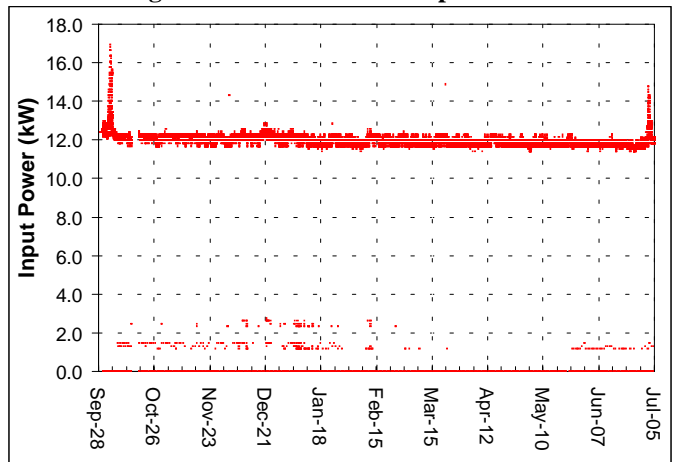
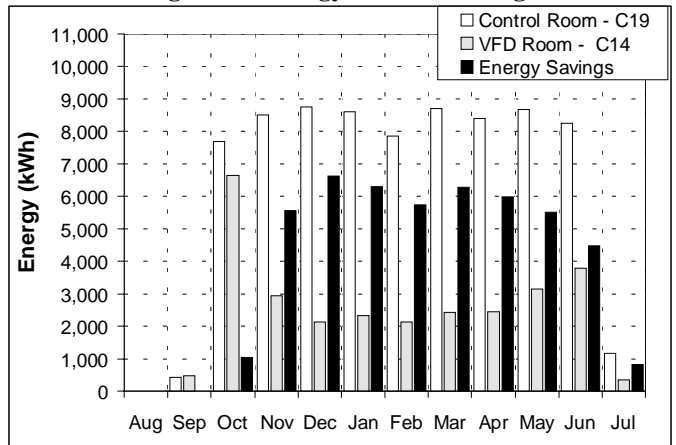


Figure 7 - Energy Use and Savings



The VFD room operate as a common storage room from April to the conclusion the field trial in July. Energy savings of 63.7% were achieved with the VFD installation.

Fruit Lab Test Results

The fruit samples were lab tested for the following characteristics. Values for the control room were adjusted to normalize to an equal storage period with the VFD room using linear extrapolations.

Table 7 - Lab Test Results

| Fruit Characteristic | Initial Conditions | Conditions at the End of CA Holding | | |
|----------------------|--------------------|-------------------------------------|------------------|------------------------------|
| | | Control Room Room 19 | VFD Room Room 14 | Difference Room 19 - Room 14 |
| Soluble Solids | 13.6 | 13.8 | 14.3 | -0.5 |
| Titratable Acid | 0.411 | 0.384 | 0.331 | 0.053 |
| Fruit Lightness* | 74.6 | 73.5 | 73.2 | 0.3 |
| Color Hue** | 103.6 | 100.5° | 99.7° | 0.8° |

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

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

Fruit in the VFD room was extrapolated to be:

- Higher in soluble solids.
- Lower in titratable acid.
- Darker in shade/lightness.
- More yellow in color.

Temperature Monitoring

In each room, temperature probes were placed with each of the 15 fruit samples. Two additional temperature probes were placed to measure return and discharge air temperatures from the evaporator coil. Average temperatures during the holding period are presented in the following table.

Table 8 - Average Space Temperatures

| Probe Location | Space Temperature (°F) | | Difference (°F) |
|----------------------------------|------------------------|--------------|-----------------|
| | VFD Room | Control Room | |
| Evaporator End, Lower Left | 34.8 | 34.8 | -0.02 |
| Evaporator End, Lower Right | 34.7 | 34.7 | 0.00 |
| Evaporator End, Middle | 34.6 | 34.6 | 0.00 |
| Evaporator End, Upper Left | 34.5 | 34.5 | -0.06 |
| Evaporator End, Upper Right | 34.4 | 34.6 | -0.25 |
| Mid-room, Lower Left | 34.8 | 34.7 | 0.06 |
| Mid-room, Lower Right | NA | 34.7 | NA |
| Mid-room, Middle | 34.6 | 34.6 | 0.00 |
| Mid-room, Upper Left | 34.6 | 34.5 | 0.01 |
| Mid-room, Upper Right | 34.5 | 34.6 | -0.13 |
| Opposite Evaporator, Lower Left | 34.9 | 34.7 | 0.25 |
| Opposite Evaporator, Lower Right | 34.7 | 34.7 | -0.02 |
| Opposite Evaporator, Middle | 34.9 | 34.7 | 0.20 |
| Opposite Evaporator, Upper Left | 34.7 | 34.6 | 0.15 |
| Opposite Evaporator, Upper Right | 34.5 | 34.5 | -0.03 |
| Average | 34.6 | 34.6 | 0.01 |
| Minimum (average) | 34.4 | 34.5 | -0.16 |
| Maximum (average) | 34.9 | 34.8 | 0.16 |
| Typical Temperature Variation | 0.59 | 0.27 | 0.32 |
| Evaporator End (5 Probes) | 34.6 | 34.6 | -0.07 |
| Mid-Room (5 Probes) | 34.6 | 34.6 | -0.03 |
| Opposite Evaporator (5 Probes) | 34.7 | 34.6 | 0.11 |
| Upper (6 Probes) | 34.5 | 34.6 | -0.05 |
| Middle (3 Probes) | 34.7 | 34.6 | 0.07 |
| Lower (6 Probes) | 34.8 | 34.7 | 0.06 |
| Entering Coil | 34.5 | 34.5 | 0.02 |
| Leaving Coil | 34.1 | 34.3 | -0.26 |
| Temperature Drop Across Coil | 0.46 | 0.19 | 0.28 |

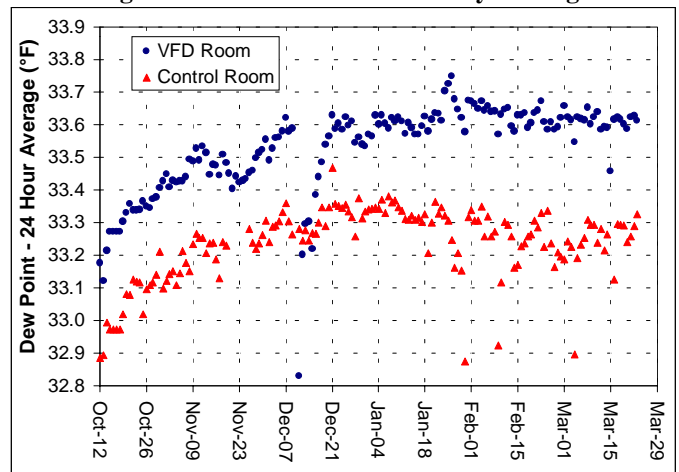
Temperature monitoring showed:

- No hot or cold areas in either room.
- Space temperatures varied more in the VFD room. The typical variation for the 15 space temperature probes in the VFD and Control rooms were 0.59°F and 0.27°F respectively.
- The VFD room had a lower discharge air temperature and a higher temperature difference across the coil. This was the result of reducing the airflow by 50% while accomplishing the same amount of refrigeration, minus the fan heat savings, as the control room.

Dew Point Monitoring

Monitoring showed a higher dew point in the VFD room. A high dew point is associated with a high level of relative humidity and lower mass loss.

Figure 8 - Room Dew Point - Daily Average



Economic Calculations

The economic calculations are shown in the following table.

Table 9 - Annual Savings Calculations

| | |
|----------------------------------|----------------|
| Bins per Room | 2300 |
| lbs. per Bin | 800 |
| % Packout | 90.0% |
| Total lbs | 1,656,000 |
| *Mass Loss Savings | 0.33% |
| Product Savings (lbs) | 5,452 |
| Product Savings (boxes) | 130 |
| Product Value (\$/box) | \$12 |
| Product Value Saved | \$1,558 |
| Energy Savings (kWh) | 59,193 |
| **Effective Energy Cost (\$/kWh) | \$0.0128 |
| Energy Savings | \$758 |
| Total Annual Savings | \$2,316 |

*Claims only 75% of the extrapolated value

**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.

