# APPENDIX A
# Examples of Completed Engineered Worksheets
# January 2025

# RETROFIT COMPRESSED AIR ENGINEERED WORKSHEET

A company has a compressed air system consisting of five (5) compressors operating from 9:00 a.m. to 9:00 p.m. Mondays to Fridays and from 9:00 a.m. to 6:00 p.m. on Saturdays.  The facility is closed on Sundays and certain holidays.  The existing compressor and motor information are as follows:

**Existing Compressed Air System**

| | A.C.#1 | A.C.#2 | | |
|---|---|---|---|---|
| Compressor Designated Name | Main Unit | Paint Line | | |
| Manufacturer (CAGI Box 1) | Please select | Please select | | |
| Model (CAGI Box 2) | R110I-A110 | R551-A110 | | |
| Rated Capacity at Full Load Operating Pressure (CAGI Box 3) | 751 | 361 | 1,112 | acfm (Total) |
| Full Load Operating Pressure (CAGI Box 4) | 100 | 100 | 100.0 | psig (Average) |
| Maximum Full Flow Operating Pressure (CAGI Box 5) | 110 | 110 | 110.0 | psig (Average) |
| Drive Motor Nominal Rating (CAGI Box 6) | 150 | 75 | 225 | HP (Total) |
| Total Package Input Power at Zero Flow (CAGI Box 10) | 36.8 | 20.0 | 56.8 | kW (Total) |
| Total Package Input Power at Rated Capacity and Full Load Operating Pressure (CAGI Box 11) | 129.9 | 65.8 | 97.9 | kW (Average) |
| **Typical Percent of Full Load Operating Point (F.L.) *** | **90.0%** | **70.0%** | 80.0% | Percent Full Load |
| **Typical Operating Pressure for this Compressor *** | **108.0** | **107.0** | 107.5 | psig (Average) |
| Operating Flow | 675.9 | 252.7 | 928.6 | cfm |
| | | | 179.3 | kW |
| | | | 815,975 | kWh |
| | | | $   89,757 | dollars |

**Proposed Energy Efficiency Measures:**

The company is implementing the four measures included in the Compressed Air Engineered Worksheet, namely:

>    Measure 1 – Reduce Air Leaks

>    Measure 2 - Reduce Operating Pressure

>    Measure 3 - Use Efficient Air Dryers

>    Measure 4 – Use Zero Loss Air Drains

**Calculation of Energy Savings (kWh) for each Measure:**

## Measure 1 – Reduce Air Leakage

Information needed:     Target for Maximum Allowable Air Leaks and Non-Productive Air Use = 15.0 %

### Dimensions of Air receiver tanks

|  | Receiver Tank Diameter (feet) | Receiver Tank Height (feet) | No. of Similar Receivers (#) |
|---|---|---|---|
| Air Receiver(s) - Type 1 | 1.0 | 5.0 | 3 |
| Air Receiver(s) - Type 2 | 2.5 | 8.0 | 1 |

### Dimensions of Distribution Pipes

|  | Outside Pipe Diameter (inches) | Pipe Length (feet) |
|---|---|---|
| Largest Diameter Distribution Pipe (Diameter and Length) | 4.0 | 600 |
| Second Largest Diameter Distribution Pipe (Diameter and Length) | 2.5 | 300 |

### Pressure Decay Test Results

| Test Number | Initial Pressure (psig) | Final Pressure (psig) | Time for Decay (Seconds) |
|---|---|---|---|
| 1 | 105.0 | 70.0 | 125 |
| 2 | 106.0 | 68.0 | 120 |
| 3 | 102.5 | 60.0 | 105 |
| 4 | 106.4 | 70.0 | 130 |
| 5 | 104.5 | 71.0 | 115 |
| **Average** | **104.9** | **67.8** | **119** |

**Volume of Air Receiver Tanks**

Example for AC #1:

$$\text{Tank Volume (ft}^3) = \frac{\text{Outside Cylinder Diameter} \times 3.14 \text{ ft}^2}{4} \times \text{Cylinder Height (ft)} \times \text{Quantity on Site}$$

$$= \frac{1.00^2 \times 3.14}{4} \times 5.00 \times 3.00$$

$$= 11.78 \text{ ft}^3$$

Repeating the same calculation for AC #2 will yield a volume of 39.25 ft$^3$.

**Volume of Largest Distribution Pipes**

Example for AC #1:

$$\text{Pipe Volume (ft}^3) = \frac{\text{Outside Pipe Diameter}^2 \text{ (inch}^2) \times 3.14}{4 \times 144} \times \text{Pipe Length (ft)}$$

$$= \frac{4.00^2 \times 3.14}{4 \times 144} \times 600$$

$$= 52.33 \text{ ft}^3$$

Repeating the same calculation for second distribution pipe will yield a volume of 10.22 ft$^3$.

**Total Volume of Air Receiver Tanks and Largest Distribution Pipes**

$$\text{Total Volume of Piping and Receivers (ft}^3) = \text{AC \#1 Tank (ft}^3) + \text{AC \#2 Tank (ft}^3) + \text{AC \#1 Pipe (ft}^3) + \text{AC \#2 Pipe (ft}^3)$$

$$= 11.78 + 39.25 + 52.33 + 10.22$$

$$= 113.58 \text{ ft}^3$$

**Estimated Leakage and Non-Productive Air Losses (at 100% Compressor Flow Output)**

$$\text{Estimated Leakage at 100\% Compressor Flow Output (cfm)} = 1.25 \times \text{Total Volume of Piping and Receivers (ft}^3) \times \frac{\text{Starting Pressure (psig)} - \text{Ending Pressure (psig)}}{\text{Decay Time (min)} \times 14.7 \text{ psig}} \times \frac{60}{\text{sec/min}}$$

$$= 1.25 \times 113.58 \times (104.9 - 67.8) / (119 \times 14.7) \times 60$$

$$= 181 \text{ cfm}$$

**Operating Flow**

Example for AC #1:

$$\text{Operating Flow (cfm)} = \text{Rated Capacity at Full Load Operating Pressure (acfm)} \times \text{Typical Percent of Full Load Operating Point (\%)}$$

$$= 751 \times 90\%$$

$$= 675.9 \text{ cfm}$$

Repeating the same calculation for AC #2 will yield an operating flow of 675.9 cfm.

**Estimated Air Leaks and Non-Productive Air Losses as Percentage of Normal Compressor Flow**

| Estimated Air Leaks as Percentage of Normal Compressor Flow (%) | = | $\dfrac{\text{Estimated Leakage at 100\% Compressor Flow Output (cfm)}}{\text{Total Operating Flow (cfm)}}$ x 100 |

$$= \ (181) / (675.9 + 252.7) \ \text{x} \ 100$$

$$= \ 19.4\ \%$$

## Slope of Compressor Performance Line

Example with AC #1

| Slope | = | $\dfrac{\text{Total Package Input Power at Rated Capacity (kW)} - \text{Total Package Input Power at Zero Flow (kW)}}{\text{Rated Capacity at Full Load Operating Pressure (acfm)}}$ |

$$= \ (129.9 - 76.8) \ / \ 751$$

$$= \ 0.1240$$

## Expected Power at Operating Flow and Design Pressure

Example with AC #1

| Expected Power | = | Total Package Input Power at Zero Flow (kW) | + | Slope | x | Operating Flow (kW) |

$$= \ 36.8 \ + \ 0.1240 \ \text{x} \ 675.9$$

$$= \ 120.59 \ \text{kW}$$

## Expected Power at Operating Flow and Actual Operating Pressure
Example for AC #1:

Power Demand at Typical Operating Level (kW) = [ 1 - ( Full Load Operating Pressure (acfm) - Typical Operating Pressure for Compressor (psig) ) x 0.05 ] x Power Demand at Operating Flow (kW)

$$= \ [ \ 1 - ( \ 100.0 - 108.0 \ ) \ \text{x} \ 0.05 \ ] \ \text{x} \ 120.59$$

$$= \ 125.41 \ \text{kW}$$

## Estimated annual kWh consumption per Air Compressor
Example for AC #1:

| Energy Consumption of Compressor at Operating Level (kWh) | = | Power Demand at Typical Operating Level (kW) | x | Annual Operating Hours (hrs) |

$$= \ 125.41 \ \text{x} \ 4551$$

$$= \ 570{,}757 \ \text{kWh}$$

**Estimated total annual kWh consumption**

| | | | | |
|---|---|---|---|---|
| Annual Energy Consumption for Air Compressors at Typical Operating Level (kWh) | = | AC#1 Energy Consumption of Compressor at Operating Level (kWh) | + | AC#2 Energy Consumption of Compressor at Operating Level (kWh) |

$$= 570{,}757 + 245{,}217$$

$$= 815{,}975 \text{ kWh}$$

| | | | | | | |
|---|---|---|---|---|---|---|
| Annual Energy Savings (kWh) | = | [ Estimated Air Leaks (%) | − | Target Allowable Leaks (%) ] | x | Annual Energy Consumption for Air Compressors at Typical Operating Level (kWh) |

$$= (19.4\% - 15.0\%) \times 815{,}975$$

$$= 36{,}270 \text{ kWh}$$

A maintenance program is in place to ensure leaks are maintained.  Hence, the annual energy savings by repairing air leaks is discounted by 50%.  Annual energy savings therefore is 18,135 kWh.

**Estimated Annual Demand Savings from Reducing Air Leaks**

$$\text{Annual Demand Savings (kW)} = \frac{\text{Annual Energy Savings (kWh)}}{\text{Annual Operating Hours (hours)}}$$

$$= \frac{36{,}270}{4551}$$

$$= 8.0 \text{ kW}$$

A maintenance program is in place to ensure leaks are maintained.  Hence, the annual demands savings by repairing air leaks is discounted by 50%.  Annual demands savings therefore is 4.0 kW.

## Measure 2 – Reduce Discharge Pressure

Information needed:     Baseline calculations (see Measure 1 calculations)
Target for Average Air Discharge Pressure = 98 psig

**Annual kWh Savings**

$$\text{Annual kWh Savings} = \frac{\left[ \text{Average normal operating discharge pressure (psig)} - \text{Target pressure (psig)} \right] \times \left( \text{Annual Energy Consumption of Compressors (kWh)} - \text{Annual Energy Savings from Reduced Leaks (kWh)} \right)}{2 \text{ psig} \times 100}$$

$$\text{Annual kWh Savings} = \left[\begin{array}{ccc} 107.5 & - & 98.0 \end{array}\right] \times \frac{815{,}975 - 36{,}270}{2 \text{ psig} \times 100}$$

$$\text{Annual kWh Savings} = 37{,}036 \text{ kWh}$$

## Annual kW Savings

$$\text{Annual kW Savings (kW)} = \frac{\text{Annual Energy Savings (kWh)}}{\text{Annual Operating Hours (hours)}}$$

$$= \frac{37{,}036}{4551}$$

$$= 8.1 \text{ kW}$$

Similar to Measure 1, if the facility has a maintenance program that ensures that a reduced set point is maintained, the Annual Energy Savings is discounted by 50%. Otherwise, it is discounted by 25%. In this example the annual kW and kWh savings are discounted by 50%, resulting in savings of 4.1 kW and 18,518 kWh.

### Measure 3 – Use Appropriate Dryer

Information needed:    Type of dryer currently employed = refrigerant or desiccant dryers
Amount of flow allocated to each Dryer = 500 cfm and 200 cfm
Tested flows for each of the dryer at 100% and 10% output
Each Dryer's Total Input Power

### Base Case Dryer 1 Power (Refrigerant Example)

$$\text{Base Case Dryer 1 Power (kW)} = \text{Dryer Input Power at 10\% Flow of Existing Dryer (kW)} + \left[\begin{array}{c}\text{Amount of Flow Allocated to Dryer \#1 (cfm)} - \text{Tested 10\% Flow (CAGI Box 6 for Refrigerant Dryers) (cfm)}\end{array}\right] \times \frac{\text{Dryer Input Power at 100\% Flow of Existing Dryer (kW)} - \text{Dryer Input Power at 10\% Flow of Existing Dryer (kW)}}{\text{Tested Existing Flow at 100\% (cfm)} - \text{Tested Existing Flow at 10\% (cfm)}}$$

$$= 7.2 + \left[\begin{array}{ccc} 500 & - & 131 \end{array}\right] \times \frac{7.4 - 7.2}{981 - 131}$$

$$= 7.29 \text{ kW}$$

A similar calculation is applied to generate a value for the power consumed by the Proposed Case Dryers. Repeating the calculation for Proposed Case Dryer 1 and 2 would yield the values 3.0 kW and 2.1 kW respectively.

**Base Case Dryer 2 Power (Desiccant Example)**

$$\text{Base Case Dryer 2 Power (kW)} = \frac{\text{Amount of Flow Allocated to Dryer \#2 (cfm)}}{100} \times 2.5 \ \text{(kW/cfm)}$$

$$= 200 / 100 \times 2.5$$

$$= 5 \ \text{kW}$$

**Base Case Total Dryer Power**

$$\text{Base Case Total Dryer Power (kW)} = \text{Base Case Dryer 1 Power (kW)} + \text{Base Case Dryer 2 Power (kW)}$$

$$= 7.29 + 5.00$$

$$= 12.29 \ \text{kW}$$

Repeating a similar calculation for the Proposed Case Total Dryer Power (kW) yields 5.10 kW.

**Annual kW Demand Savings**

$$\text{Annual kW Demand Savings (kW)} = \text{Base Case Total Dryer Power (kW)} - \text{Proposed Case Dryer (kW)}$$

$$= 12.29 - 5.10$$

$$= 7.2 \ \text{kW}$$

**Base Case Dryer Energy Consumption (kWh)**

$$\text{Base Case Dryer Energy Consumption (kWh)} = \text{Base Case Total Dryer Demand (kW)} \times \text{Annual Operating Hours (hours)}$$

$$= 12.29 \times 4551$$

$$= 55{,}932 \ \text{kWh}$$

Repeating a similar calculation for the Proposed Case Dryer Energy Consumption (kWh) yields 23.210 kWh.

**Annual kWh Energy Savings**

$$\text{Annual kWh Energy Savings (kWh)} = \text{Base Case Dryer (kWh)} - \text{Proposed Case Dryer (kWh)}$$

$$= 55{,}932 - 23{,}210$$

$$= 32{,}722 \text{ kWh}$$

## Measure 4 – Zero Loss Drain

Information needed:   Compressed Air System Operating Hours per Year = 4551
Blended Cost of Power = \$0.11/kWh
Seeking Incentive for this quantity of Zero Loss Drains = 3
Average drain blowdown time between cycles = 15 seconds
Average time between blowdown cycles = 2 minutes

| Annual Energy Savings (kWh) | = | Average drain blowdown time between cycles (s) | x | $\dfrac{\text{Compressed Air System Operating Hours per Year (hr)}}{\text{Average time between blowdown cycle (min)}}$ | x | 0.02125 | x | $\dfrac{\text{Seeking Incentive for this quantity of Zero Loss Drains}}{\text{Blended Cost of Power (\$/kWh)}}$ |
|---|---|---|---|---|---|---|---|---|
| | = | 15 | x | 4551 / 2 | x | 0.02125 | X | 3 / 0.11 |
| | = | 19,781 kWh | | | | | | |

**Annual kW Savings**

| Annual kW Savings (kW) | = | $\dfrac{\text{Annual Energy Savings (kWh)}}{\text{Compressed Air System Operating Hours per Year (hr)}}$ |
|---|---|---|
| | = | $\dfrac{19{,}781}{4551}$ |
| | = | 4.3 kW |

**Total Annual Energy Savings**

| Total Annual Energy Savings (kWh) | = | Annual Energy Savings from Measure 1 (kWh) | + | Annual Energy Savings from Measure 2 (kWh) | + | Annual Energy Savings from Measure 3 (kWh) | + | Annual Energy Savings from Measure 4 (kWh) |
|---|---|---|---|---|---|---|---|---|
| | = | 18,135 | + | 18,518 | + | 32,722 | + | 19,781 |
| | = | 89,156 kWh | | | | | | |

A similar calculation is applied to Total Annual Demand Savings, which yields a value of 19.6 kW.

**Calculation of Total Project Costs ($):**

Total Project Costs ($) are calculated from the summation of the total eligible project costs of each measure shown in the individual measures tab.

| Total Project Costs ($) | = | Total Eligible Project Cost for Measure 1 ($) | + | Total Eligible Project Cost for Measure 2 ($) | + | Total Eligible Project Cost for Measure 3 ($) | + | Total Eligible Project Cost for Measure 4 ($) |
|---|---|---|---|---|---|---|---|---|
| | = | 1,547 | + | 1,593 | + | 27,000 | + | 1,825 |
| | = | $ 31,965 | | | | | | |

**Calculation of Incentives ($):**

In calculating the Participant Incentives, $1,200/kW and $0.13 incentive rates are used for compressed air measures.

Calculated kW Participant Incentive ($1,200/kW of Demand Savings):

| Participant Incentive | = | 19.6 kW | x | $ 1,200/kW |
|---|---|---|---|---|
| | = | $ 23,520.00 | | |

Calculated kWh Participant Incentive ($0.13/kW of Energy Savings)

| Participant Incentive | = | 89,156 kWh | x | $ 0.13/kWh |
|---|---|---|---|---|
| | = | $ 11,590.28 | | |

Participant Incentive based on kW savings ($23,520.00) is greater than the Participant Incentive based on kWh savings ($11,590.28). Therefore, $23,520.00 is selected.

A cap is placed on the Participant Incentives as 50% of the total eligible project costs. 50% of the total eligible project costs in this scenario is $15,982.50. Therefore the Participant Incentives is capped at $15,982.50

## RETROFIT VARIABLE SPEED DRIVE (VSD) COMPRESSED AIR WORKSHEET

A facility is installing a new VSD air compressor to replace the existing fixed speed air compressor with intended compressor discharge pressure of 100 psig. The CAGI data sheets for the existing and new compressors are shown below. The operating hours of the air compressor is from 7 AM to 10 PM on weekday and 1 PM to 6 PM on weekends with 11 days of holidays annually.

Existing Fixed Speed Air Compressor is Kaeser Model # DSD 150, the efficiency performance of the compressor is captured on a CAGI data sheet available from the manufacturer.

Proposed VSD Air Compressor is Kaeser Model # SFC 90S, the efficiency performance of the compressor is captured on a CAGI data sheet available from the manufacturer and shown below.

On the Design and Assumption Tab, enter the intended compressor operating Discharge Pressure in psig.

| TYPICAL OPERATING PRESSURE | |
|---|---|
| 100 | Intended Compressor Operating Discharge Pressure (psig) |

Using the fixed speed air compressor CAGI Data Sheet shown below, enter information in Box # 1, 2, 3, 4, 10 & 11. Once all information is entered, a graph is generated on the side showing power and flow relationship of (y = mx + b) y = 0.131x + 29.7

### FIXED SPEED COMPRESSOR (CAGI DATA SHEET INPUTS)

| CAGI Data Sheet Field # | Description | Value | Units |
|---|---|---|---|
| 1 | Manufacturer | Kaeser | |
| 2 | Model | DSD 150 | |
| 3 | Rated Capacity at Full Load Operating Pressure: | 671 | acfm |
| 4 | Full Load Operating Pressure | 115 | psig |
| 10 | Total Package Input Power at Zero Flow | 29.7 | kW |
| 11 | Total Package Input Power at Rated Capacity and Full Load Operating Pressure | 117.5 | kW |

5.7  Full Load Flow:Power ratio seems OK (4-6 acfm/kW)
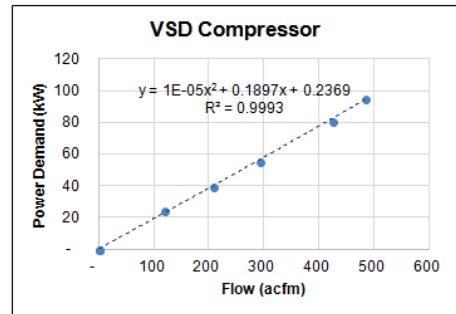Rated Pressure of Fixed Speed Compressor seems OK for Operating Pressure Requirements.



Fixed Speed Compressor

## KAESER COMPRESSORS

**COMPRESSOR DATA SHEET**
**Rotary Compressor: Fixed Speed**

### MODEL DATA - FOR COMPRESSED AIR

| | | | | |
|---|---|---|---|---|
| 1 | Manufacturer: | Kaeser Compressors, Inc. | | |
| 2 | Model Number: | DSD 150 - 125 psig / 460V/3ph/60Hz | Date: | 12/3/2012 |
| | ☐ Air-cooled   ☒ Water-cooled | | Type: | Screw |
| | ☒ Oil-injected   ☐ Oil-free | | # of Stages: | 1 |
| 3* | Rated Capacity at Full Load Operating Pressure [a, e] | | 671 | acfm [a,e] |
| 4 | Full Load Operating Pressure [b] | | 115 | psig [b] |
| 5 | Maximum Full Flow Operating Pressure [c] | | 125 | psig [c] |
| 6 | Drive Motor Nominal Rating | | 150 | hp |
| 7 | Drive Motor Nominal Efficiency | | 95.8 | percent |
| 8 | Fan Motor Nominal Rating (if applicable) | | 0.4 | hp |
| 9 | Fan Motor Nominal Efficiency | | 75 | percent |
| 10* | Total Package Input Power at Zero Flow [e] | | 29.7 | kW [e] |
| 11 | Total Package Input Power at Rated Capacity and Full Load Operating Pressure [d] | | 117.5 | kW [d] |
| 12* | Specific Package Input Power at Rated Capacity and Full Load Operating Pressure [e] | | 17.5 | kW/100 cfm [e] |

Using the VSD Compressor CAGI Data Sheet, enter information shown in Box # 1, 2, 3, 4, 10 & 11. Once all information is entered, a 2$^{nd}$ degree polynomial equation is generated (y = ax$^2$ + bx + c) y = 1.01E-05x$^2$ + 0.1897x + 0.2369 and graphically shown on the side.
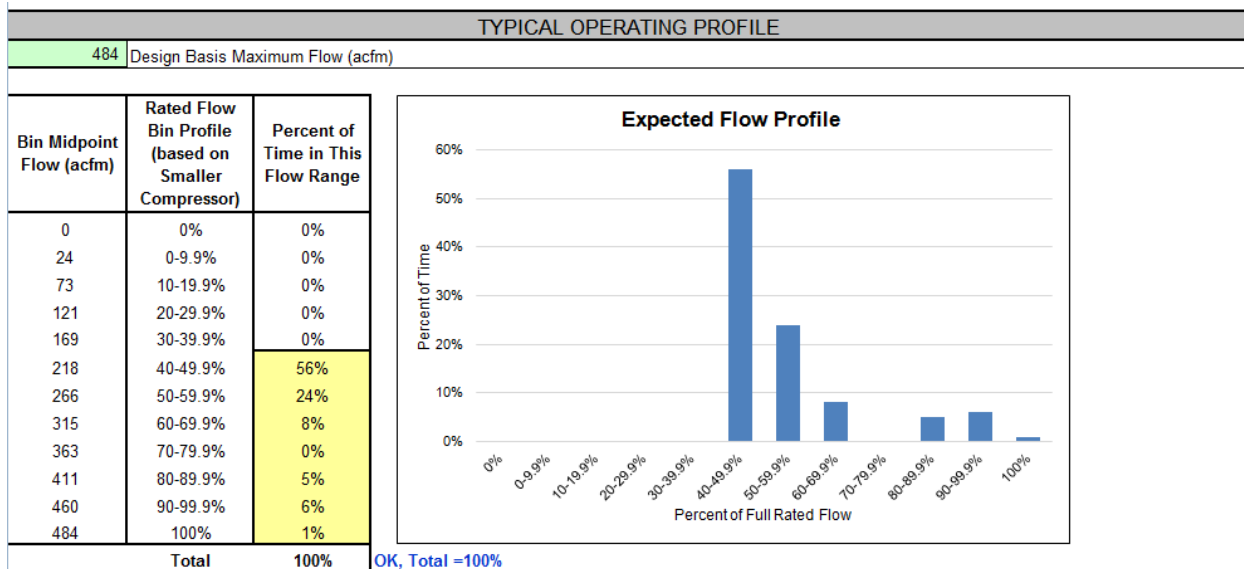
### VSD COMPRESSOR (CAGI DATA SHEET INPUTS)

| CAGI Data Sheet Field # | Description | Data Input | |
|---|---|---|---|
| 1 | Manufacturer | Kaeser | |
| 2 | Model Number | SFC 90S | |
| 3 | Rated Operating Pressure (psig) | 125 | |
| 8 | Input Power and Capacity | Input Power (kW) | Capacity (acfm) |
| | Point 1 (Max) | 95.5 | 484.0 |
| | Point 2 | 81.4 | 424.0 |
| | Point 3 | 55.6 | 293.0 |
| | Point 4 | 40.0 | 207.0 |
| | Point 5 | 24.7 | 118.0 |
| | Point 6 | 0.0 | 0.0 |
| | Point 7 | 0.0 | 0.0 |
| | Point 8 | 0.0 | 0.0 |
| 9 | Total Package Input Power at Zero Flow | 0.0 | |

**Rated Pressure** ~~Enter the cost of the VSD compressor, including~~ **s OK for Operating Pressure Requirements.**

**VSD Compressor**

y = 1E-05x$^2$ + 0.1897x + 0.2369
R$^2$ = 0.9993

(Power Demand (kW) vs Flow (acfm))

## COMPRESSOR DATA SHEET
### Rotary Compressor: Variable Frequency Drive

**KAESER COMPRESSORS**

| | MODEL DATA - FOR COMPRESSED AIR | | | |
|---|---|---|---|---|
| 1 | Manufacturer: | Kaeser Compressors, Inc. | | |
| 2 | Model Number: | SFC 90S - 125 psig / 460V/3ph/60Hz | Date: | 12/3/2012 |
| | X Air-cooled ☐ Water-cooled | | Type: | Screw |
| | X Oil-injected ☐ Oil-free | | # of Stages: | 1 |
| 3 | Rated Operating Pressure | | 125 | psig[b] |
| 4 | Drive Motor Nominal Rating | | 100 | hp |
| 5 | Drive Motor Nominal Efficiency | | 94.1 | percent |
| 6 | Fan Motor Nominal Rating (if applicable) | | 2 | hp |
| 7 | Fan Motor Nominal Efficiency | | 84 | percent |
| 8* | Input Power (kW) | | Capacity (acfm)[a,d] | Specific Power (kW/100 acfm)[d] |
| | 95.5 | Max | 484 | 19.74 |
| | 81.4 | | 424 | 19.20 |
| | 55.6 | | 293 | 18.97 |
| | 40.0 | | 207 | 19.36 |
| | 24.7 | Min | 118 | 20.86 |
| 9* | Total Package Input Power at Zero Flow[c,d] | | 0.0 | kW |

Enter a typical operationg profile that sums up to 100%. For example as shown below, 56% of the time, the air compressor operates between 40 to 49.9% of maximum flow.

### TYPICAL OPERATING PROFILE

**484** Design Basis Maximum Flow (acfm)

| Bin Midpoint Flow (acfm) | Rated Flow Bin Profile (based on Smaller Compressor) | Percent of Time in This Flow Range |
|---|---|---|
| 0 | 0% | 0% |
| 24 | 0-9.9% | 0% |
| 73 | 10-19.9% | 0% |
| 121 | 20-29.9% | 0% |
| 169 | 30-39.9% | 0% |
| 218 | 40-49.9% | 56% |
| 266 | 50-59.9% | 24% |
| 315 | 60-69.9% | 8% |
| 363 | 70-79.9% | 0% |
| 411 | 80-89.9% | 5% |
| 460 | 90-99.9% | 6% |
| 484 | 100% | 1% |
| **Total** | | **100%** |

OK, Total =100%



Expected Flow Profile

It is MANDATORY to provide a short note describing or explaining how the flow profile was determined. If this field is left blank, the energy savings will automatically default to 0.

### SHORT EXPLANATION

Provide short explanation regarding method used for flow profile estimate. Note this calculator does not accept VSD Compressor flows less than 40% of fully rated capacity.

Flow pattern based on data logging results for April 10-17 by XYZ Testing company...

**Calculation of Energy and demand savings:**

Refer to the following tables for the computation of the energy and demand savings:

For example at 40 to 49.9% Flow Bin Profile, demand for fixed power is y = 0.131x + 29.7 = 0.131 (218) + 29.7 = 58.26 x 56% = 32.59 kW

Demand for Variable speed power is y = 1.01E-05$x^2$ + 0.1897x + 0.2369 = 1.01E-05 (218)$^2$ + 0.1897x + 0.2369 = 42.03 x 56% = 23.59 kW

| Rated Flow Bin Profile | % Time | Expected Flow | Fixed Power | VSD Power | | |
|---|---|---|---|---|---|---|
| 0% | 0% | 0 | 0.00 | 0.00 | | |
| 0-9.9% | 0% | 24 | 0.00 | 0.00 | | |
| 10-19.9% | 0% | 73 | 0.00 | 0.00 | | |
| 20-29.9% | 0% | 121 | 0.00 | 0.00 | | |
| 30-39.9% | 0% | 169 | 0.00 | 0.00 | | |
| 40-49.9% | 56% | 218 | 32.59 | 23.54 | | |
| 50-59.9% | 24% | 266 | 15.49 | 12.35 | | |
| 60-69.9% | 8% | 315 | 5.67 | 4.87 | | |
| 70-79.9% | 0% | 363 | 0.00 | 0.00 | | |
| 80-89.9% | 5% | 411 | 4.18 | 4.00 | | |
| 90-99.9% | 6% | 460 | 5.39 | 5.38 | | |
| 100% | 1% | 484 | 0.93 | 0.94 | | |
| | | | 64.25 | 51.07 | | |
| | | | 0.925 | 0.875 | | |
| | | | 59.43 | 44.69 | 14.74 | |
| | | | | | Demand Savings | |
| | | | | | | |
| | | | 4260 | 4260 | No. of Hours | |
| | | | 253,166 | 190,373 | 62,793 | |
| | | | | | Energy Savings | |

The sum of demand is adjusted by the pressure difference between rated pressure and actual operating pressure expressed in psig as per following table.

| Pressure Adjustment for Fixed Speed Compressor | |
|---|---|
| Conventional Rated Pressure (psig) | 115 |
| Actual Operating Pressure (psig) | 100 |
| Pressure Difference x 0.5% | 0.075 |
| Adjustment | 0.925 |
| Pressure Adjustment for Variable Speed Compressor | |
| Conventional Rated Pressure (psig) | 125 |
| Actual Operating Pressure (psig) | 100 |
| Pressure Difference x 0.5% | 0.125 |
| Adjustment | 0.875 |

**VSD Air Compressor Engineered Worksheet**

| OPERATING INFORMATION |
|---|
| Using the 24 hour 7 day table below, enter "1" if the equipment is scheduled to operate and "0" if the equipment is not scheduled to operate. Times during operation will Illuminate purple. These numbers are used in energy calculations therefore if the time falls within the hour (i.e. 7:30) use your best estimate to choose the appropriate |

| Hour of Day | Sun | Mon | Tue | Wed | Thu | Fri | Sat |
|---|---|---|---|---|---|---|---|
| 0:00-0:59 am | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1:00-1:59 am | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2:00-2:59 am | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3:00-3:59 am | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4:00-4:59 am | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5:00-5:59 am | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6:00-6:59 am | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7:00-7:59 am | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 8:00-8:59 am | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 9:00-9:59 am | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 10:00-10:59 am | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 11:00-11:59 am | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 12:00-12:59 pm | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 1:00-1:59 pm | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2:00-2:59 pm | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3:00-3:59 pm | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4:00-4:59 pm | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5:00-5:59 pm | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6:00-6:59 pm | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 7:00-7:59 pm | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 8:00-8:59 pm | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 9:00-9:59 pm | 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 10:00-10:59 pm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11:00-11:59 pm | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Adjust the number of weekdays (Monday-Friday) by month that the equipment is not operating due to statutory, civic or other holidays, lieu days or scheduled shutdowns. The numbers pre-populated in the table represent the default statutory, civic or other holidays, per the table on the right.

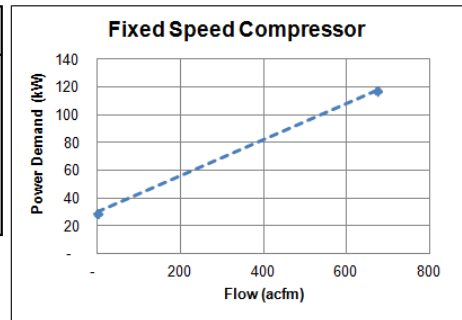| Month | Value |
|---|---|
| January | 1 |
| February | 1 |
| March | 0 |
| April | 2 |
| May | 1 |
| June | 0 |
| July | 1 |
| August | 1 |
| September | 1 |
| October | 1 |
| November | 0 |
| December | 2 |
| TOTAL: | 11 |

| Ontario Holidays | |
|---|---|
| New Years Day | January 1 |
| Family Day | 3rd Monday in February |
| Good Friday | Friday before Easter Sunday |
| Easter Monday | Monday after Easter Sunday |
| Victoria Day | Monday before May 25 |
| Canada Day | July 1 |
| Civic Holiday | 1st Monday in August |
| Labour Day | 1st Monday in September |
| Thanksgiving Day | 2nd Monday in October |
| Christmas Day | December 25 |
| Boxing Day | December 26 |

| | |
|---|---|
| 85 | This is the typical weekly number of operating hours for the equipment based on the schedule above (excluding holidays) |
| 4260 | This is the annual number of operating hours for the equipment based typical weekly and holiday schedule entered |

| | TYPICAL OPERATING PRESSURE |
|---|---|
| 100 | Intended Compressor Operating Discharge Pressure (psig) |

## FIXED SPEED COMPRESSOR (CAGI DATA SHEET INPUTS)

| CAGI Data Sheet Field # | Description | Value | Units |
|---|---|---|---|
| 1 | Manufacturer | Kaeser | |
| 2 | Model | DSD 150 | |
| 3 | Rated Capacity at Full Load Operating Pressure: | 671 | acfm |
| 4 | Full Load Operating Pressure | 115 | psig |
| 10 | Total Package Input Power at Zero Flow | 29.7 | kW |
| 11 | Total Package Input Power at Rated Capacity and Full Load Operating Pressure | 117.5 | kW |

**Fixed Speed Compressor**



**5.7  Full Load Flow:Power ratio seems OK (4-6 acfm/kW)**
**Rated Pressure of Fixed Speed Compressor seems OK for Operating Pressure Requirements.**

## VSD COMPRESSOR (CAGI DATA SHEET INPUTS)

| CAGI Data Sheet Field # | Description | Data Input | |
|---|---|---|---|
| 1 | Manufacturer | Kaeser | |
| 2 | Model Number | SFC 90S | |
| 3 | Rated Operating Pressure (psig) | 125 | |
| 8 | Input Power and Capacity | Input Power (kW) | Capacity (acfm) |
| | Point 1 (Max) | 95.5 | 484.0 |
| | Point 2 | 81.4 | 424.0 |
| | Point 3 | 55.6 | 293.0 |
| | Point 4 | 40.0 | 207.0 |
| | Point 5 | 24.7 | 118.0 |
| | Point 6 | | |
| | Point 7 | | |
| | Point 8 | | |
| 9 | Total Package Input Power at Zero Flow | 0.0 | |

**VSD Compressor**

$$y = 1E\text{-}05x^2 + 0.1897x + 0.2369$$
$$R^2 = 0.9993$$
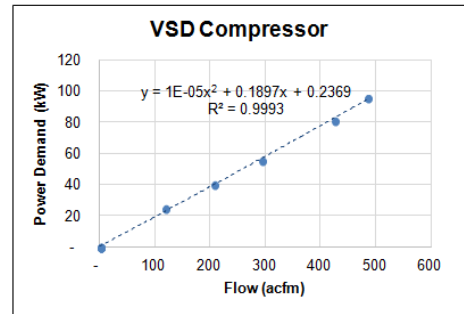


**Rated Pressure of VSD Compressor seems OK for Operating Pressure Requirements.**

## TYPICAL OPERATING PROFILE

| | |
|---|---|
| 484 | Design Basis Maximum Flow (acfm) |

| Bin Midpoint Flow (acfm) | Rated Flow Bin Profile (based on Smaller Compressor) | Percent of Time in This Flow Range |
|---|---|---|
| 0 | 0% | 0% |
| 24 | 0-9.9% | 0% |
| 73 | 10-19.9% | 0% |
| 121 | 20-29.9% | 0% |
| 169 | 30-39.9% | 0% |
| 218 | 40-49.9% | 56% |
| 266 | 50-59.9% | 24% |
| 315 | 60-69.9% | 8% |
| 363 | 70-79.9% | 0% |
| 411 | 80-89.9% | 5% |
| 460 | 90-99.9% | 6% |
| 484 | 100% | 1% |
| **Total** | | **100%** |

**Expected Flow Profile**



**OK, Total =100%**

| SHORT EXPLANATION |
|---|
| Provide short explanation regarding method used for flow profile estimate. Note this calculator does not accept VSD Compressor flows less than 10% of fully rated capacity. |
| Test Case |

**VSD and Fixed Speed Compressors are within 10% Capacity**

| COMMENTS & NOTES FOR TECHNICAL REVIEWER TO BE AWARE OF |
|---|
| Test Case |

| ECONOMIC VALUES | | | |
|---|---|---|---|
| | Value | Units | Description |
| $ | 0.25 | $/kWh | Blended Cost of Power based on Actual Billing Data |
| | | $ | Show Non Electrical Annual Savings as Positive  (Show Costs as a Negative Number) |

| PROJECT COST BREAKDOWN FOR FIXED SPEED AND VSD COMPRESSOR | |
|---|---|
| Costs which are eligible to be included in determining applicable Participant Incentives must be directly related to the procurement and implementation of the Eligible Measures and are limited to the following list.  Please enter the Eligible Costs below as applicable. | |
| $      44,500 | Actual costs of the VSD Compressor purchased and installed |
| $      32,550 | Actual costs of an equivalent Fixed Speed Compressor purchased and installed |
| $          - | Actual costs to dispose or decommission the replaced equipment |
| $          - | Actual costs of inspection of the Project as may be required pursuant to Laws and Regulations |
| $      11,950 | Incremental Cost of VSD Compressor vs. Fixed Speed Compressor if Project is Implemented |
| $      44,500 | **TOTAL ELIGIBLE COSTS FOR THE PROJECT** |

| ANNUAL SAVINGS AND ECONOMICS | | |
|---|---|---|
| **Value** | **Units** | **Description** |
| 253,166 | kWh | Estimated Fixed Speed Compressor Annual Energy Consumption |
| 190,373 | kWh | Estimated VSD Compressor Annual Energy Consumption if Project is Implemented |
| 62,793 | kWh | **Estimated Annual Energy Savings (Permanent and Non-Permanent) if Project is Implemented** |
| 59.4 | kW | Estimated Fixed Speed Compressor Peak Demand while Operating |
| 44.7 | kW | Estimated VSD Compressor Peak Demand while Operating if Project is Implemented |
| 14.7 | kW | Estimated Demand Reduction (while operating) if Project is Implemented |
| 25% | % | % Energy Savings |
| $ 15,698 | $ | Annual Electrical Savings if Project is Implemented ($) |
| $ 15,698 | $ | **Annual Total Savings if VSD Project is Implemented** |
| $ 44,500 | $ | Total Project Cost for VSD Compressor ($) |
| $ 11,950 | $ | **Incremental Capital Cost for Improvements if Project is Implemented ($)** |
| 2.8 | Years | Simple Payback for Incremental Cost Before Incentive (years) |
| $ 11,760 | $ | **Potential Incentive Amount ($)** |
| 2.1 | Years | **Simple Payback for Incremental Cost After Incentive (years)** |

## VSD Option is Better than Fixed Speed Option

| CONDITIONS AND DISCLAIMERS |
|---|

*Note 1:* Costs which are eligible to be included in determining applicable Participant Incentives must be directly related to the procurement and implementation of the

For certainty, costs which are not eligible to be included in Eligible Costs include:
(i) any costs that are not third party costs or that are internal costs of the Participant, including costs of the Participant's labour, service, administration or overhead;
(ii) financing costs of the Participant;
(iii) related insurance costs of the Participant;
(iv) costs associated with post-installation maintenance or service contracts;
(v) costs of spare parts, spare equipment or other inventories;
(vi) purchase or lease of tools for installation of equipment;
(vii) HST; and
(viii) a portion of the costs of Eligible Measures that have been or will be received from financial incentives generally funded by energy ratepayers or taxpayers in the Province of Ontario (other than funding principally directed to Social Housing Providers if, combined with the Participant Incentive, such funding does not exceed the actual cost of the Project) or rebates from manufacturers or wholesalers or other supply chain participants.
Note: Capitalized terms above are as defined in the Participant Agreement

## PROJECT ENGINEERING ESTIMATES

This section highlights the demand and energy consumption for the Base Case and Energy Efficient Case. From this data, the savings associated with implementing the energy efficient option are calculated.

| | Base Case Measure | Energy Efficient Case Measure | Savings Summary | |
|---|---|---|---|---|
| Maximum Summer Peak Period Demand (kW) | 59.4 | 44.7 | 14.7 | (Occurs During Summer On-Peak Period) |
| Average Summer Peak Demand (kW) | 57.3 | 43.1 | 14.2 | (Summer On-Peak Energy/On-Peak Hours) |
| Average to Maximum Ratio (%) | 96% | 96% | 96% | |
| Maximum Winter Peak Period Demand (kW) | 59.4 | 44.7 | 14.7 | (Occurs During Winter On-Peak Period) |
| Average Winter Peak Demand (kW) | 56.6 | 42.6 | 14.0 | (Winter On-Peak Energy/On-Peak Hours) |
| Average to Maximum Ratio (%) | 95% | 95% | 95% | |
| Annual Electricity Consumption (kWh) | 253,166 | 190,373 | 62,793 | |

## PROJECT ECONOMICS

Based on cost information entered by the user along with calculated Participant Incentive amounts, the project economics are summarized. If the motor option is selected, the Participant Incentive is based on the Prescriptive Motor Eligible Measures Worksheet. In this scenario, the Demand Savings and Energy Savings are backed out of the calculated Participant Incentive and the prescriptive amount is entered.

| | |
|---|---|
| Assumed Blended Electricity Rate ($/kWh): | $ 0.250 |
| Estimated Annual Energy Savings ($/year): | $ 15,698 |
| Other Savings (Cost) ($/year): | $ - |
| Estimated Total Annual Savings ($/year): | $ 15,698 |
| Demand Savings[1] (kW) for the purpose of calculating the Participant Incentive | 14.7 |
| Energy Savings[2] (kWh) for the purpose of calculating the Participant Incentive | 62,793 |
| Total Eligible Costs for the Project($): | $ 44,500 |
| Calculated kW Participant Incentive ($800/kW of Demand Savings) | $ 11,760 |
| Calculated kWh Participant Incentive ($0.10/kWh of Energy Savings) | $ 6,279 |
| **Estimated Participant Incentive Amount[3,4]:** | $ 11,760 |
| Simple Payback (without Participant Incentive) | 2.8 |
| Simple Payback (with Participant Incentive) | 2.1 |

*NOTE: These values go to the saveONenergy RETROFIT Program Application under the Site and Project Details of the Engineered Approach - Demand (kW) and Energy (kWh) Savings*

## OPA QC & DIAGNOSTICS

This section displays some checks that can be used to identify if the savings calculated are realistic with respect to the facility consumption.

| | | | |
|---|---|---|---|
| Peak kW Savings - Percent of Facility Summer Peak Demand | 10.5% | Facility Total kWh | 6,320,000 |
| Average kW Savings - Percent of Summer Peak Demand | 10.2% | Max Summer kW | 140 |
| Percent of Facility Winter Peak Demand | 11.2% | Max Winter kW | 132 |
| Average Savings - Percent of Winter Peak Demand | 10.6% | | |
| Percent of Facility Total Annual Electricity Consumption | 1.0% | | |
| LDC Average to Maximum Threshold Level (%) | 50% | | |
| Actual Average to Maximum Threshold Level (%) | 96% | | |
| Average to Maximum Ratio exceeds Average to Maximum Threshold Level[4]: | YES | | |

## CONDITIONS AND DISCLAIMERS

*Note 1:* Demand Savings (kW) are the maximum reduction in electricity demand between the Base Case and the Energy Efficient Case occurring in the same hour between 11 am to 5 pm on business days, June 1 through September 30. For Measures that are weather dependent, Demand Savings shall be considered as occurring at peak design load conditions.

*Note 2:* Energy Savings (kWh) are those electricity savings achieved over the course of the first year after the completion of a Project.

*Note 3:* Estimated Participant Incentive Amount is calculated as the maximum of Calculated kW Participant Incentive and Calculated kWh Participant Incentive, with a Maximum Allowable Participant Incentive at 50% of Total Eligible Costs for the Project.

*Note 4:* The Participant Incentive Amount indicated in this Engineering Worksheet is added up to the Prescriptive and Custom Incentive Amounts, if there are any. Likewise, the Project Cost in this Engineering Worksheet is added up to the Prescriptive and Custom Project Costs, if there are any, summing it up to the Total Project Cost which would, in turn, serve as the basis for the 50% Project Cost Cap.

Pro

**Calculation of Total Project Costs ($):**

It is assumed that the total project costs amount to $ 44,500.00

**Calculation of Incentives ($):**

Calculated kW Participant Incentive ($1,200/kW of Demand Savings):

| Participant Incentive | = | 14.7 kW | x | $1,200/kW |
|---|---|---|---|---|
| | = | $ 17,640.00 | | |

Calculated kWh Participant Incentive ($0.13/kW of Energy Savings)

| Participant Incentive | = | 62,793 kWh | x | $ 0.13/kWh |
|---|---|---|---|---|
| | = | $ 8,163.09 | | |

A cap is placed on the Participant Incentives as 50% of the total eligible project costs. 50% of the total eligible project costs in this scenario is $22,250. Therefore the Participant Incentives is at $17,640.

# RETROFIT VARIABLE SPEED DRIVE (VSD) ON FANS ENGINEERED WORKSHEET

A company has decided to install a VSD on its 50,000 cfm fan. The fan's operating hours are from 6:00 a.m. to 10:00 p.m. Mondays to Fridays and from 7:00 a.m. to 7:00 p.m. on Saturdays. The facility is closed on Sundays and holidays. The existing fan and motor information are as follows:
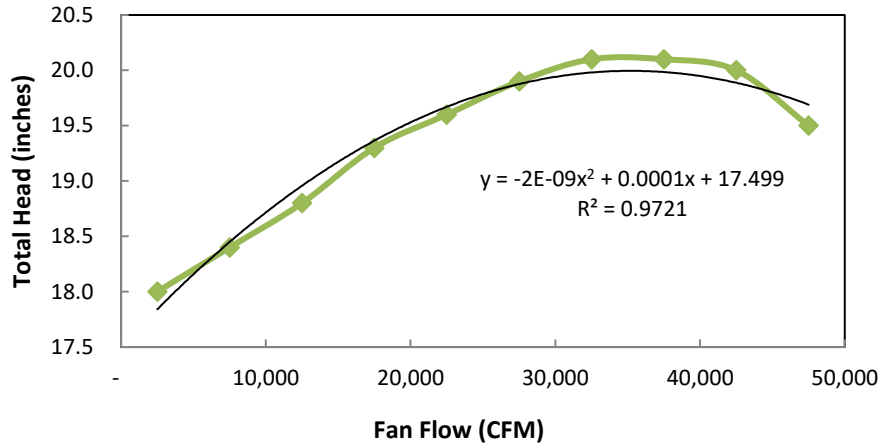
| FAN AND MOTOR INFORMATION | | |
|---|---|---|
| | **Units** | **Description** |
| 890 | rpm | Motor Rated Speed |
| 200 | BHP | Motor Rated Power |
| 68 | °F | Gas Temperature |
| 0.075 | lb/ft3 | Density of Gas (use 0.075 lb/ft3 for air at 68F) |
| 19.5 | "WG | Design Head (at X) |
| 0.0 | "WG | Static Head |
| ABC-123 | n/a | Motor Make and Model |
| XYZ-999 | n/a | Fan Make and Model |
| 10 | years | Approximate age of Motor |
| 10 | years | Approximate age of Fan |

The design head and fan efficiency for different percent flow as read from the performance curve of the fan, as well as the operating profile are entered on the following table:
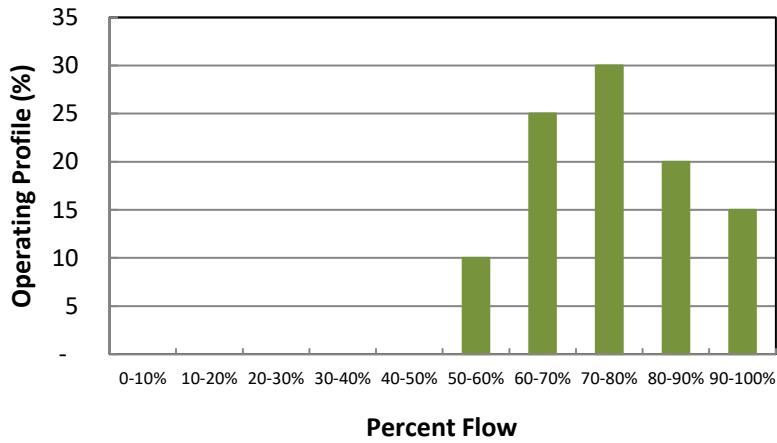
| %Flow | Design Head ("WG) | Corresponding Fan Efficiency (%) | Operating Profile (%) |
|---|---|---|---|
| 0-10% | 18.0 | 20 | |
| 10-20% | 18.4 | 20 | |
| 20-30% | 18.8 | 20 | |
| 30-40% | 19.3 | 20 | |
| 40-50% | 19.6 | 30 | |
| 50-60% | 19.9 | 40 | 10 |
| 60-70% | 20.1 | 50 | 25 |
| 70-80% | 20.1 | 60 | 30 |
| 80-90% | 20.0 | 70 | 20 |
| 90-100% | 19.5 | 80 | 15 |
| **Design** | **19.5** | **87** | **100** |

The fan curve and the operating profile as generated by the Engineered Worksheet are shown on the next page.

## Fan Curve

$$y = -2E\text{-}09x^2 + 0.0001x + 17.499$$
$$R^2 = 0.9721$$

Total Head (inches) vs Fan Flow (CFM)

## Fan Operating Profile

Operating Profile (%) vs Percent Flow

| FAN AND MOTOR EFFICIENCY | | |
|---|---|---|
| | **Units** | **Description** |
| 93.0 | % | Motor Full Load Efficiency |
| 86.7 | % | Fan Efficiency at Damper Fully Open |
| 0.96 | fraction | Motor Efficiency Correction Factor for Lower Loads |
| 0.95 | fraction | VSD Efficiency Factor (When Operating > 40% Load) |
| 0.82 | fraction | Motor Efficiency Correction Factor for VSD Operation |
| 0.96 | fraction | Belt/Coupling Efficiency Factor |

**Calculation of Energy Savings (kWh):**

For each % flow in the conventional fan system, the fan horsepower (FHP) is calculated using the following equation:

$$\text{Fan Horsepower (FHP}_b) = \frac{Q_b \times P \times \rho}{\eta_{fan} \times 6356}$$

For 50-60% flow, consider $Q_b$ = 50,000 cfm x 0.55 = 27,500 cfm; P = 19.9"WG; $\rho$ = 0.075 lbs/ft$^3$; and $\eta_{fan}$ = 0.40

$$\text{Fan Horsepower (FHP}_b) = \frac{27,500 \times 19.9 \times 1.0}{0.40 \times 6356}$$

$$= 215.25 \text{ hp}$$

The conventional fan system energy consumption (kWh) for each bin is calculated using the following equation:

$$\text{Conventional Annual Energy Consumption (kWh}_b) = \frac{FHP_b \times 0.746 \times H}{(\eta_{motor} \times \eta_{belt/coupling}) / 100}$$

The annual operating hours is located under the *System Schedule* tab. For the above equation, H represents the operating hours for each % flow. For 50-60%, H = 4620 hours x 0.10 = 462 hours.

$$\text{Conventional Annual Energy Consumption (kWh}_b) = \frac{215.25 \times 0.746 \times 462}{(0.93 \times 0.96 \times 0.96) / 100}$$

$$= 86,556 \text{ kWh}$$

**Conventional Annual Energy Consumption (kWh$_b$) for each Flow**

| %Flow | Flow (cfm) | Design Head ("WG) | Fan Efficiency (%) | Operating Profile (%) | Hours | Fan HP | kWh |
|---|---|---|---|---|---|---|---|
| 0-10% | 2,500 | 18.0 | 20 | | | 35.40 | |
| 10-20% | 7,500 | 18.4 | 20 | | | 108.56 | |
| 20-30% | 12,500 | 18.8 | 20 | | | 184.86 | |
| 30-40% | 17,500 | 19.3 | 20 | | | 265.69 | |
| 40-50% | 22,500 | 19.6 | 30 | | | 231.28 | |
| 50-60% | 27,500 | 19.9 | 40 | 10 | 462 | 215.25 | 86,556 |
| 60-70% | 32,500 | 20.1 | 50 | 25 | 1,155 | 205.55 | 206,643 |
| 70-80% | 37,500 | 20.1 | 60 | 30 | 1,386 | 197.65 | 231,209 |
| 80-90% | 42,500 | 20.0 | 70 | 20 | 924 | 191.05 | 148,990 |
| 90-100% | 47,500 | 19.5 | 80 | 15 | 693 | 182.16 | 106,546 |
| **Design** | | **19.5** | **87** | **100** | | **Total:** | **779,945** |

The total annual energy consumption for the base case sums up all the energy consumption in the 10 bins. For this particular example, total annual energy consumption is 779,945 kWh.

Likewise, for the Variable Speed Drive on Fans option, the annual energy consumption in kWh is calculated the same way as the Conventional Fan System except that there is an additional definition for total head and efficiencies.

$$P = P_s + (P_d - P_s)(Q / Q_d)^2$$

For the 50-60% flow, static head $P_s = 0$; design head for $P_d = 19.5$ in $H_2O$; $Q = 27,500$ cfm; $Q_d = 50,000$ cfm

$$P = 0 + (19.5 - 0)(27,500 / 50,000)^2$$
$$P = 5.90 \text{ in } H_2O$$

Calculate the fan horsepower for the VSD option:

$$\text{Fan Horsepower (FHP}_r) = \frac{Q_r \times P \times \rho}{\eta_{fan} \times 6356}$$

For 50-60% flow, consider $Q_r = 50,000$ cfm x 0.55 = 27,500 cfm; P = 5.9"WG; $\rho = 0.075$ lbs/ft³; and $\eta_{fan} = 0.867$

$$\text{Fan Horsepower (FHP}_r) = \frac{27,500 \times 5.9 \times 1.0}{0.867 \times 6356}$$
$$= 29.44 \text{ hp}$$

The energy consumption (kWh) for each bin for the VSD option is calculated using the following equation:

$$\text{VSD Option Annual Energy Consumption (kWh}_r) = \frac{FHP_r \times 0.746 \times H}{\eta_{motor} \times \eta_{VSD} \times \eta_{belt/coupling}}$$
$$= \frac{29.44 \times 0.746 \times 462}{(0.93 \times 0.82) \times 0.95 \times 0.96}$$
$$= 14,587 \text{ kWh}$$

The total annual energy consumption for the VSD option sums up all the energy consumption in the 10 bins. For this particular example, total annual energy consumption is 406,201 kWh. See table on the next page.

Getting the difference between the conventional and the VSD option, annual savings is calculated to be 373,743 kWh.

**VSD Option Annual Energy Consumption (kWh_b) for each Flow**

| %Flow | Flow (cfm) | System Head | Operating Profile (%) | Hours | Fan HP | kWh | Savings |
|---|---|---|---|---|---|---|---|
| 0-10% | 2,500 | 0.05 | | | 0.02 | | |
| 10-20% | 7,500 | 0.44 | | | 0.60 | | |
| 20-30% | 12,500 | 1.22 | | | 2.76 | | |
| 30-40% | 17,500 | 2.39 | | | 7.59 | | |
| 40-50% | 22,500 | 3.95 | | | 16.12 | | |
| 50-60% | 27,500 | 5.90 | 10 | 462 | 29.44 | 14,587 | 71,969 |
| 60-70% | 32,500 | 8.24 | 25 | 1,155 | 48.59 | 60,196 | 146,447 |
| 70-80% | 37,500 | 10.97 | 30 | 1,386 | 74.64 | 110,968 | 120,242 |
| 80-90% | 42,500 | 14.09 | 20 | 924 | 108.66 | 107,691 | 41,300 |
| 90-100% | 47,500 | 17.60 | 15 | 693 | 151.70 | 112,759 | (6,213) |
| Design | | | 100 | | Total: | 406,201 | 373,743 |

**Calculation of Demand Savings (kW):**

The maximum summer and winter peak period demand (kW) savings are calculated by dividing the annual energy savings (kWh) by the total annual hours of operation.

$$\text{Demand Savings (kW)} = \frac{\text{Annual Energy Savings (kWh)}}{\text{Annual Operating Hours (hrs)}}$$

= 373,743 kWh /4620 hrs

= 80.9 kW

**Calculation of Total Project Costs ($):**

It is assumed that the total project costs amount to $ 141,500.00 broken down as follows:

Variable speed drive cost    $ 125,000.00
Labour to install VSD    $ 16,500.00

        Total:    $ 141,500.00

**Calculation of Incentives ($):**

Calculated kW Participant Incentive ($1,200/kW of Demand Savings):

Participant Incentive  =  80.9 kW  x  $1,200/kW

      =  $ 97,080.00

Calculated kWh Participant Incentive ($0.13/kW of Energy Savings)

Participant Incentive     =    373,743 kWh    x    $ 0.13/kWh

                                 =    $ 48,586.59

A cap is placed on the Participant Incentives as 50% of the total eligible project costs. 50% of the total eligible project costs in this scenario is $70,750.00. As this value is lower than Participant Incentives selected of $97,080.00, therefore the Participant Incentives is capped at $70,750.00
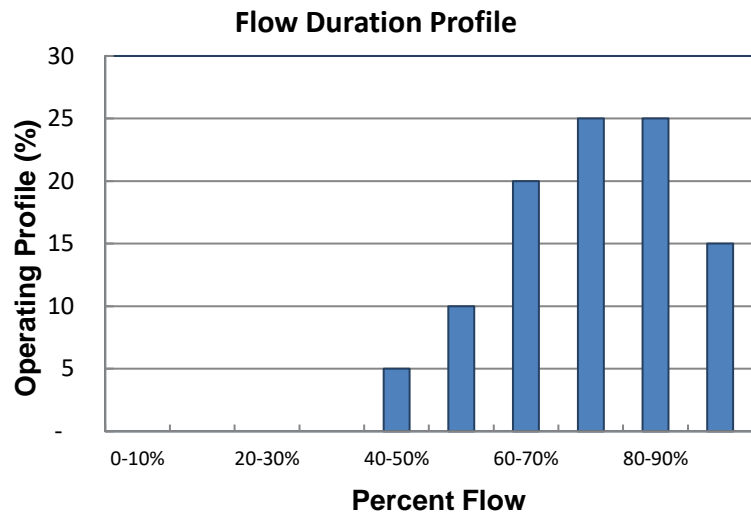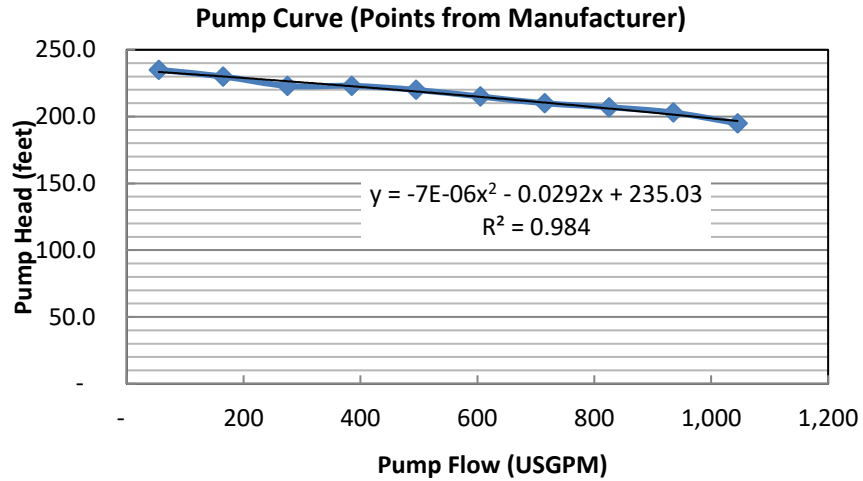
## RETROFIT VARIABLE SPEED DRIVE (VSD) ON PUMP ENGINEERED WORKSHEET

A company has decided to install a VSD on its 1,100 gpm pump. The fan's operating hours are from 10:00 a.m. to 8:00 p.m. Mondays to Fridays and from 10:00 a.m. to 5:00 p.m. on Saturdays. The facility is closed on Sundays and holidays. The existing pump and motor information are as follows:

| FAN AND MOTOR INFORMATION | | |
|---|---|---|
| | **Units** | **Description** |
| 1750 | rpm | Motor Rated Speed |
| 75 | BHP | Motor Rated Power |
| 65 | °F | Fluid Temperature |
| 1.00 | S.G. | Specific Gravity of Fluid (Water =1.00) |
| 190.0 | ft | Design Head (at X) |
| 20.0 | ft | Static Head |
| ABC-123 | n/a | Motor Make & Model |
| XYZ-999 | n/a | Pump Make and Model |
| 5 | years | Approximate age of Motor |
| 3 | years | Approximate Age of Pump |

The pump head and pump efficiency for different percent flow as read from the performance curve of the pump, as well as the operating profile are entered on the following table:

| %Flow | Pump Head (ft) | Corresponding Pump Efficiency (%) | Operating Profile (%) |
|---|---|---|---|
| 0-10% | 235.0 | 20.0 | |
| 10-20% | 230.0 | 20.0 | |
| 20-30% | 223.0 | 35.0 | |
| 30-40% | 223.0 | 50.0 | |
| 40-50% | 220.0 | 60.0 | 5.0 |
| 50-60% | 215.0 | 70.0 | 10.0 |
| 60-70% | 210.0 | 72.0 | 20.0 |
| 70-80% | 207.0 | 74.0 | 25.0 |
| 80-90% | 203.0 | 76.0 | 25.0 |
| 90-100% | 195.0 | 78.0 | 15.0 |
| **Design** | **190** | **80** | **100** |

The pump curve and the operating profile as generated by the Engineered Worksheet are shown on the next page.

**Pump Curve (Points from Manufacturer)**

$y = -7E\text{-}06x^2 - 0.0292x + 235.03$
$R^2 = 0.984$

Pump Head (feet) vs Pump Flow (USGPM)

**Flow Duration Profile**

Operating Profile (%) vs Percent Flow

| PUMP AND MOTOR EFFICIENCY | | |
|---|---|---|
| | **Units** | **Description** |
| 95.4 | % | Motor Full Load Efficiency |
| 80.0 | % | Pump Efficiency (at X) |
| 0.95 | fraction | Motor Efficiency Correction Factor for Lower Loads |
| 0.95 | fraction | VSD Efficiency Factor (When Operating > 40% Load) |
| 0.82 | fraction | Motor Efficiency Correction Factor for VSD Operation |

**Calculation of Energy Savings (kWh):**

For each % flow in the conventional pump system, the pump horsepower (PHP) is calculated using the following equation:

$$\text{Pump Horsepower (PHP}_b) = \frac{Q_b \times P \times \gamma}{\eta_{pump} \times 3958}$$

For 50-60% flow, consider $Q_b$ = 1,100 gpm x 0.55 = 605 gpm; P = 215 ft; $\gamma$ = 1.0; and $\eta_{pump}$ = 0.70

$$\text{Pump Horsepower (PHP}_b) = \frac{605 \times 215 \times 1.0}{0.70 \times 3958}$$

$$= 46.95 \text{ hp}$$

The conventional pump system energy consumption (kWh) for each bin is calculated using the following equation:

$$\text{Conventional Annual Energy Consumption (kWh}_b) = \frac{PHP_b \times 0.746 \times H}{(\eta_{motor})}$$

The annual operating hours is located under the *System Schedule* tab. For the above equation, H represents the operating hours for each % flow. For 50-60%, H = 2861 hours x 0.10 = 286 hours.

$$\text{Conventional Annual Energy Consumption (kWh}_b) = \frac{46.95 \times 0.746 \times 286.1}{(0.954 \times 0.95)}$$

$$= 11,056.6 \text{ kWh}$$

**Conventional Annual Energy Consumption (kWh$_b$) for each Flow**

| %Flow | Flow (GPM) | Design Head (ft) | Pump Efficiency (%) | Operating Profile (%) | Hours | Pump HP | kWh |
|---|---|---|---|---|---|---|---|
| 0-10% | 55 | 235.0 | 20.0 | | | 16.33 | - |
| 10-20% | 165 | 230.0 | 20.0 | | | 47.94 | - |
| 20-30% | 275 | 223.0 | 35.0 | | | 44.27 | - |
| 30-40% | 385 | 223.0 | 50.0 | | | 43.38 | - |
| 40-50% | 495 | 220.0 | 60.0 | 5.0 | 143 | 45.86 | 5,699 |
| 50-60% | 605 | 215.0 | 70.0 | 10.0 | 286 | 46.95 | 11,056 |
| 60-70% | 715 | 210.0 | 72.0 | 20.0 | 572 | 52.69 | 24,816 |
| 70-80% | 825 | 207.0 | 74.0 | 25.0 | 715 | 58.31 | 32,940 |
| 80-90% | 935 | 203.0 | 76.0 | 25.0 | 715 | 63.10 | 35,648 |
| 90-100% | 1,045 | 195.0 | 78.0 | 15.0 | 429 | 66.01 | 22,374 |
| **Design** | | **190** | **80** | **100** | | **Total:** | **132,534** |

The total annual energy consumption for the base case sums up all the energy consumption in the 10 bins. For this particular example, total annual energy consumption is 132,534 kWh.

Likewise, for the Variable Speed Drive on Pump option, the annual energy consumption in kWh is calculated the same way as the Conventional Pump System except that there is an additional definition for total head and efficiencies.

$$P = P_s + (P_d - P_s)(Q / Q_d)^2$$

For the 50-60% flow, static head $P_s$ = 20 ft; design head for $P_d$ = 190 ft; Q = 605 gpm; $Q_d$ = 1100 gpm

$$P = 20 + (190 - 20)(605 / 1100)^2$$
$$P = 71.43 \text{ ft}$$

Calculate the fan horsepower for the VSD option:

$$\text{Pump Horsepower (PHP}_r) = \frac{Q_r \times P \times \gamma}{\eta_{pump} \times 3958}$$

For 50-60% flow, consider $Q_r$ = 1,100 gpm x 0.55 = 605 gpm; P = 71.43 ft; $\gamma$ = 1.0; and $\eta_{pump}$ = 0.80

$$\text{Pump Horsepower (PHP}_r) = \frac{605 \times 71.43 \times 1.0}{0.8 \times 3958}$$
$$= 13.65 \text{ hp}$$

The energy consumption (kWh) for each bin for the VSD option is calculated using the following equation:

$$\text{VSD Option Annual Energy Consumption (kWh}_r) = \frac{PHP_r \times 0.746 \times H}{\eta_{motor} \times \eta_{VSD}}$$
$$= \frac{13.65 \times 0.746 \times 286}{(0.954 \times 0.82) \times 0.95}$$
$$= 3,919 \text{ kWh}$$

The total annual energy consumption for the VSD option sums up all the energy consumption in the 10 bins. For this particular example, total annual energy consumption is 93,617 kWh. See table on the next page.

Getting the difference between the conventional and the VSD option, annual savings is calculated to be 38,917 kWh.

**VSD Option Annual Energy Consumption (kWh$_b$) for each Flow**

| %Flow | Flow (gpm) | System Head | Operating Profile (%) | Hours | Pump HP | kWh | Savings |
|---|---|---|---|---|---|---|---|
| 0-10% | 55 | 20.43 | | | 0.35 | - | - |
| 10-20% | 165 | 23.83 | | | 1.24 | - | - |
| 20-30% | 275 | 30.63 | | | 2.66 | - | - |
| 30-40% | 385 | 40.83 | | | 4.96 | - | - |
| 40-50% | 495 | 54.43 | 5.0 | 143 | 8.51 | 1,222 | 4,478 |
| 50-60% | 605 | 71.43 | 10.0 | 286 | 13.65 | 3,919 | 7,137 |
| 60-70% | 715 | 91.83 | 20.0 | 572 | 20.73 | 11,910 | 12,906 |
| 70-80% | 825 | 115.63 | 25.0 | 715 | 30.13 | 21,630 | 11,311 |
| 80-90% | 935 | 142.83 | 25.0 | 715 | 42.17 | 30,280 | 5,367 |
| 90-100% | 1,045 | 173.43 | 15.0 | 429 | 57.24 | 24,656 | (2,282) |
| Design | | | 100 | | Total: | 93,617 | 38,917 |

## Calculation of Demand Savings (kW):

The maximum summer and winter peak period demand (kW) savings are calculated by dividing the annual energy savings (kWh) by the total annual hours of operation.

Demand Savings (kW)
$$= \frac{\text{Annual Energy Savings (kWh)}}{\text{Annual Operating Hours (hrs)}}$$

= 38,917 /2861 hrs

= 13.6 kW

## Calculation of Total Project Costs ($):

It is assumed that the total project costs amount to $ 30,800.00 broken down as follows:

Variable speed drive cost     $ 23,200.00
Labour to install VSD     $ 7,600.00
        Total:     $ 30,800.00

## Calculation of Incentives ($):

Calculated kW Participant Incentive ($1,200/kW of Demand Savings):

Participant Incentive    =    13.6 kW    x    $1,200/kW

                   =    $ 16,320.00

Calculated kWh Participant Incentive ($0.13/kW of Energy Savings)

Participant Incentive    =    38,917 kWh    x    $ 0.13/kWh

                   =    $ 5,059.21

A cap is placed on the Participant Incentives as 50% of the total eligible project costs. 50% of the total eligible project costs in this scenario is $15,400. As this value is lower than Participant Incentives selected of $16,320, therefore the Participant Incentives is capped at $15,400.

## RETROFIT UNITARY AIR-CONDITIONING (A/C) ENGINEERED WORKSHEET

A community centre in Ottawa is installing an energy efficient rooftop unit to retrofit its existing unit serving 400 m$^2$ of space. The facility operates from 10:00 am to 9:00 p.m. Monday to Friday and from 10:00 a.m. to 5:00 p.m. on Saturday, Sunday and holidays.

**Existing Unitary A/C System (Quantity of 2)**:

- Capacity – 72,000 Btu/h
- EER – 8.9

**Proposed Unitary A/C System (Quantity of 2)**:

- Capacity – 72,000 Btu/h
- EER – 12.0

**Calculation of Demand Savings (kW):**

The energy performance of the Unitary A/C is determined by calculating the energy consumption of both the existing (base case) and retrofit (design case) units for each hour that the equipment operates during the year. First, peak (rated) power (in watts) is calculated by dividing the capacity (Btu/hr) by the energy efficiency ratio (EER). This is then converted to kilowatts.

$$\text{Rated kW}_b = \frac{\text{Capacity (Btu/h)}}{\text{EER (Btu/Wh) x 1000}}$$

$$= 72,000 / (8.9 \text{ x } 1000)$$

$$= 8.09 \text{ kW}$$

$$\text{Rated kW}_r = \frac{\text{Capacity (Btu/h)}}{\text{EER (Btu/Wh) x 1000}}$$

$$= 72,000 / (12.0 \text{ x } 1000)$$

$$= 6.0 \text{ kW}$$

Power consumption at part load is calculated via a methodology published by NRCan for use in a building modeling software called EE4. This methodology is based on percentage unit output, wet bulb and dry bulb temperatures and yields the % of peak power consumed at part load. This calculation is performed for each hour of the year that operation is scheduled.

For this example, a community centre is selected and will assume a part load for the whole 8760 hours represented by the graph below. For calculation purposes, we will show how power consumption at part load is estimated using NRCan's methodology. We will assume a weekday in July from 11:00 a.m. to 5:00 p.m.
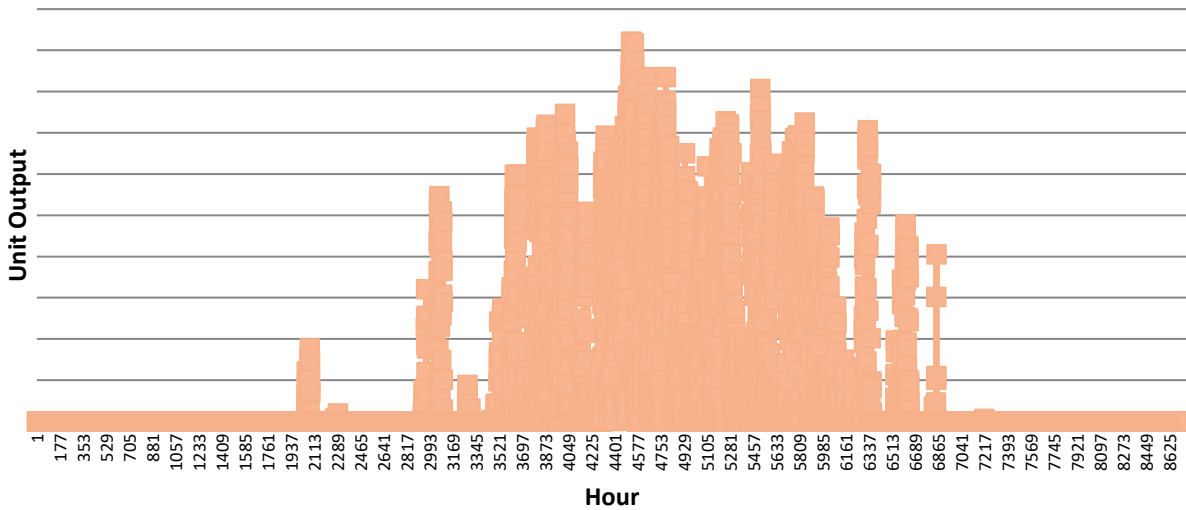
**Data Input Requirements**

| Time | % Unit Output | Dry Bulb Temperature | Wet Bulb Temperature |
|---|---|---|---|
| 11:00 am – 12:00 pm | 0.01250 | 73.22 | 59.62 |
| 12:00 pm – 1:00 pm | 0.03075 | 73.76 | 58.90 |
| 1:00 pm – 2:00 pm | 0.04600 | 75.20 | 58.96 |
| 2:00 pm – 3:00 pm | 0.13325 | 74.84 | 57.98 |
| 3:00 pm – 4:00 pm | 0.05625 | 75.74 | 58.99 |
| 4:00 pm – 5:00 pm | 0.13950 | 75.74 | 57.73 |

For each hour, the base consumption and retrofit consumptions will be calculated using NRCan's methodology.

Cooling Capacity Adjustment Curve

$$\text{CAP\_FT} = 0.8740302 + (-0.0011416 \times t_{wb}) + (0.0001711 \times t_{wb}^2) + (-0.0029570 \times t_{odb}) + (0.0000102 \times t_{odb}^2) + (-0.0000592 \times t_{wb} \times t_{odb})$$

Adjustment to Rated Efficiency due to Environmental Variables

$$\text{EIR\_FT} = -1.0639310 + (0.0306584 \times t_{wb}) + (-0.0001269 \times t_{wb}^2) + (0.0154213 \times t_{odb}) + (0.0000497 \times t_{odb}^2) + (-0.0002096 \times t_{wb} \times t_{odb})$$

Part Load Ratio

$$\text{PLR} = \frac{Q_{operating}}{Q_{available}\,(t_{wb},\,t_{odb})}$$

$Q_{operating}$ = % Unit Output x Capacity

$Q_{available}$ ($t_{wb}$, $t_{odb}$) = CAP_FT x $Q_{rated}$

Adjustment to Rated Efficiency due to Changes in Coil Load

EIR_FPLR = $0.2012301 + (-0.0312175 \times PLR) + (1.9504979 \times PLR^2) + (-1.1205105 \times PLR^3)$

**Calculated Values**

| Time | CAP_FT | EIR_FT | PLR$_b$ | PLR$_r$ | EIR_FPLR$_b$ | EIR_FPLR$_r$ |
|---|---|---|---|---|---|---|
| 11:00 am – 12:00 pm | 0.9939 | 0.7935 | 0.0126 | 0.0126 | 0.2011 | 0.2011 |
| 12:00 pm – 1:00 pm | 0.9806 | 0.7989 | 0.0314 | 0.0314 | 0.2021 | 0.2021 |
| 1:00 pm – 2:00 pm | 0.9743 | 0.8140 | 0.0472 | 0.0472 | 0.2040 | 0.2040 |
| 2:00 pm – 3:00 pm | 0.9620 | 0.8100 | 0.1385 | 0.1385 | 0.2314 | 0.2314 |
| 3:00 pm – 4:00 pm | 0.9721 | 0.8197 | 0.0579 | 0.0579 | 0.2057 | 0.2057 |
| 4:00 pm – 5:00 pm | 0.9541 | 0.8197 | 0.1462 | 0.1462 | 0.2349 | 0.2349 |

To compute for the base and retrofit demand (kW) for each hour, we use

Demand (kW)$_b$ = Rated kW$_b$ x CAP_FT x EIR_FT x EIR_FPLR$_b$

Demand (kW)$_r$ = Rated kW$_r$ x CAP_FT x EIR_FT x EIR_FPLR$_r$

| Time | Base Case kW | Efficiency Case kW | Savings |
|---|---|---|---|
| 11:00 am – 12:00 pm | 1.2833 | 0.9518 | 0.3315 |
| 12:00 pm – 1:00 pm | 1.2810 | 0.9501 | 0.3309 |
| 1:00 pm – 2:00 pm | 1.3088 | 0.9707 | 0.3381 |
| 2:00 pm – 3:00 pm | 1.4584 | 1.0817 | 0.3768 |
| 3:00 pm – 4:00 pm | 1.3262 | 0.9836 | 0.3426 |
| 4:00 pm – 5:00 pm | 1.4859 | 1.1020 | 0.3839 |

Demand (kW) savings is automatically obtained by the engineered worksheet by getting the difference of the maximum kW occurring during the summer peak window (11:00 a.m. to 5:00 pm), Mondays to Fridays from June 01 to September 30 for both the base and retrofit case.

Max Demand (kW)$_b$ = Existing AC Unit Type 1 x Quantity Type 1 + Existing AC Unit Type 2 x Quantity Type 2 + Existing AC Unit Type 3 x Quantity Type 3

= 6.7026 kW x 2 + 0 kW x 0 + 0 kW x 0

= 13.4 kW

Max Demand (kW)$_r$ = Retrofit AC Unit Type 1 x Quantity Type 1 + Retrofit AC Unit Type 2 x Quantity Type 2 + Retrofit AC Unit Type 3 x Quantity Type 3

$$= \quad 4.9710 \text{ kW} \times 2 + 0 \text{ kW} \times 0 + 0 \text{ kW} \times 0$$
$$= \quad 9.9 \text{ kW}$$

For this particular example, base case maximum demand is 13.4 kW while the retrofit case maximum demand is 9.9 kW. Getting their difference, the demand (kW) savings is 3.5 kW (13.4 kW – 9.9 kW).

**Calculation of Energy Savings (kWh):**

The base case and retrofit case energy consumption (kWh) are obtained by summing up all the demand (kW) for each hour for the whole 8760 hours. Base case energy consumption is 6,051 kWh while the retrofit case energy consumption is 4,488 kWh. Energy savings, therefore, is 1,563 kWh (6,051 kWh - 4,488 kWh)

**Calculation of Total Project Costs ($):**

It is assumed that the total project costs amount to $ 12,000.00 broken down as follows:

| | |
|---|---|
| Variable speed drive cost | $ 10,000.00 |
| Labour to install VSD | $ 2,000.00 |
| Total: | $ 12,000.00 |

**Calculation of Incentives ($):**

Calculated kW Participant Incentive ($1,200/kW of Demand Savings):

$$\text{Participant Incentive} \quad = \quad 3.5 \text{ kW} \quad \times \quad \$1,200/\text{kW}$$
$$= \quad \$ 4,200.00$$

Calculated kWh Participant Incentive ($0.13/kWh of Energy Savings)

$$\text{Participant Incentive} \quad = \quad 1,563 \text{ kWh} \quad \times \quad \$ 0.13/\text{kWh}$$
$$= \quad \$ 203.19$$

Maximum Allowable Participant Incentive (50% of Total Eligible Costs for the Project)

$$\text{Participant Incentive} \quad = \quad \$ 12,000.00 \quad \times \quad 50\%$$
$$= \quad \$ 6,000.00$$

The Participant Incentive is the greater value between the calculated incentive based on kW and kWh savings, subject to a maximum 50% of total eligible costs for the project. Therefore, the total incentive for this project is $4,200.