TECHNICAL USER GUIDE MANUAL for the Retrofit Program Custom Track Engineered Worksheets January 2025

Table of Contents

1) INTRODUCTION

1.1 DOCUMENT PURPOSE

This Technical User Guide Manual (the "Guide") has been developed to help Applicants and their respective Representatives, Project Consultants and Project Evaluators complete the Engineered Worksheets (Microsoft Excel spreadsheets) that are part of the Retrofit program. The Guide describes how the Engineered Worksheets calculate the Participant Incentives. It is not related to any specific version of the Engineered Worksheets.

1.2 DISCLAIMER

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1.3 DOCUMENT LAYOUT

The Guide has six sections and one appendix:

Section 1 - this section is an introduction. It describes the purpose and layout of the Guide. It also presents some key definitions used in the Retrofit program.

Section 2 - this section presents a brief overview of the Retrofit program. It also provides a description of the Engineered Worksheets and their general layout.

Section 3 - this section describes the steps involved in completing the *Applicant and Facility Info* tab of the worksheets, which includes the applicant and project contact information, the facility information, the facility schedule, and the billing data.

Section 4 - this section describes how the operating hours of a measure are to be entered under the *System Schedule* tab, as well as how to account for statutory, civic or other holidays, lieu days, or scheduled shutdowns

Section 5 - this section discusses the various input data that is to be included on the *System Design Assumptions* tab in order to calculate Demand and Energy Savings for commercial lighting, compressed air systems, variable speed drives on fans, variable speed drives on pumps, and unitary air-conditioning systems. It also describes the energy and cost data used in calculating the total project cost.

Section 6 - this section explains the Demand and Energy Savings calculated under the *Outputs* tab for each Engineered Worksheet. It also describes the economic benefits that could be derived from the project and provides quality control (QC) and diagnostics.

Appendix A – this section provides examples of completed Engineered Worksheets and discusses how energy and demand savings are calculated using case scenarios.

Phrases in *italics* refer to the different tabs of the Engineered Worksheets. Notes, where available, are also italicized to emphasize them. Words and phrases in **Bold** are specific terms used on the worksheets and are shown in bold in the Guide to help the user quickly find the related information on the worksheet.

1.4 Definitions

The following Retrofit program defined terms may help the users of this Guide to better understand the Guide.

"Demand Savings" means the estimated, determined or actual (as the context may require) reduction in electricity demand, expressed in kilowatts, obtained as a result of an Engineered Measure or a Custom Measure and as determined pursuant to an Engineered Worksheet or a Custom Worksheet.

"Energy Savings" means the estimated, determined or actual (as the context may require) electricity savings achieved over the course of the first year after the completion of a Project, expressed in kilowatt hours, obtained as a result a Custom Measure and as determined pursuant to an Engineered Worksheet or a Custom Worksheet.

"Engineered Worksheet" means a worksheet that provides calculations of Energy Savings and Demand Savings and Participant Incentives for associated Measures in the form provided from time to time.

"Participant" means a non-residential Consumer who has (i) submitted an Application which was approved by the IESO; (ii) agreed to the terms and conditions in the Participant Agreement, and (iii) satisfied the Eligibility Criteria.

2) Overview

Under the Retrofit program substantial Participant Incentives are available for replacing existing equipment with high efficiency equipment and for installing new control systems that can improve the efficiency of businesses' operational procedures and processes. The program offers two approaches to achieving energy and peak demand savings: a "Prescriptive" track and a "Custom" track.

Under the Prescriptive track an Applicant can select high efficiency retrofit measures from a defined list that includes a corresponding per-unit incentive. Examples of the types of measures that are possible under this track are: the retrofit of inefficient equipment, such as lighting, motors, and unitary air conditioners (A/C), to more efficient equipment. If the proposed retrofit project involves upgrading existing equipment, the incentive amount that may be available depends on the type, efficiency, and quantity of the equipment to be installed. To be eligible for the Prescriptive track, the proposed retrofit measures have to match the requirements for the high efficiency measures on the Prescriptive Measures List. If, however, a particular measure does not appear on the Prescriptive Measures List, the Applicant might still be able to proceed using the Custom track.

The Custom track is a choice that might be suitable for installation of more complex or innovative solutions not covered under the Prescriptive track. Technology, equipment, and system improvements are evaluated on their peak demand and energy-performance. Participant Incentives can be paid after installation, once the savings have been measured and verified (for large projects), or once quality assurance and quality control (QA/QC) requirements have been met for (small projects). The Custom track also includes Engineered Worksheets that have preset calculations for estimation of energy and peak demand savings for certain specific measures. Based on the reductions possible in peak demand and energy, the worksheets are used in calculating the possible incentive.

Participant Incentives that may be available for Prescriptive projects are indicated on the Prescriptive worksheets, which set out the dollar amount per unit installed. For Custom track projects, the Participant Incentives available are:

- $1,200/kW of Demand Savings or $0.13/kWh of Energy Savings for lighting and non-lighting measures (whichever is higher), to a maximum of 50% of the project costs that are directly related to the procurement and implementation of the Engineered Measure. More details are found in Section 5.6 – Project Cost Breakdown.

2.1 The Retrofit Engineered Worksheets

There are nine Engineered worksheets available under the Custom track of the Retrofit program (https://saveonenergy.ca/RetrofitDocuments):

- Custom Projects Engineered Worksheet
- Compressed Air Engineered Worksheet
- Variable Speed Drive (VSD) Compressed Air Engineered Worksheet

- Variable Speed Drive (VSD) on Fan Engineered Worksheet
- Variable Speed Drive (VSD) on Pump Engineered Worksheet
- Unitary A/C Engineered Worksheet
- Horticultural Lighting Engineered Worksheet

These Engineered Worksheets are used to estimate the Demand Savings and Energy Savings for the purpose of calculating the Participant Incentives that may be available as a result of implementing Conservation Demand Management (CDM) measures. The Engineered Worksheets are not meant to be, and should not be, used as design tools.

2.2 Engineered Worksheet Layout

The Engineered Worksheets follow a similar layout, with an *Introduction* tab and the following four major tabs:

- Applicant and Facility Information
- System Schedule[1]
- System Design Assumptions
- Outputs

As well, most of the worksheets have either a *Reference* tab or a set of additional tabs containing relevant technical specifications.

2.2.1 Types of Cells

There are three types of cells used in the worksheets– input cells, output cells, and optional cells:

Input cells – you can enter information in these cells in text or numerical format. Information entered into these cells is used in calculating potential Energy and Demand Savings, Participant Incentives, and the project economics.

Output cells – you cannot enter information into these cells. These cells show the calculated potential Energy and Demand Savings, Participant Incentives and project economics. In the various Commercial Lighting Engineered Worksheets they also show calculated potential lighting level output based on information you may provide in optional cells (see below).

[1] For Unitary A/C Engineered Worksheet, the System Schedule is found on the *System Design Assumptions* tab.

Optional cells – on the various Commercial Lighting Engineered Worksheets you can enter numerical information in these cells. The cells are used in calculating the estimate of: a room's cavity ratio, average illuminance in the workplane, estimated usable lumens per watt, and percent change in workplane illuminance.

3) THE APPLICANT AND FACILITY INFORMATION TAB

The *Applicant and Facility Information* tab collects relevant information about the Applicant, including their primary project contact details, facility information, facility schedule, and the facility's electricity billing data. Once the *Applicant and Facility Information* tab has been completed, the Engineered Worksheet may be saved and used for multiple applications, changing only the information under the *System Schedule* and *System Design Assumptions* tabs. (Given the ability to save and re-use this information, to prevent accidentally overwriting it, it is recommended to save a separate master copy of the worksheet.)

3.1 APPLICANT AND PROJECT CONTACT INFORMATION

Note: *If the Applicant has completed and submitted an Application for the* Retrofit program *using the online application process via the Save on Energy website (www.saveonenergy.ca), then it is not necessary to complete the* **Applicant and Project Contact Information** *section. However, since the worksheet will be uploaded as supporting documentation for an application using the online application process, we recommend naming of the worksheet in a manner that is suitable for the* Retrofit program*.*

Contact details for the Applicant Representative or Primary Project Contact person are entered in the appropriate cells of the worksheet as shown in Figures 1 and 2. The Applicant Representative or Primary Contact person may need to be contacted for inquiries relating to the information provided on the worksheet or regarding the project.

Figure 1 – Applicant Information

APPLICANT INFORMATION					
Legal Name of Applicant:	Company ABC				
Address/City/Postal Code:	Toronto, ON M6H 2T2				
Contact Name and Title:	Company Representative 1/President				
Day Phone Number:	416-999-9999	Fax:	416-111-1111	E-mail:	companyabc@yahoo.com
Owner/Tenant:	Owner			Local Distribution Company:	LDC Y

Figure 2 – Applicant Representative/Project Contact Information

APPLICANT REPRESENTATIVE/PROJECT CONTACT INFORMATION					
Please enter the following information for the primary contact information for this project. This person may be contacted for any inquiries relating to the information within this workbook, or regarding the project.					
Name and Title of Contact:	Applicant Representative 1				
Address/City/Postal Code:	Toronto, ON M5H 1T2				
Day Phone Number:	416-888-8888	Fax:	416-888-8889	E-mail:	applicant1@gmail.com

3.2 FACILITY INFORMATION

Facility information, such as the Building Name, Address, Building/Property Type and Gross Facility Floor Area in square feet, is entered in the appropriate cells as shown in Figure 3. This information is for the individual who may be tasked with doing pre- and post-project site visits.

Figure 3 – Facility Information

FACILITY INFORMATION			
Enter the following information regarding your building. Where the building has mixed uses (i.e., office and industrial) please indicate the percentage of floor space allocated to each of the uses.			
Building Name:	Office X		
Address/City/Postal Code:	Toronto, ON		
Building/Property Type:	Health Care	Gross Facility Floor Area (ft^2):	30,000
If 'Other', indicate type:		Type of Project:	Planned Replacement
If 'Mixed Use', please allocate the proportions in the following table:		Percent (%):	Facility Description:
Floor Area Description	Health Care	80%	
Floor Area Description	Office	20%	
Floor Area Description	Please select from dropdown list		

The Applicant selects the building/property type from one of the 11 listed choices in the dropdown list: Office, Retail, Health Care, Multi-Residential, Warehouse, Agri-business, Hospitality, Educational, Industrial, and Other.

Notes:

1) *Select "Other" from the dropdown list if the building/property type is not one of specific types and then specify the building/property type in the cell next to the one that reads "If 'Other', indicate type".*

2) *If the Building/Property Type has mixed uses, indicate the percentage of floor space allocated to each of the uses of the building (Figure 3, for example, shows a 30,000 sq. foot Health Care property in which 80% of the floor area is used for Health Care and 20% for Office).*

3) *Indicate the Type of Project being applied for by selecting from the drop-down list whether it is Planned Replacement, Unexpected Replacement, New Equipment for new process or Expansion of Operations, or Efficiency Upgrade.*

4) THE SYSTEM SCHEDULE TAB

The operating hours for the equipment or measure (for example, high bay lighting, variable speed drive, compressed air system) are entered in the *System Schedule* tab of the Engineered Worksheet using the 24 hour 7 day table as shown in Figure 6. If the equipment is scheduled to operate for a certain hour, enter “1” and if the equipment is not scheduled to operate for a certain hour, enter “0”.

As shown in Figure 6, the cells within this table will change to purple when “1” is entered, indicating that the equipment is in operation. The information on this table is used to estimate the total annual operating hours for the equipment and serves as the basis for energy calculations. If the equipment operates for only part of an hour (for example, it starts working at 9:30 a.m.), it is recommended to show the full hour of operation.

Figure 4 – Zone Operating Hours for the Interior Lighting

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 time.

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	0	0	0	0	0	0
8:00-8:59 am	0	0	0	0	0	0	0
9:00-9:59 am	0	1	1	1	1	1	1
10:00-10:59 am	0	1	1	1	1	1	1
11:00-11:59 am	0	1	1	1	1	1	1
12:00-12:59 pm	0	1	1	1	1	1	1
1:00-1:59 pm	0	1	1	1	1	1	1
2:00-2:59 pm	0	1	1	1	1	1	1
3:00-3:59 pm	0	1	1	1	1	1	1
4:00-4:59 pm	0	1	1	1	1	1	1
5:00-5:59 pm	0	1	1	1	1	1	1
6:00-6:59 pm	0	1	1	1	1	1	1
7:00-7:59 pm	0	1	1	1	1	1	1
8:00-8:59 pm	0	1	1	1	1	1	1
9:00-9:59 pm	0	0	0	0	0	0	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

The total annual operating hours can be further adjusted by the number of days the equipment is not operational due to statutory, civic or other holidays, lieu days, or scheduled shutdowns. Under the *System Schedule* tab there is a chart showing 11 Ontario civic and statutory holidays. As can be seen in Figure 7, the holiday information is used to pre-populate the table located just to the left of the list of holidays.

Figure 5 – Adjustments Due to Holidays and Scheduled Shutdowns

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 holidays, per the table on the right.

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

Note: *The figures presented in the table to the left of the list of Ontario holidays can be further adjusted to reflect the actual operation schedule at the facility. For example, if the equipment at the facility is on during Canada Day but not operational for 3 days during the month of February, as shown in Figure 8, the user would reduce the pre-populated number in the cell for July by 1 day, and increase the pre-populated number in the cell for February by 3 days.*

Figure 6 – Pre-Populated versus Adjusted Days

Pre-Populated

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

Adjusted

January	1
February	4
March	0
April	2
May	1
June	0
July	0
August	1
September	1
October	1
November	0
December	2
TOTAL:	13

February was adjusted to include 3 weekdays the equipment is not operational.

July was adjusted to remove pre-populated holiday since equipment is running during the holiday.

The Engineered Worksheet automatically computes the total annual operating hours for the equipment based on the weekdays, weekends, and holiday schedule entered by the Applicant. A summary of these operating hours are displayed as shown in Figure 9. In this summary table, the typical weekly number of operating hours for the equipment based on the schedule (excluding holidays) is also shown.

Figure 7 – Summary of Operating Hours for the Interior Lighting in a Specific Zone

55	This is the typical weekly number of operating hours for the equipment based on the schedule above (excluding holidays)
2695	This is the annual number of operating hours for the equipment based typical weekly and holiday schedule entered

5) THE SYSTEM DESIGN ASSUMPTIONS TAB

The *System Design Assumptions* tab collects information on input assumptions (for example, wattages, operating pressure, pump curve, and so on) for the base case and retrofit systems, operating profiles, economic value assumptions, and project cost breakdown. Because the information collected under the *System Design Assumptions* tab is relevant to the particular worksheet, the different worksheets are discussed in the following subsections:

5.1 Compressed Air Engineered Worksheet

5.2 VSD Compressed Air Engineered Worksheet

5.3 VSD on Fans Engineered Worksheet

5.4 VSD on Pumps Engineered Worksheet

5.5 Unitary Air Conditioning (A/C) Engineered Worksheet

5.6 Horticultural Lighting Engineered Worksheet

Note: *Applicants are encouraged to gather all relevant technical and economic input assumptions they will need before they begin filling in the System Design Assumptions tab of the worksheet*.

5.1 COMPRESSED AIR ENGINEERED WORKSHEET

The Compressed Air Engineered Worksheet uses information entered by the Applicant to evaluate the base case and the energy efficient case for a series of potential improvements to a compressed air system. It is expected that the user will have a good understanding about compressed air system components, and the "cause and effect" relationship between potential equipment and operational changes and corresponding energy consumption.

The *System Design Assumptions* tab for the Compressed Air Engineered Worksheet is divided into seven (7) tabs. Two (2) tabs, namely *Compressor Inventory* and *Pipe Volume & Pressure Test* collects information on the existing air compressors and their main distribution pipes and receiver tanks, respectively. A *Summary* tab has been added to provide a summary on the measures, energy impact, project economics and incentives. The last four (4) tabs collect information on the base case and the energy efficient case for a series of potential improvements to a compressed air system, such as:

- Measure 1 - Reducing leaks
- Measure 2 - Reduce pressure
- Measure 3 - Using an energy efficient refrigerant air dryer (cycling, non-cycling and desiccant)
- Measure 4 - Using zero loss air drains

The Engineered Worksheet contains two (2) additional tabs, namely, a *Navigation* tab and a *Start Here* tab. The *Navigation* tab provides information on the different tabs of the worksheet and explains how to navigate the different tabs. The *Start Here* tab is an important tab and users are instructed to study this carefully.

5.1.1 Compressed Air Systems Overview

To provide context, a brief description of compressed air systems is useful.

Compressed air systems are comprised of several major sub-systems and many sub-components and, consequently, the energy efficiency results from multiple measures are not necessarily additive. Major sub-systems include: the compressor, prime mover, controls, treatment equipment and accessories, and the distribution system. The compressor is the mechanical device that takes in ambient air and increases its pressure. The prime mover powers the compressor. Controls serve to regulate the amount of compressed air being produced. Treatment equipment removes contaminants from the compressed air and accessories keep the system operating properly. Distribution systems are analogous to wiring in the electrical world –they transport compressed air to where it is needed. Compressed air storage can also serve to improve system performance and efficiency.

When analyzing a compressed air system, it is useful to start by sketching a block diagram. Note the number and location of each air compressor and their designated names (for example, maintenance shop compressor) along with each compressor's make and model, motor size (horsepower), estimated motor age, motor speed, whether it is a standard or premium efficiency motor, and motor designation (ODP or TEFC).

Record details about other auxiliary equipment, especially:

1) air dryers (refrigerated, desiccant, or none), and
2) wet and dry air receivers – note the nameplate capacity or estimate the approximate volume (cubic feet) for each receiver.

Trace the entire length of the air compressor distribution piping, noting the pipe diameter (in inches) for the main header and the overall length (in feet) of the distribution piping system. Engineering judgment will likely be needed to convert smaller diameter or smaller length pipes to equivalent main header dimensions.

5.1.2 Start Here Tab

The *Start Here* tab contains a checklist of scenarios to determine if the project qualifies to use the Engineered Worksheet as well as a list of information or data to have on hand when completing it. The pre-qualifying checklist includes the following scenarios:

- The largest individual air compressor in the system is not more than 350 HP.
- There are no more than five (5) fixed speed positive displacement (rotary screw or piston) compressors in the system.

- The typical system operating air pressure is between 70 to 150 psig.
- There are no variable speed air compressors under evaluation (Note: for a VSD compressor, use the IESO's VSD Compressed Air Worksheet)
- There is at least 1 hour available when the compressor(s) can be operated to perform the Pressure Decay Test (Refer to Guide for details)
- The compressor(s) are all connected to the same distribution system, which operate at a common discharge pressure.
- This compressed air system is used for general plant air or building controls.
- This application does not involve retrofitting an existing compressor motor with a premium efficiency motor (Note: for motor changes, use the IESO's prescriptive application for motors)
- If applying for incentive to reduce air leaks, Applicant must agree to implement an air leak management program for a minimum period acceptable to the IESO.
- If applying for incentive to reduce air discharge pressure, Applicant must agree to implement an air leak management program for a minimum period acceptable to the IESO.
- This worksheet is designed for MS Excel 2007. User acknowledges that it may not be fully compatible with earlier or later versions of MS Excel.

At the end of the list of scenarios, the user selects either "Yes" or "No". By selecting "Yes", the user is certifying that all of the above-stated requirements and pre-qualifications are met. By selecting "No", the user is certifying that one or more of the above-stated requirements and pre-qualifications is not met and that the Engineered Worksheet should not be used. If the applicant user still wants to apply for incentives, the Retrofit Program's Custom Track can be explored. Figure 16 shows the checklist of different pre-qualification scenarios.

Figure 16 - List of Pre-Qualifiers for the Use of the Engineered Worksheet

CONFIRM PROJECT QUALIFICATION	
✓	The largest individual air compressor in the system is not more than 350 HP.
✓	There are no more than five (5) fixed speed positive displacement (rotary screw or piston) compressors in the system.
✓	The typical system operating air pressure is between 70 to 150 psig.
✓	There are no variable speed air compressors under evaluation (Note: for a VSD compressor, use the IESO's VSD Compressed Air Worksheet)
✓	There is at least 1 hour available when the compressor(s) can be operated to perform the Pressure Decay Test (Refer to Guide for details)
✓	The compressor(s) are all connected to the same distribution system, which operate at a common discharge pressure.
✓	This compressed air system is used for general plant air or building controls.
✓	This application does not involve retrofitting an existing compressor motor with a premium efficiency motor (Note: for motor changes, use the IESO's prescriptive application for motors)
✓	If applying for incentive to reduce air leaks, Applicant must agree to implement an air leak management program for a minimum period acceptable to the IESO.
✓	If applying for incentive to reduce air discharge pressure, Applicant must agree to implement an air leak management program for a minimum period acceptable to the IESO.
✓	This worksheet is designed for MS Excel 2007. User acknowledges that it may not be fully compatible with earlier or later versions of MS Excel.
No	**By selecting 'Yes' you are certifying that all of the above-stated requirements and qualifications are met; by selecting 'No' then one or more of the above-stated requirements and prequalifications is not met and this worksheet should not be used. If you still wish to apply for the project, you must use the IESO's Custom Application track").**

At the *Start Here* tab, it is important to indicate the compressed air efficiency measures that the users are applying for as shown in Figure 17. This triggers the estimation of the savings in the respective measure tabs of the worksheet. If a "No" is selected, savings will appear as zero.

Figure 17 - Indicate Intention to Apply

INDICATE THE COMPRESSED AIR EFFICIENCY MEASURES YOU ARE APPLYING FOR	
Intention to Apply?	**Select "Yes" for the measure(s) you are applying for.**
Yes	Measure #1 - Reduce Air Leaks
Yes	Measure #2 - Lower System Operating Pressure
Yes	Measure #3 - Use Energy Efficient Dryer(s)
Yes	Measure #4 - Use Zero Loss Air Drain(s)

At the bottom part of the *Start Here* tab, a list of information and compressed air data needed to complete the Engineered Worksheet is provided. See Figure 18 for this list of information and data.

Figure 18 - Information Required Before Completing the Worksheet

INFORMATION TO HAVE ON HAND BEFORE COMPLETING THIS WORKSHEET	
To save time when completing the worksheet, please be familiar with the User Guide and have the following information and documents on hand.	
Electricity Cost per kWh	Blended cost per kWh paid by the facility (includes energy, demand and other rate charges divided by total kWh consumed for same period)
Operating Schedule	Typical weekly operating hours for the compressed air system
	Shutdown days for statutory holidays or planned outages
Compressors	Nameplate information about compressors
	Typical operating discharge pressures for each compressor
	Typical operating flows for each compressor
	Compressed Air and Gas Institute (CAGI) data sheet for each compressor (Note: If data sheet is not available, select CAGI data sheet for similar compressor and make a note in the comment box)
Air Dryers	Nameplate information about existing air dryers
	CAGI data sheet for each existing refrigerated dryer (Note: If data sheet is not available, select CAGI data sheet for similar refrigeration dryer and make a note in the comment box)
	CAGI data sheet for each proposed refrigerated dryer (Note: If data sheet is not available, select CAGI data sheet for similar refrigeration dryer and make a note in the comment box)
Distribution Piping & Storage	Total length(s) and corresponding nominal pipe diameter(s) for major distribution pipes with diameter of 2 inches and above
	Inventory and size (height and diameter) of air receiver (storage) tanks
Condensate Drains	Total number of condensate drains
	Number of existing zero loss drains included in the total number of condensate drains indicated above
Leakage Testing	Five (5) separate test results showing starting pressure (greater than 50 psig), ending pressure and time for pressure decay (See Guide for pressure decay test method)

Compressor Inventory

The Engineered Worksheet relies on information provided by the Compressed Air and Gas Institute (CAGI) for air compressors. CAGI is an independent organization with membership from major air compressor and refrigerant dryer vendors and other stakeholders from the compressed air community. It has developed standard data sheets completed by manufacturers of rotary compressors from 25 - 200 hp, and standalone refrigerated compressed air dryers from 200 - 1000 scfm[2]. Participation is voluntary and is open to all equipment manufacturers, whether they are a CAGI member or not. The use of CAGI Data Sheets has been incorporated into the Compressed Air Engineered Worksheet calculation process as it provides an open, transparent and industry-accepted method to evaluate different compressors and/or refrigerant dryers. For more detailed information about CAGI and its Data Sheets, refer to section 5.4.1.

The *Compressor Inventory* tab collects information on the existing air compressors using the CAGI Data Sheets and typical operating parameters as well as information on the cost of power which will be used in the economic analysis of the project.
The first section of the *Compressor Inventory* tab as shown in Figure 19 asks for the blended cost of power ($/kWh) and the estimated monthly peak demand unit cost ($/kW) which can be obtained from

[2] In practice, some manufacturers publish for equipment sizes larger or smaller than the CAGI limits. The Engineered Worksheet can evaluate individual rotary screw compressors up to 350 hp and refrigerant dryers up to 2000 scfm.

the utility bill. The compressed air system operating hours per year is automatically estimated from the *System Schedule* tab.

Figure 19 - Annual Operating Hours and Unit Cost of Power

ANNUAL OPERATING HOURS AND UNIT COST OF POWER		
Compressed Air System Operating Hours per Year	4,551	Hours
Blended Cost of Power	$ 0.1100	$/kWh
Estimated Monthly Peak Demand Unit Cost	$ 5.50	$/kW

The *Air Compressors* section requires data from the CAGI Data Sheets and from typical operating data of the compressors as shown in Figure 20. Up to five air compressors can be included in the engineered worksheet. Use the AC#1 column to input data on the largest compressor. Continue using the columns to the right for the next largest compressor and so on.

Figure 20- Air Compressors Input Data

AIR COMPRESSORS							
	A.C.#1	A.C.#2	A.C.#3	A.C.#4	A.C.#5		
Compressor Designated Name	Main Unit	Paint Line					
Manufacturer (CAGI Box 1)	Please select	Please select	Please select	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)
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	acfm
Power Demand for Air Compressors at Typical Operating Level						179.3	kW
(See below for Warning Message) Annual Energy Consumption for Air Compressors at Typical Operating Level						815,975	kWh
Annual Energy Cost for Air Compressors						$ 89,757	dollars
Please provide an explanation below about methods used to determine the Typical Percent of Full Load Operating Point and Typical Operating Pressure Values.							
Based on operating logs.	OK						

As shown in Figure 20 above, the required data from the CAGI Data Sheets are indicated in box numbers. For example, the Rated Capacity at Full Load Operating Pressure in actual cubic feet per min (acfm) can be found in Box No. 3 from the CAGI Data Sheet for the selected compressor. In addition, the user is required to provide an estimate of the **Typical Percent of Full Load Operating Point (F.L.)** and **Typical Operating Pressure** for each compressor and to provide an explanation in the space provided in the worksheet about the methods used as the basis to estimate these two parameters. This explanation will be used by the Technical Reviewer. **Not providing an explanation will cause the worksheet to make the energy savings and incentive amounts zero.**

If there are more than one compressor, the input parameters will either be summed up or averaged as indicated in the last column in green of the *Air Compressors* section. The Operating Flow will automatically be estimated for each compressor using the following equation:

$$\text{Operating Flow (cfm)} = \frac{\text{Rated Capacity at Full Load Operating Pressure (acfm)} \times \text{Typical Percent of Full Load Operating Point (\%)}}{100}$$

The Power Demand (kW) and Annual Energy Consumption (kWh) for Air Compressors at Typical Operating Level are summation of the power demand and annual energy consumption at typical operating level of each compressor as shown in the following equations:

$$\text{Power Demand at Typical Operating Level (kW)} = \text{Power Demand at Operating Flow (kW)} \times \text{Pressure Adjustment Factor}$$

Power demand at operating flow (kW) is extrapolated using a linear relationship between air flow and input power of the compressor. The CAGI Data Sheets provide the rated capacity at full load operating pressure for the air flow and the total package input power at both zero flow and at the rated capacity air flow. The Pressure Adjustment Factor assumes a 0.5% increase or decrease in power demand depending on the difference between the full load operating pressure and the typical operating pressure.

The annual energy consumption at typical operating level for each compressor is estimated as follows:

$$\text{Energy Consumption of Compressor at Operating Level (kWh)} = \text{Power Demand at Typical Operating Level (kW)} \times \text{Annual Operating Hours (hrs)}$$

The annual energy cost of compressors is estimated by applying the blended cost of power to the total annual energy consumption of compressors.

Pipe Pressure and Volume Tests

It is assumed that the user of the engineered worksheet is familiar with the practical and safety aspects of conducting a pressure decay test to estimate air leaks. Air leaks are estimated using the air distribution volume which is in turn estimated using dimensional data for pipes and storage tanks in conjunction with pressure decay testing.

Air leaks are determined through pressure decay tests. The purpose of such tests is to determine the approximate amount of leakage. The best time to perform such tests is during a non-production period, such as over a weekend. During a non-production period the compressed air system is permitted to pressurize until the compressor begins modulating. Under normal circumstances, only one air compressor (typically the largest) needs to operate.

Pressure decay tests are conducted as follows:

- The (higher) initial pressure is measured when the compressor is unloaded and the (lower) final pressure is when the compressor loads.
- The time for the pressure to decay from high to low can be considered equivalent to the time between loading and unloading.

Using a stopwatch, the observer measures the time interval between compressor loading and unloading, in seconds. Simultaneously, the load and unload discharge pressure, as shown on the air compressor pressure gauge or system pressure gauge, is noted. The time is expressed in seconds (for example, 4 minutes and 20 seconds = 260 seconds).

The *Pipe Pressure and Volume Test* tab consists of two sections, namely, the *System Volume of Main Distribution Pipes and Receiver Tanks* section and the *Pressure Decay Test* section. The first section requires the user to include data about the distribution pipes having the two largest pipe diameter dimensions as shown in Figure 21. If there is only one pipe and no receiver tanks, only the largest diameter distribution pipe dimensions should to be entered. Use technical judgment to adjust for equivalent pipe diameter and length if there are more than two sizes of distribution pipes or for complex air distribution configurations. Up to five different dimensioned receiver tanks can be entered as well as the number of similar tanks for some situations.

Figure 21 - System Volume of Main Distribution Pipes and Receiver Tanks

SYSTEM VOLUME OF MAIN DISTRIBUTION PIPES AND RECEIVER TANKS					
For Step 1 of the air leakage estimate, enter dimensions of the main distribution pipes and air receiver tanks.					
	Outside Pipe Diameter (inches)	Pipe Length (feet)		Volume	Units
Largest Diameter Distribution Pipe (Diameter and Length)	4.0	600		52.3	ft^3
Second Largest Diameter Distribution Pipe (Diameter & Length)	2.5	300		10.2	ft^3
	Receiver Tank Diameter (feet)	Receiver Tank Height (feet)	No. of Similar Receivers (#)	Volume	Units
Air Receiver(s) - Type 1	1.0	5.0	3	11.8	ft^3
Air Receiver(s) - Type 2	2.5	8.0	1	39.3	ft^3
Air Receiver(s) - Type 3	-			-	ft^3
Air Receiver(s) - Type 4	-	-		-	ft^3
Air Receiver(s) - Type 5	-	-		-	ft^3
Total Volume of Receivers and Large Pipes				**114**	ft^3

The engineered worksheet automatically calculates the approximate internal volume of the air header supply and receiver storage tanks based on the given diameters and lengths provided by the user.

On the *Pressure Decay Test* section, the average of five (5) pressure decay tests is used to estimate the air leakage as shown in Figure 22. The starting and ending pressures in psig recorded during the testing and time for the pressure decay in seconds are entered.

Figure 22 - Pressure Decay Test

PRESSURE DECAY TEST			
For Step 2 of the air leakage estimate, enter the results of five (5) pressure decay tests below.			
The highest possible pressure for the decay test (based on the compressors) is:	110.0		
	Starting Pressure (psig)	Ending Pressure (psig)	Time for Decay Test (seconds)
Test Results #1	105.0	70.0	125
Test Results #2	106.0	68.0	120
Test Results #3	102.5	60.0	105
Test Results #4	106.4	70.0	130
Test Results #5	104.5	71.0	115
Test Average	**104.9**	**67.8**	**119**

The engineered worksheet will reject some incorrect entries. For example, if the ending pressure is higher than the starting pressure, or if the starting pressure is higher than the capability of the compressor. If there are less than three values entered for a particular test result, a warning message will appear at the bottom of the pressure decay test field.

5.1.3 Measure 1 – Reduce Air Leakage

Leaks can be a significant source of wasted energy in an industrial compressed air system, sometimes representing 20-30% losses of a compressor's output. They can also contribute to other operating losses. Leaks typically cause a drop in system pressure, which can mean air tools function less efficiently, adversely affecting production. Finally, leaks can contribute to the addition of unnecessary compressors or compressor capacity. Reducing air leakage can not only improve the operating performance of the compressor, it can also reduce energy consumption.

The *1 Reduce Leaks* tab requires the following inputs to estimate the annual energy savings and energy costs as shown in Figure 23:

- First, the user must toggle the response from "No" to "Yes" regarding commitment to implement a sustained air leakage management program. It is to be noted that leaving the default "No" response will result in zero energy savings and zero potential incentive.
- Second, the user must enter a target percent for maximum allowable air leaks. Most industrial facilities consider 10% air leakage to be a reasonable amount.
- Third, the user must enter economic parameters about the cost to repair and maintain that air leaks at the targeted amount.

Figure 23 - Reduce Air Leaks and Non-Productive Compressed Air Use

MEASURE #1 - REDUCE AIR LEAKS AND NON-PRODUCTIVE COMPRESSED AIR USE		
Please review the "**Start Here**" tab to determine if the project qualifies to use this Worksheet as well as the information or data to have on hand when completing the Worksheet. Demand and energy savings will default to zero if no explanation is provided for Compressor Loading (Cell A23) and/or Operating Pressure (Cell A24) found under the **Compressor Inventory** tab.		
Intention to Reduce Air Leaks (as selected on 'Start Here' Tab)?	Yes	From "Start Here" Tab
Commitment to repair and maintain Targeted Allowable Air Leaks for Stipulated period if applying for incentive?	Yes	
Estimated Leakage and Non-Productive Air Losses (at 100% Compressor Flow Output)	181	cfm
Estimated Air Leaks and Non-Productive Air Losses as Percentage of Normal Compressor Flow	19.4%	percent
Target for Maximum Allowable Air Leaks and Non-Productive Air Use (10% or less is best practice)	15.0%	percent
Estimated Annual Energy Losses through Air Leaks and Non-Productive Air Usage	158,667	kWh
Estimated Annual Cost of Air Leaks and Non-Productive Air Usage	17,453	dollars
Estimated Air Leaks at Target Leak Level	139	cfm
Required Reduction in Air Leaks to Meet Target	41	cfm
Estimated Annual Energy Savings from Reducing Air Leaks to Targeted Amount	36,270	kWh
Estimated Annual Demand Savings from Reducing Air Leaks	8.0	kW

The annual energy savings attributed to reducing air leaks is estimated from the difference of the Estimated Air Leaks and Non-Productive Air Losses as Percentage of Normal Compressor Flow and the Percent Target for Maximum Allowable Air Leaks and Non-Productive Air Use. The Estimated Air Leaks and Non-Productive Air Losses as Percentage of Normal Compressor Flow is calculated as the percentage of the Estimated Leakage and Non-Productive Air Losses (at 100% Compressor Flow Output) to the total operating flow. The following equations are used to calculate the values in green in the *1 Reduce Leaks* tab:

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

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

$$\text{Estimated Annual Energy Losses through Air Leaks (kWh)} = \text{Annual Energy Consumption for Air Compressors at Typical Operating Level (kWh)} \times \text{Estimated Air Leaks as Percentage of Normal Compressor Flow (\%)}$$

$$\text{Estimated Air Leaks at Target Leak Level (cfm)} = \frac{\text{Estimated Leakage at 100\% Compressor Flow Output (cfm)} \times \text{Target Allowable Leaks (\%)}}{\text{Estimated Air Leaks as Percentage of Normal Compressor Flow (\%)}}$$

$$\text{Required Reduction in Air Leaks to Meet Target (cfm)} = \text{Estimated Leakage at 100\% Compressor Flow Output (cfm)} - \text{Estimated Air Leaks at Target Leak Level (cfm)}$$

$$\text{Annual Energy Savings (kWh)} = \left[\text{Estimated Air Leaks (\%)} - \text{Target Allowable Leaks (\%)} \right] \times \text{Annual Energy Consumption for Air Compressors at Typical Operating Level (kWh)}$$

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

Since there exists some uncertainty on energy savings from air leaks, a "permanence factor" is applied to the energy and demand savings.

The annual cost of air leaks as well as annual cost savings are automatically calculated by the engineered worksheet.

5.1.4 Measure 2 – Reduce Discharge Pressure

As a rule of thumb, when air compressor discharge pressure is reduced by 2 pounds per square inch gauge (psig), this generally results in compressed air energy savings equivalent to 1% of the total compressor output.

During a site visit, it is prudent to ask plant personnel if the overall plant air pressure can be reduced without impacting plant and equipment operation and if so, what a reasonable air pressure target value might be.

The *2 Reduce Pressure* tab requires the following inputs to estimate the annual energy savings and energy costs as shown in Figure 23:

- First, the user must toggle the response from "No" to "Yes" regarding commitment to implement a sustained system pressure reduction management program. It is to be noted that leaving the default "No" response will result in zero energy savings and zero potential incentive.
- Second, the user must enter a target average air discharge pressure.
- Third, the user must enter economic parameters about the cost to maintain target average air discharge pressure.

The annual energy savings attributed to reducing discharge pressure is estimated based on the difference of the average existing typical operating pressure of the compressor and the targeted lower discharge pressure as shown below.

$$\text{Annual Energy Savings (kWh)} = \left[\text{Average normal operating discharge pressure (psig)} - \text{Target pressure (psig)}\right] \times \left[\text{Annual Energy Consumption of Compressors (kWh)} - \text{Annual Energy Savings from Reduced Leaks (kWh)}\right] \times 0.005$$

Demand savings is estimated as follows:

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

Similar to Measure 1, there exists some uncertainty on energy savings from reducing discharge pressure and hence, a “permanence factor” is applied to the energy and demand savings.

5.1.5 Measure 3 – Energy Efficient Dryer

In most manufacturing facilities, dryers are used to control moisture in the compressed air system. A potential energy saving opportunity is to use a dryer that has a dew point (degree of moisture removal) that is appropriate for how dry the air is required to be for the process. (The lower the dew point, the more energy is used.) For example, a refrigerated dryer can often be used instead of a desiccant dryer for general plant use. A desiccant dryer, on the other hand, is only required if the air needs to have a very low dew point, for example in a pneumatic control system. For desiccant dyers, the engineered worksheet assumes a power consumption of 2.5 kW per 100 scfm.

The *3 Air Dryer* tab has four sections, the confirmatory section, the existing and the proposed air dryers section, a dryer technical summary and the economics section.

If the explanation for the flow and pressure estimation methods was provided in the *Compressor Inventory* tab, an “OK” message will appear. If the explanation was not provided, a warning message will appear instead and all of the dryer energy calculations will default to zero.

The confirmatory section asks the user if the required dew point is to be above 32°F (0°C) as shown in Figure 24. If the response is YES, then the project is eligible to convert from a desiccant dryer to a refrigerant dryer or from a refrigerant dryer to a more efficient refrigerant dryer. If the required moisture dew point is less than 32°F, then a desiccant dryer should be used and refrigerant dryers should not be considered.

Figure 24 - Confirmatory Section for Required Dew Point

MEASURE #3 - USE ENERGY EFFICIENT AIR DRYER(S)		
Please review the "**Start Here**" tab to determine if the project qualifies to use this Worksheet as well as the information or data to have on hand when completing the Worksheet. Demand and energy savings will default to zero if no explanation is provided for Compressor Loading (Cell A23) and/or Operating Pressure (Cell A24) found under the **Compressor Inventory** tab.		
Intention to install at least one energy efficient air dryer?	Yes	From "Start Here" Tab
Is the required dewpoint to be ABOVE 32°F (or 0°C)?	Yes	*Eligible to convert from Desiccant to Refrigerant OR from Refrigerant to more efficient Refrigerant Dryer*
Total Compressed Air Operating Flow (scfm)	929	

In the next section, up to five (5) existing and five (5) new dryers can be included in the worksheet. The user must allocate a portion of the total air flow for Dryer#1 as shown in Figure 25. This quantity may be based on actual measurements or good judgment.

Figure 25 - Existing and Proposed Air Dryers

EXISTING AND PROPOSED AIR DRYERS					
Amount of Flow Allocated to Dryer #1 (cfm)	500				
Existing Dryer #1 Type (Refrigerant or Desiccant)	Refrigerant				
	Fill Up Existing and Proposed Dryer Sections				
	Existing Dryer #1		**Proposed Dryer**		
Manufacturer (CAGI Box 1 for Refrigerant Dryers)	Ingersoll Rand		Ingersoll Rand		
Model Number (CAGI Box 3 for Refrigerant Dryers)	D1700INA400		NVC1000W400		
Cycling /Non-Cycling (CAGI Box 4 for Refrigerant Dryers)	Please select		Cycling Refrigerant		
	Full Flow	**10% Flow**	**Full Flow**	**10% Flow**	**Units**
Tested Flow (CAGI Box 6 for Refrigerant Dryers)	981	131	1014	160	cfm
Outlet Pressure Dewpoint (CAGI Box 7 for Refrigerant Dryers)	39	39	39	39	psig
Pressure Drop (CAGI Box 8 for Refrigerant Dryers)	2.5	0.33	2.5	0.33	psig
Total Dryer Input Power (CAGI Box 9 for Refrigerant Dryers)	7.4	7.2	5.73	1.2	kW
Power Requirement for Dryer	7.3		3.0		kW
Amount of Untreated Air for Remaining Dryer(s)	429	cfm			

If it is determined that the required dew point is above 32°F and the existing dryer is a desiccant dryer, the user may omit completing the remaining columns in the Existing Dryer panel and to only complete the Proposed Dryer panel to the right. However, if the existing dryer is a refrigerant dryer then the user should continue completing both the Existing and the Proposed Dryer panels.

The subsequent calculation for the power requirement of the Existing and the Proposed Dryer is based on the allocated air flow for the dryer and information from the CAGI data sheets for both full flow and 10% flow conditions assuming a linear relationship between flow and power. Any untreated air quantity will be shown at the bottom of the panel. It is to be noted that there may be an overall mismatch between total compressor capacity and total dryer capacity and hence, the user must make the choice for the appropriate dryer size and configuration. The process is repeated for the next dryers until the untreated amount air turns zero.

For situations where a CAGI data sheet is not available the user may use data points from similar air dryer from the same manufacturer. Alternatively, an estimation for the CAGI missing data points subject to providing a separate and detailed explanation for the project reviewer be provided.

For easy reference, a Dryer Technical Summary has been provided after the *Existing and Proposed Dryers* section as shown in Figure 26. There will also be some guidance notes appearing after the summary section.

At the last section where eligible costs are entered, the overall energy and demand savings are shown. In some situations, depending on the dryer selection and configuration, there can be a net increase (rather than decrease) with the energy consumption of the dryers. The engineered worksheet will convert negative savings numbers to zero.

Figure 26 - Existing and Proposed Air Dryers

DRYER TECHNICAL SUMMARY						
Dryer Summary	**Existing Dryer Type**	**Base Case (kW)**	**Proposed Case (kW)**	**New Dryer Type**	**Allocated Flow**	**Untreated Air**
Dryer #1	Refrigerant	7.3	3.0	Cycling Refrigerant	500	429
Dryer #2	Desiccant	5.0	2.1	Cycling Refrigerant	200	229
Dryer #3	-	-	-	-	-	229
Dryer #4	-	-	-	-	-	229
Dryer #5	-	-	-	-	-	229
Totals	-	**12.3**	**5.1**	-	**700**	**229**

Notes:
Dryer capacity or allocated amounts may be insufficient to treat air produced by compressors

5.1.6 Measure 4 – Zero Loss Drains Tab

For the *4 Zero Loss Air Drains* tab, the user will indicate the total number of wet drains, and the existing number of zero loss air drains as shown in Figure 27. The engineered worksheet will then calculate the eligible number of drains that may be converted. The user will then enter the desired number of drains together with the cost per drain and the engineered worksheet will compute for the capital cost using some prescriptive input assumptions. The user may also enter other installation and miscellaneous implementation cost.

Figure 27 - Use of Zero Loss Condensate Drains

MEASURE #4 - USE ZERO LOSS CONDENSATE DRAINS		
Please review the "**Start Here**" tab to determine if the project qualifies to use this Worksheet as well as the information or data to have on hand when completing the Worksheet. Demand and energy savings will default to zero if no explanation is provided for Compressor Loading (Cell A23) and/or Operating Pressure (Cell A24) found under the **Compressor Inventory** tab.		
Intention to Install Zero Air Loss Drains?	Yes	From "Start Here" Tab
Total Quantity of ALL Drains upstream of Dryers including those used for Dryers	6	Quantity
Total Quantity of Existing Zero Loss Air Dryers in Above Quantity	3	Quantity
Eligible Quantity of Zero Loss Air Drains	3	
Seeking Incentive for this quantity of Zero Loss Drains	3	Quantity
Average drain blowdown time between cycles	15	seconds
Average time between blowdown cycles	2	minutes
Estimated per Unit Cost for Zero Loss Drains	$ 250.00	

Ratio of drain blowdown time to cycle time between blowdowns is not typical

5.1.7 Summary of Measures, Energy Impact, Project Economics & Incentives

After all necessary information has been entered; the Engineered Worksheet will calculate the Estimated Energy Savings (Permanent and Non-Permanent) from the difference between the Estimated Base Case and Estimated Net New Annual Energy Consumption. It will then compute the Estimated Base Case Peak Demand and Estimated Proposed Case Peak Demand (while operating) by dividing the Annual Energy Consumption by the annual operating hours for both the base case and proposed case. Estimated Demand Reduction, in turn, is calculated by getting the difference between the base and proposed case. It shows how much energy is expected to be saved in Figure 28.

Figure 28 – Annual Savings and Economics

ENERGY IMPACT, PROJECT ECONOMICS AND INCENTIVE SUMMARY						
	Measure #1 - Reduce Leaks	**Measure #2 - Reduce Pressure**	**Measure #3- Efficient Dryers**	**Measure #4- Zero Loss Drains**	**Totals**	**Units**
Gross kWh Savings	36,270	37,036	32,722	19,781	125,809	kWh
Gross kW Reduction	8.0	8.1	7.2	4.3	27.6	kW
TOTAL ELIGIBLE COSTS FOR THE PROJECT	$ 1,547	$ 1,593	$ 27,000	$ 1,825	$ 31,965	dollars
Permanence Factor for Measure (Determined by OPA)	50%	50%	100%	100%		percent
Adjusted Energy Savings for this Measure	18,135	18,518	32,722	19,781	**89,156**	kWh
Adjusted Demand Savings for this Measure	4.0	4.1	7.2	4.3	**19.6**	kW
Estimated Annual Cost Savings (based on Adjusted Energy Saving	$ 1,995	$ 2,037	$ 3,599	$ 2,176	$ 9,807	dollars
	Estimated Base Case Annual Energy Consumption				871,907	kWh
	Estimated Base Case Peak Demand while Operating				191.6	kW
	Efficient Case Annual Energy Consumption				782,751	kWh
	Estimated Efficient Case Peak Demand while Operating				172.0	kW
	Percent Energy Savings Identified				**10.2%**	Percent

5.1.8 Summary of Underlying Calculation and Assumptions

The following equations are used to calculate the Base Case Energy and net CDM[3] Case Energy consumption in kWh.

Base Case Energy:

$$\text{Total Compressor Output (cfm)} = \sum_{n=1}^{n} \left[\text{Motor Rated Power (bhp)} \times \text{Compressor Efficiency Factor (cfm/hp)} \times \text{\% Loading of Compressor} \right]$$

Where n represents the number of compressors included in the Retrofit Application

$$\text{Total Energy Consumption of Compressors (kWh)} = \frac{\text{Total Compressor Output (cfm)}}{\text{Average Compressor Efficiency Factor (cfm/hp)}} \times 0.746\ \text{kW/hp} \times \text{Annual Operating Hours (hrs)}$$

[3] Conservation and Demand Management

$$\text{Energy Consumption of Dryer (kWh)} = \text{Total Compressor Output (cfm)} \times \text{Energy Factor (kWh per 100 cfm)} \times \text{Annual Operating Hours (hrs)}$$

The total energy consumption for the base case is:

$$\text{Total Energy Consumption } (kWh_b) = \text{Total Energy Consumption of Compressors (kWh)} + \text{Energy Consumption of Dryer (kWh)}$$

The base case peak demand is:

$$\text{Total Peak Demand } (kW_b) = \frac{\text{Total Energy Consumption } (kWh_b)}{\text{Annual Operating Hours (hrs)}}$$

Net CDM Case Energy:

Measure 1 – Reduce Air Leakage

$$\text{Air leaks at target leak level (cfm)} = \text{\% target allowable leak level} \times \text{Total Compressor Output (cfm)}$$

$$\text{Amount of air leaks to be reduced (cfm)} = \text{Air Leaks at 100\% Compressor Output (cfm)} - \text{Air leaks at target leak level (cfm)}$$

$$\text{Annual Energy Savings (kWh)} = \frac{\text{Amount of air leaks to be reduced (cfm)}}{\text{Average Compressor Efficiency Factor (cfm/hp)}} \times 0.746 \text{ kW/hp} \times \text{Annual Operating Hours (hrs)}$$

If the facility has a maintenance program that ensures that leaks are monitored, the Annual Energy Savings is discounted by 50%. Otherwise, it is discounted by 25%.

Measure 2 – Reduce Discharge Pressure

$$\text{Annual Energy Savings (kWh)} = \left[\text{Average normal operating discharge pressure (psig)} - \text{New discharge pressure (psig)} \right] \times \frac{\text{Total Compressor Output (kWh)}}{2 \text{ psig} \times 100}$$

Similar to Measure 1, if the facility has a maintenance program that ensures that a reduced setpoint is maintained, the Annual Energy Savings is discounted by 50%. Otherwise, it is discounted by 25%.

Measure 3 – Use Appropriate Air Dryer

Desiccant Dryer uses 2.5 kW per scfm.

For a cycling or non-cycling dryer, data is used from the CAGI Data Sheets:

$$Annual\ Energy = \left(\begin{matrix} Power \\ Consumption \\ at\ Zero\ Flow \end{matrix} + \frac{Power\ at\ 100\%\ Flow - Power\ at\ 10\%\ Flow}{Flow\ at\ 100\% - Flow\ at\ 10\%} \times Operating\ Flow \right) \times Operating\ Hours\ per\ Year$$

Measure 4 – Use Premium Efficiency Motor

The underlying energy savings calculation assumes that the drain uses 85 cfm while open, operates at 100 psig, and costs $0.25 per 1,000 cfm of compressed air. This underlying value is multiplied by the number of cycles per hour and then multiplied by the annual operating hours for the compressed air system.

5.2 Variable Speed Drive (VSD) Compressed Air Engineered Worksheet

5.2.1 Backgrounder - VSD and Fixed Speed Air Compressors

There are two general categories of industrial air compressors:

- Positive displacement - includes rotary screw and piston
- Dynamic – includes centrifugal

Except for a handful of very large manufacturing facilities which use dynamic compressors, the majority of industrial facilities employ positive displacement air compressors.

The common way to vary compressor capacity is by controlling inlet or discharge valves. This in turn restricts the output of the compressor as it continues to run at full speed. Most positive displacement air compressors become less energy efficient as air demand is reduced. In extreme cases, up to 65% of the rated electrical power is still used even when there is no demand for air.

For positive displacement compressors, a more energy efficient solution can be achieved by varying the motor speed. Using this method the power consumption decreases as demand for air reduces.

Many manufacturing facilities can gain financial and energy performance benefits from installing variable speed (VSD) compressors.

The main advantages of variable speed drives are:

- Improved efficiency over fixed speed machines part load conditions under 75%.
- Improved discharge pressure control
- Eliminating high inrush currents by using soft starting VSD controls thereby extending the life of the motor

In air systems where multiple compressors are used, the controls can be set so that one or more fixed speed compressors are operating at full load (usually optimal performance) and the balance of the air is made by the VSD compressor.

Compressed Air and Gas Institute (CAGI) Data Sheets

The Compressed Air and Gas Institute (CAGI) serves as the unbiased authority on technical, educational, promotional, and other matters that affect the compressed air industry. CAGI has developed standard energy performance data sheet formats for:

- Fixed speed air compressors
- Variable speed drive air compressors

The CAGI data sheets are only suitable for air compressors with nominal sizes ranging from 25 to 200 hp and for discharge pressure ratings from 100 to 150 psig. Participating manufacturers can test their air compressors for energy performance and publish the results using the CAGI format.

It should be noted that the CAGI testing is voluntary in nature. Moreover, the reported results are not validated by CAGI, but are subject to spot checks. Using the CAGI performance sheets for the VSD Air Compressor Engineered Worksheet provides an open and transparent method to compare the energy performance a Fixed Speed and a corresponding VSD compressor.

Participating compressor vendors have published CAGI specification sheets as follows:

Manufacturer	Web Link
Atlas Copco	http://www.atlascopco.us/usus/aboutus/sales/compressors_generators/cagi.asp
BOGE	http://www.boge.com/us/CAGI/index.jsp?msf=200,100,500
CompAir	http://www.compairusa.com/products_sixty_hz/cagi_data/01fixed_speed_cagi_data_sheets.aspx
FS Curtis	http://us.fscurtis.com/products/cagi/
Gardner Denver	http://www.gardnerdenverproducts.com/compressors/downloads.aspx
Ingersoll Rand	http://www.ingersollrandproducts.com/cagi_sheets/index.aspx
Kaeser	http://us.kaeser.com/Advisor/CAGI_data_sheets/default.asp#0
Quincy	http://www.quincycompressor.com/cagi.html
Sullair	http://www.sullairinfo.com/

(Weblinks validated October 2013)

CAGI Fixed Speed Compressor Data Sheet

The standard format for the CAGI fixed speed compressor performance sheet uses the format as shown in Figure 29.

Figure 29 - Fixed Speed Air Compressor CAGI Datasheet

COMPRESSOR DATA SHEET

Rotary Compressor: Fixed Speed

MODEL DATA - FOR COMPRESSED AIR			
1	Manufacturer:		
2	Model Number: ☐ Air-cooled ☐ Water-cooled ☐ Oil-injected ☐ Oil-free	Date: Type: # of Stages:	
3*	Rated Capacity at Full Load Operating Pressure [a, e]		acfm [a,e]
4	Full Load Operating Pressure [b]		psig [b]
5	Maximum Full Flow Operating Pressure [c]		psig [c]
6	Drive Motor Nominal Rating		hp
7	Drive Motor Nominal Efficiency		percent
8	Fan Motor Nominal Rating (if applicable)		hp
9	Fan Motor Nominal Efficiency		percent
10*	Total Package Input Power at Zero Flow [e]		kW [e]
11	Total Package Input Power at Rated Capacity and Full Load Operating Pressure [d]		kW [d]
12*	Specific Package Input Power at Rated Capacity and Full Load Operating Pressure [e]		kW/100 cfm [e]

*For models that are tested in the CAGI Performance Verification Program, these items are verified by the third party administrator. Consult CAGI websitefor a list of participants in the third party verification program: www.cagi.org

NOTES:

a. Measured at the discharge terminal point of the compressor package in accordance with ISO 1217, Annex C; ACFM is actual cubic feet per minute at inlet conditions.
b. The operating pressure at which the Capacity (Item 3) and Electrical Consumption (Item 11) were measured for this data sheet.
c. Maximum pressure attainable at full flow, usually the unload pressure setting for load/no load control or the maximum pressure attainable before capacity control begins. May require additional power.
d. Total package input power at other than reported operating points will vary with control strategy.
e. Tolerance is specified in ISO 1217, Annex C, as shown in table below:

Member CAGI Compressed Air & Gas Institute

Volume Flow Rate at specified conditions		Volume Flow Rate	Specific Energy Consumption	No Load / Zero Flow Power
m^3 / min	ft3 / min	%	%	
Below 0.5	Below 15	+/- 7	+/- 8	+/- 10%
0.5 to 1.5	15 to 50	+/- 6	+/- 7	
1.5 to 15	50 to 500	+/- 5	+/- 6	
Above 15	Above 500	+/- 4	+/- 5	

ROT 030
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This form was developed by the Compressed Air and Gas Institute for the use of its members. CAGI has not independently verified the reported data.

5.2.2 Suitability of Use and Limitations

The VSD Compressed Air Engineered Worksheet may not be suitable for some situations. Before commencing, carefully review the following Validation Statements. If ALL statements are true for the situation under consideration, then the VSD Compressed Air Engineered Worksheet tool may be used. If one or more of the Validation statements shown below is not true, then follow the corresponding suggested step.

Check	Validation Statement	Steps to Take if Validation Statement is NOT True
☑	The intended air compressor system only has ONE compressor?	• If there is more than one compressor and NO VSD compressors, consider using the IESO *Compressed Air Engineered Worksheet* • If the compressed air system will have more than one compressor, and will include a VSD compressor, follow the IESO's "Custom" track for project evaluation
☑	The Fixed Speed and VSD compressors are positive displacement machines?	• If the compressor is "Dynamic", follow the IESO's "Custom" track for evaluation
☑	The Fixed Speed and VSD compressors are 25 to 200 HP in size?	• If the compressors are outside the 25-200 HP capacity follow the IESO's "Custom" track for project evaluation
☑	The Fixed Speed and VSD	• If the compressors are outside the 0-2,000 acfm capacity follow the

Check	Validation Statement	Steps to Take if Validation Statement is NOT True
	compressors have maximum capacity of 2,000 acfm?	IESO's "Custom" track for project evaluation
☑	The Intended compressor Operating Discharge pressure is from 70-150 psig?	• If the intended operating discharge pressure is outside the 70-150 psig range, follow the IESO's "Custom" track for project evaluation
☑	There is a CAGI data sheet available for both the Fixed Speed, and the VSD Compressor under consideration?	• If no CAGI sheet is published by the vendor, use the CAGI sheet for a similar compressor and provide an explanation in the "Notes for Reviewer" section of the VSD Compressor Worksheet. • If the vendor does not participate in the CAGI specifications follow the follow the IESO's "Custom" track for project evaluation
☑	The VSD Compressor is expected to operate less than 100% of rated capacity for the vast majority of the time?	• If the VSD Compressor operates at or near 100% of capacity for the majority of the time, chances are that the more energy efficiency option would be a Fixed Speed compressor. • The VSD Compressor calculator tool may be used and will provide an indication of the VSD or Fixed Speed compressor is the more suitable option
☑	The turndown mode for the VSD compressor is always expected to be more 40% of the rated capacity?	• Although VSD compressors have good turndown ratios, in the majority of cases they should not be operated at less than 40% rated capacity. • If the system in question, is expected to be operated at less than 40% of rated capacity, even for part of the time, use the "Custom" track for project evaluation

5.2.3 Typical Operating Pressure

The *System Design Assumptions* tab requests information on the fixed speed compressor and the VSD compressor together with information about typical operating patterns, intended operating pressure and cost factors. Initially, the Engineered Worksheet asks for the Intended Compressor Operating Discharge Pressure (psig) for the compressed air system as shown in Figure 30.

Figure 30 - Typical Operating Pressure

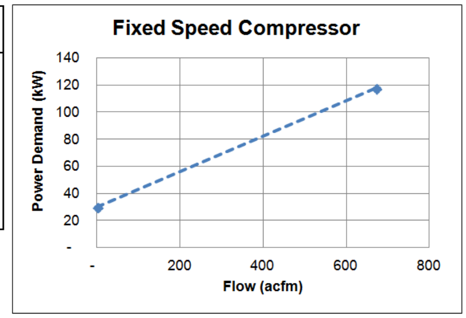
TYPICAL OPERATING PRESSURE	
100	Intended Compressor Operating Discharge Pressure (psig)

5.2.4 Fixed Speed Compressor (CAGI Data Sheet Inputs)

Only some data from the fixed speed compressor data sheet is required for the energy calculations. The number corresponding to the CAGI data field is shown in the left column. Using the CAGI data sheet, enter information such as the manufacturer (Note: Use the drop down menu), the model number, rated capacity, full load operating pressure, and total package input power at zero flow and at rate flow. Figure 31 shows an example of information entered in the worksheet from the CAGI data sheet.

Figure 31 - Fixed Speed Compressor (CAGI Data Sheet Inputs)

FIXED SPEED COMPRESSOR (CAGI DATA SHEET INPUTS)			
CAGI Data Sheet Field #	**Description**	**Value**	**Units**
1	Manufacturer	Manufacturer ABC	
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

If the Manufacturer is not listed in the dropdown list, select "Other" and then provide a note in the "Comments & Notes for Technical Reviewer to be Aware of" field.

The worksheet will provide a warning if the flow to power ratio seems to be outside a reasonable amount (4 to 6 scfm per kW). If it falls outside the range, the user is suggested to double check the values entered to ensure that they correspond with the CAGI data sheet. The worksheet will also provide an alert if the full load operating pressure is insufficient to meet the required intended operating pressure.

Immediately to the right of the data entry section, the worksheet will display a Power Demand (kW) versus Flow (acfm) performance curve for the fixed speed compressor based on the zero and maximum flow (known) points. The performance curve is based on a linear equation y = mx + b, where:

y = Power Demand (kW)

$$m = \frac{\text{Maximum Flow Power Demand} - \text{Minimum Flow Power Demand}}{\text{Maximum Flow} - \text{Zero Flow}}$$

b = Power Demand (kW) at Zero Flow

5.2.5 VSD Compressor (CAGI Data Sheet Inputs)

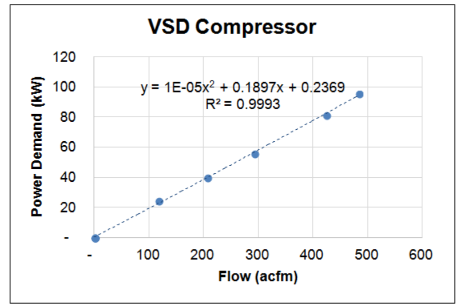
Only some data from the VSD compressor data sheet is required for the energy calculations. The number corresponding to the data field is shown in the left column. Using the CAGI data sheet, enter information such as the manufacturer (Note: Use the drop down menu), model number, rated operating pressure, input power and capacity values and the total power at zero flow capacity as shown in Figure 32.

Figure 32 - VSD Compressor (CAGI Data Sheet Inputs)

VSD COMPRESSOR (CAGI DATA SHEET INPUTS)

CAGI Data Sheet Field #	Description	Data Input	
1	Manufacturer	Manufacturer ABC	
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 of VSD Compressor seems OK for Operating Pressure Requirements



If the Manufacturer is not listed in the dropdown list, select "Other" and then provide a note in the "Comments & Notes for Technical Reviewer to be Aware of" field.

The CAGI VSD Compressor data sheet generally has about 5 pairs of values of input power (kW) and capacity (acfm) but could have up to eight field pairs. Use Point 1 to show the maximum input power (kW) and corresponding capacity (acfm). Use Point 2 to show the second highest, Point 3 the third highest and so on.

IMPORTANT NOTE: If there are no more values to enter (typically at Point 6, 7 or 8), enter the total package input power at zero flow power values in the next available vacant field (e.g. Point 6 or 7 or 8). The corresponding flow value will be zero. Enter the total package input power at zero flow again in the next vacant field (e.g. Point 7 or 8) also showing zero flow, and again in Point 8 if still vacant.

Show the total package input power at zero flow one final time in the field with the namesake field. If the compressor's pressure is lower than the intended operating pressure a warning message will show up.

At the right side of the data entry, a graph of power demand (kW) versus flow (acfm) appears. The worksheet uses regression to determine the equation of a line that fits the data. The equation is in the form of $y = ax^2 + bx + c$ where:

y	=	Power demand (kW)
x	=	Flow (acfm)
a, b, c	=	Coefficients determined by the worksheet

The R^2, or Coefficient of Determination, value is shown in the graph in Figure 29. R^2 can have a value between -1 and +1, and it indicates how well the equation of the curve actually matches the data points. The closer the R^2 value is to 1, the better is the fit.

Tip: A good equation should have an R^2 value of more than 0.95. If your R^2 value is less than 0.95 recheck the data entry, and if still less than 0.95, use the IESO “Custom” track for the evaluation.

5.2.6 Typical Operating Profile

To complete the estimation of savings, a typical operating profile needs to be inputted. An operating profile is a representation of the anticipated air flow variation and is usually measured by data-logging or performing a field test of the compressor system. Flows are allocated into 11 bins which include 10 bins in increments of 10% from 0 to 99.9% and one bin at 100% of flow as shown in Figure 33. The user is required to provide a short explanation regarding how the compressor profile was determined.

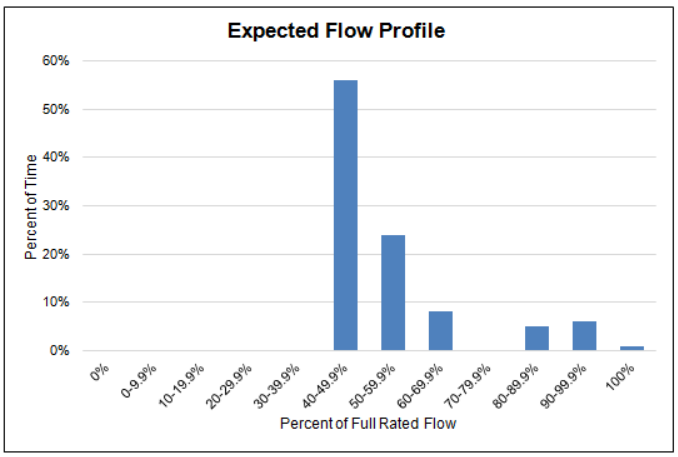
Figure 33 - Typical Operating Profile

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%



The expected flow profile histogram appears immediately to the right of the data entry panel. The worksheet does not permit entry of flow ranges less than 40% of maximum flow as it is generally a symptom of over sizing a fixed speed or VSD compressor.

The worksheet will automatically estimate the design basis maximum flow (acfm) shown as a green cell in the top left portion of the section. If the fixed speed compressor and VSD compressor have different maximum flow rates, the lesser of the two will be used for an “apples” to “apples” comparison.

5.2.7 Short Explanation

At the bottom of the *Typical Operating Profile* section, a box is provided for a short explanation regarding the method used for estimating the flow profile as shown in Figure 34. It is mandatory to provide a short explanation since if this field is left blank, the energy savings will default to zero.

Figure 34 - Short Explanation

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.

5.2.8 Comments & Notes for Technical Reviewer to be Aware of

The Comments & Notes for Technical Reviewer to be Aware section is optional. It can be used to note any important information about the application, including if a substitute CAGI data sheet was used.

If the capacity of the VSD compressor is 10% or more than the capacity of the Fixed Speed compressor, the following message will display:

Figure 35 - Comments & Notes for Technical Reviewer to be Aware of

COMMENTS & NOTES FOR TECHNICAL REVIEWER TO BE AWARE OF

5.3 Variable Speed Drive (VSD) on Fans Engineered Worksheet

5.3.1 Fan Overview

Conservative engineering practices often result in the specification, purchase, and installation of fans that exceed process requirements. Engineers often decide to include a margin of safety in sizing fans to compensate for uncertainties in the design process, including anticipated future expansions in system capacity and potential fouling effects.

Variable speed drive (VSD) control for centrifugal fans can, in many situations, offer a more energy efficient solution when compared to alternative methods, such as throttling, bypassing, and on-off control.

Fans provide the means to move a gaseous fluid through a system of ductwork. They are widely classified into two major categories according to the direction of the airflow through the impeller, either centrifugal or axial.

- Centrifugal fans – these force the gas to move in a rotational manner with respect to the fan housing. The centrifugal forces created produce the pressure to move the fluid stream through the system of ductwork.
- Axial fans – these do not create centrifugal forces but impart a velocity that is created as the gas passes over the blades of an impeller.

A few percentage points of efficiency improvement can save significant energy over the life of the fan. The five most common ways of controlling a fan include: outlet dampers; inlet dampers; inlet guide vanes; on – off control; and variable speed drive control.

As a general observation, optimization of a centrifugal fan, with a large horsepower motor and a continuous operating pattern with variable load, results in the greatest energy savings opportunities for a VSD application. In many situations, energy savings can be achieved by making changes to the fan's hydraulic systems (for example, ducts). Some other measures include: right sizing equipment; trimming impellers; changing pulley ratios; installing two speed or multispeed motors; and removing system friction or pressure drop losses. It is assumed that these alternative possibilities have been evaluated and ruled out before turning to a variable speed drive (VSD) application.

Before completing the VSD on Fans Engineered Worksheet, it is highly recommended that the Applicant or Applicant Representative be familiar with the following:

- Methods to undertake field measurements of power, flow, and pressure for fan systems within the facility;
- Technical principles related to how centrifugal fans function, including the rotational speed and power consumption relationship for centrifugal drives (affinity laws); and
- Fan operational limitations for a specific application including, but not limited to, factors such as: vibration and noise, resonance, pipe/duct fatigue, pipe erosion, mechanical limitations, and zones of instability.

5.3.2 Fan Curve and Operating Profile

A key purpose of fan data gathering is to determine the system performance curve and to establish, or verify, specific operating points for the load duty curve. To ensure reliable analysis, information about flow, speed, pressure, temperature, brake horsepower, and other parameters should be obtained.

In reality, there are situations where not all this information is readily available. However, with a reasonable understanding of system operation, and by using existing records and information from operators together with good judgment, it is possible to approximate the operating points and to establish a relatively accurate fan load condition.

The system resistance curve can be estimated when system effect factors are taken into account. These factors include individual system resistances brought about by the physical configuration or layout of the equipment and associated pipes or ducts.

As with any measurements, the accuracy of energy efficiency analysis depends on the source, accuracy, and reliability of the data inputs. Common sources for information include: design data from fan curves, observations and estimates from plant operations personnel, equipment nameplate data, operating records, temporary metering, and temperature of the gas being moved.

Determining what data is the most valuable can be a matter of experience and applying sound technical judgment. One also needs to consider whether a fan's fluctuating output could be brought about by changes in batch operation, alterations or variations in material being processed, and seasonality or weather impacts.

The *System Design Assumptions* tab collects information on the base case and the efficient case for a series of potential improvements to the fan system.

Note: *Fans and fan systems are comprised of different components and configurations and the energy efficiency results for multiple measures may not be additive.*

As noted, before completing the worksheet, it is important to gather all the necessary information and have it readily available. The following information is needed:

- **Fan Design Flow (CFM)** – this is the design (100%) flow, in cubic feet per minute, that the fan has been designed for.
- **% Flow** – this indicates the percentage of full flow in which the system is being operated. (That is, 0-10% indicates operation between 0% of full flow and 10% of full flow. This range is called a flow bin.).
- **Design Head (Inch Water Gauge)** – is the corresponding pressure lift developed by the fan at a given flow rate in inches water column; it is usually determined from the as-built Fan Curve provided by the fan supplier.
- **Corresponding Fan Efficiency (%)** – this is the fan efficiency indicated on the Fan Curve for a particular flow and head; if efficiencies are shown as families of curves, and an operating point falls between two curves, the average may be used.
- **Operating Profile (%)** – the user should enter the percentage of time during which the system operates in the specified flow regimes; this information is obtained from field measurements at the site (for example, a fan can range in operation from 40% to 100%, with the most common operating point occurring in the 80% – 90% flow bin); operating points should be adjusted such that the sum of the numbers shown in the Operating Profile % is equal to 100%. The worksheet will display “YES” when the 100% criterion is met.

The **Fan Curve** box on the right hand side of the worksheet will automatically display a curve when the Fan Design Flow and the Design Head for each percent Flow are filled-in.

Notes:

1) *The user should enter the flow and efficiency values for the midpoint of the bin range. For example, for the 90%-100% bin, one would enter the design head corresponding to 95% flow.*

2) *The Fan Curve also produces a polynomial curve fit along with an R^2 value for a regression model. When entering data from a hard-to-read Fan Curve, minor adjustments (upwards or downwards) can be done to the design head to get the R^2 value to be as close as possible to 1.0.*

See Figure 36 for an example of a Fan Curve that resulted from the information input on the left.

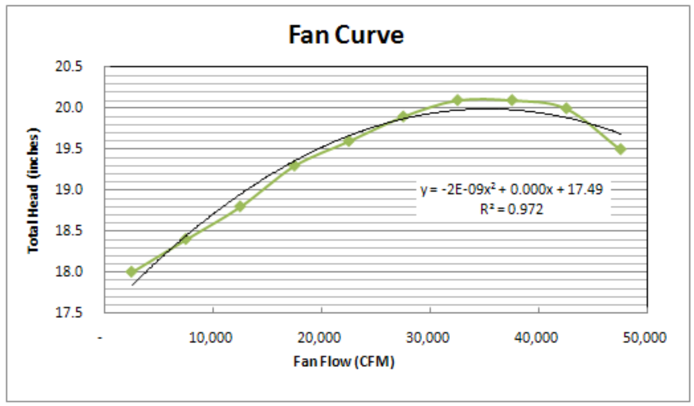
Figure 36 – Fan Curve and Operating Profile

FAN CURVE AND OPERATING PROFILE

50,000	Enter the Fan Design Flow in Cubic Feet per Minute

Using the table below, enter fan curve data (head and efficiency), and fan flow duration.
Tip: Keep an eye on the graphs to the right to aid with visualizing the fan characteristics.

%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
			OK



Important note: *Some fans will not function properly in certain flow and pressure zones. For example, operating at a certain point may result in mechanical resonance or instability. It is critical to use good engineering judgment in conjunction with the manufacturer's performance curve, conditional assessment, and actual field measurements before deciding on recommendations and retrofit designs.*

5.3.3 Fan and Motor Information

In the **Fan and Motor Information** section of the *System Design Assumptions* tab, information about the motor speed and horsepower, gas temperature and density, design head and static head, and make and manufacturer of the fan and motor, with the corresponding estimated age, is collected. This information is described below:

- **Motor Rated Speed (rpm)** – this is the manufacturer's rated speed (full-load), which can be found on a motor's nameplate.
- **Motor Rated Power (hp)** – this is the nameplate rating for the motor.
- **Gas Temperature (°F)** – this is the temperature of the gas flowing through the fan. As hotter gases are less dense, the worksheet makes adjustments for fan performance based on gas temperature. The default value is 68°F.
- **Density of Gas** (**lbs/ft^3)** – by definition, air is assigned a density of 0.075.If the gas being transported is not air, revise the density value accordingly.
- **Design Head (Inch Water Gauge)** – from the Fan Curve, enter the Design Head corresponding to the system design flow point.

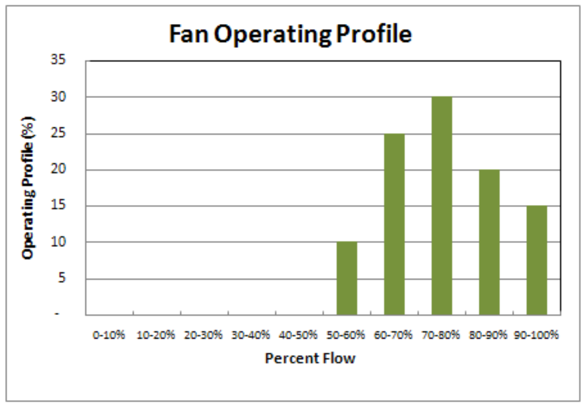
- **Static Head (Inch Water Gauge)** – this is the pressure differential caused by height differences, or pressure differences, between vessels. In addition to overcoming friction, the fan must also overcome static head in order to transfer fluid from one point to another. It is important to include this information because the fan affinity laws (power requirement is proportional to the cube of the speed) may need to be adjusted for the presence of static head. Note, however, that the vast majority of fan applications do not have a significant static head component.

- **Fan Make and Model** – enter this information for the motor and the fan, along with the **Approximate Ages** (years).

The **Fan Operating Profile** box on the right of the **Fan and Motor Information** table will automatically display the Operating Profile (graph) when the Fan and Motor Information is entered. Figure 37 shows an example of this.

Figure 37 – Fan and Motor Information

FAN AND MOTOR INFORMATION		
This information can typically be found on the motor and fan specification sheets, or can be obtained by contacting the manufacturer(s)		
	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



5.3.4 Fan and Motor Efficiency

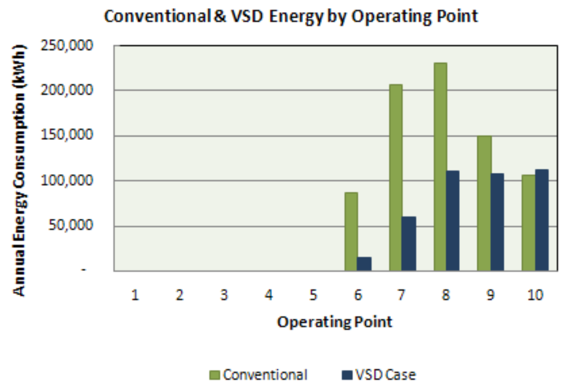
Information on fan and motor efficiencies is needed to estimate the Energy Savings (see Figure 38). Motor efficiency at full load can be obtained from the motor manufacturer, or estimated from generic values published by NRCan or the US Department of Energy, or by looking up the value in the freely available CanMOST database.[4] The Fan Efficiency at Damper Fully Open value is obtained from the Fan Curve at the *Fan Design Flow* point.

[4] Available for download free of charge from the Department of Natural Resources Canada – Office of Energy Efficiency http://oee.nrcan.gc.ca/industrial/equipment/software/intro.cfm

Figure 38 – Fan and Motor Efficiency Information

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% Loa
0.82	fraction	Motor Efficiency Correction Factor for VSD Operatio
0.96	fraction	Belt/Coupling Efficiency Factor

ECONOMIC VALUES		
	Units	**Description**
$ 0.1100	$/kWh	Blended Cost of Power
$ 6.00	$/kW	Estimated Monthly Peak Demand Unit Cost
$ -	$	Non Electrical Annual Savings (Cost is -ve)



The following other motor efficiency correction factors, expressed as decimal fractions, also should be input:

- **Motor Efficiency Correction Factor for Lower Loads** – this accounts for part loading of the motor, typically ranging from 80- 95%. Default value is 0.96.

- **VSD Efficiency Factor (When Operating > 40% Load)** – this accounts for part loading of the variable speed drive, typically ranging from 90-98%. This factor can be obtained from the VSD supplier. Default value is 0.95

- **Motor Efficiency Correction Factor for VSD Operation** – this accounts for the interactive effects between the motor and the variable speed drive when part loading with values typically ranging from 80- 95%. Default value is 0.82.

- **Belt/Coupling Efficiency Factor** – this accounts for the transmission efficiency between the motor and fan. Default value is 0.96.

Note: *Sometimes these factors are difficult to obtain. If the information is not available, pick a reasonable value from the ranges indicated above. Note that the worksheet will only use the efficiency correction factors when the flow is more than 60% of design. Various diminishing factors are applied in place of the values entered by the user when the flows are less than 60%.*

When the Fan and Motor Efficiency information is entered, a graph representing the **Conventional & VSD Energy by Operating Point** will automatically display. Figure 35 shows an example of this graph. The green bars indicate the expected energy consumption with the conventional system (that is, throttle) and the blue bars indicate the energy using a VSD.

5.4 Variable Speed Drive (VSD) on Pumps Engineered Worksheet

5.4.1 Pump Overview

Similar to fan applications, variable speed drive (VSD) control for centrifugal pumps can, in many situations, offer a more energy efficient solution when compared to alternative methods, such as throttling, bypassing, and on-off control.

A centrifugal pump is a rotodynamic pump that uses a rotating impeller to create flow by the addition of energy to a fluid. Centrifugal pumps are commonly used to move liquids through piping. The fluid enters the pump impeller along, or near, the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits into the downstream piping. Centrifugal pumps are generally divided into three general categories:

1) Radial Flow Pumps – the fluid enters the pump impeller along its axis, is accelerated by the impeller and exits outward perpendicular to the shaft (radially).

2) Axial Flow Pumps – the fluid enters in a direction that is parallel to the rotating shaft and discharged with minimal friction and no change in direction.

3) Mixed Flow Pumps – these pumps are a combination of radial and axial flow pumps; the fluid is accelerated with a push from the axial direction of the impeller and discharged diagonally somewhere between 0–90 degrees from the axial direction.

Before completing the VSD on Pumps Engineered Worksheet, it is highly recommended that the Applicant or Applicant Representative be familiar with the following:

- Methods to undertake field measurements of power, flow, and pressure for pump systems within the facility;

- Technical principles related to how centrifugal pumps work, including the rotational speed and power consumption relationship for centrifugal drives; and

- Pump operational limitations for a specific application including, but not limited to, factors such as: vibration and noise, resonance, pipe/duct fatigue, pipe erosion, mechanical limitations, and zones of instability.

5.4.2 Pump Curve and Operating Profile

The *System Design Assumptions* tab collects information on the base case and the efficient case for a series of potential improvements to the pump system.

Note: *It is important to recognize that pumps are comprised of different components and configurations and the energy efficiency results for multiple measures may not be additive.*

As noted, before completing the worksheet, it is important to gather all the necessary information and have it readily available. The following information is needed:

- **Pump Design Flow (GPM)** – this is the design (100%) flow in U.S. gallons per minute that the pump has been designed for.

- **% Flow**–this indicates the percentage of full flow in which the system is being operated. (That is, 0-10% indicates operation between 0% of full flow and 10% of full flow. This range is called a flow bin.)

- **Pump Head (ft)** – this is the corresponding height of liquid column developed by the pump at a given flow rate; it is usually read from the Pump Curve.

- **Corresponding Pump Efficiency (%)** – this is the pump efficiency indicated by the Pump Curve for a particular flow and head; if efficiencies are shown as families of curves and an operating point falls between two curves, the average may be used.

- **Operating Profile (%)** – the user must enter the percentage of time during which the system operates in the specified flow regimes; this is obtained from field measurements at the site (for example, a pump can range in operation from 40% to 100%, with the most common operating point occurring in the 80% – 90% flow bin); operating points should be adjusted such that the sum of the numbers shown in the Operating Profile % is equal to 100%.The worksheet will display "YES" when the 100% criterion is met.

The **Pump Curve** box shown on the right hand side of the worksheet will automatically display a curve when the Pump Design Flow and the Pump Head for each percent Flow are filled-in. Figure 39 shows the Pump Curve corresponding to the information filled in on the left.

Notes:

1) *The user should enter the flow and efficiency values for the midpoint of the bin range. For example, for the 90%-100% bin, one would enter the design head corresponding to 95% flow.*

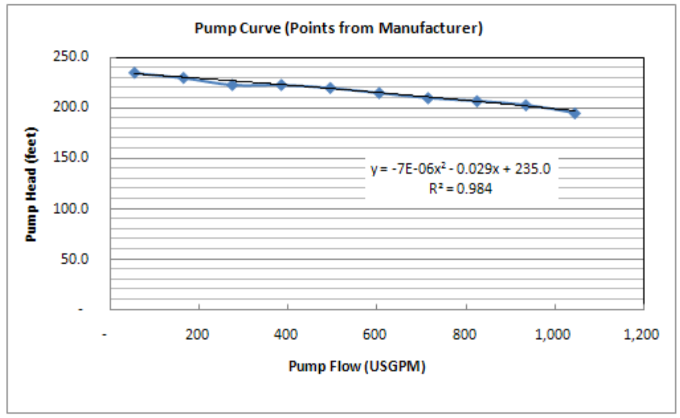
2) *The Pump Curve also produces a polynomial curve fit along with an R^2 value for a regression model. When entering data from a hard-to-read Pump Curve, minor adjustments (upwards or downwards) can be done to the design head to get the R^2 value to be as close as possible to 1.0.*

Figure 39 – Pump Curve and Operating Profile

PUMP CURVE AND OPERATING PROFILE	
1,100	Enter Pump Design Flow in US Gallons per Minute

Using the table below, enter pump curve data (head and efficiency), and pump flow duration.
Tip: Keep an eye on the graphs to the right to aid with visualizing the pump characteristics.

%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	190.0	80	100
Operating Profile sum equals 100%:			YES



Important note: *Some pumps will not function properly in certain flow and pressure zones. For example, operating at a certain point may result in mechanical resonance or instability. Before deciding on recommendations and retrofit designs it is critical to use good engineering judgment and to take into account the manufacturer's performance curve, conditional assessment, and actual field measurements before deciding on recommendations and retrofit designs.*

5.4.3 Pump and Motor Information

In this section of the *System Design Assumptions* tab, information about the motor speed and horsepower is entered. In addition, enter the fluid temperature and specific gravity. For pumps, the default specific gravity for water is 1.00. Enter the pump head or design head that would correspond to the Pump Design Flow previously entered. The static head for a pump should also be entered. It is important to include this information because the pump affinity laws (power draw is proportional to the cube of the speed) may need to be adjusted for the presence of static head. The information that should be entered is:

- **Motor Rated Speed (rpm)** – this is the manufacturer's rated speed (full-load), which can be found on the motor's nameplate.
- **Motor Rated Power (hp)** – this is the nameplate rating for the motor.
- **Fluid Temperature (°F)** – this is the temperature of the fluid that is being pumped. As hotter liquids are less dense, based on fluid temperature, the worksheet makes adjustments for pump performance.

- **Specific Gravity** – by definition, water is assigned a specific gravity of 1. If the liquid being pumped is not water, revise the specific gravity value accordingly.

- **Design Head (Inch Water Gauge)** – using the Pump Curve, enter the Pump Head (ft) corresponding to the Pump Design Flow point. Note that the Design Head corresponds to the point on the Pump Curve for the design flow (that is, the flow point shown in the input cell for "Pump Design Flow in US Gallons per Minute").

- **Static Head (Inch Water Gauge)** – this is the pressure differential caused by height differences, or pressure differences between vessels, and is unique to the specific layout of each individual facility. Static Head cannot be read from a Pump Curve, however, an indication of Static Head considerations may be available from the original system design documentation. In addition to overcoming friction, the pump must also overcome Static Head in order to transfer fluid from one point to another.

- **Pump Make and Model numbers** – enter this information for the motor and the fan along with the Approximate Ages (years).

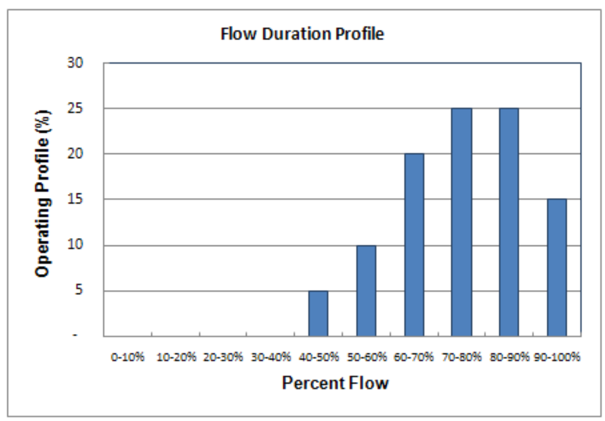
The **Flow Duration Profile** box to the right of the Pump and Motor Information table will automatically display the Fan Duration Profile (graph) when the Pump and Motor Information is entered. Figure 40 shows an example of this.

Figure 40 – Pump and Motor Information

PUMP AND MOTOR INFORMATION

This information can typically be found on the motor and pump specification sheets, or can be obtained by contacting the manufacturer(s)

	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	alphanumeric	Motor Make & Model
XYZ-999	alphanumeric	Pump Make and Model
5	years	Approximate age of Motor
3	years	Approximate Age of Pump



5.4.4 Pump and Motor Efficiency

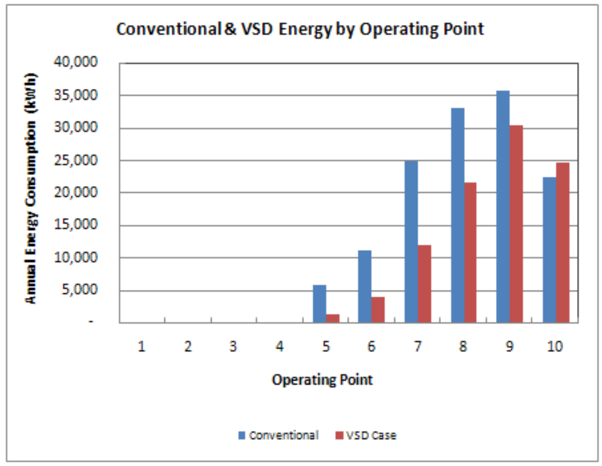
Information on pump and motor efficiencies is needed to estimate the Energy Savings (see Figure 41). Motor efficiency at full load can be obtained from the motor manufacturer, or estimated from generic values published by NRCan or the US Department of Energy, or by looking up the value in the freely available CanMOST database[5]. Next, the pump efficiency value (obtained from the Pump Curve) at the **Pump Design Flow** point is entered.

[5] Available for download free of charge from the Department of Natural Resources Canada – Office of Energy Efficiency http://oee.nrcan.gc.ca/industrial/equipment/software/intro.cfm

Figure 41 – Pump and Motor Efficiency Information

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

ECONOMIC VALUES		
	Units	Description
$ 0.11	$/kWh	Blended Cost of Power
$ 5.50	$/kW	Estimated Monthly Peak Demand Unit Cost
	$	Non Electrical Annual Savings (Cost is negative)



The following other motor efficiency correction factors, expressed as decimal fractions, are also input:

- **Motor Efficiency Correction Factor for Lower Loads** – this accounts for part loading of the motor, typically ranging from 80%– 95%. Default value is 0.96.
- **VSD Efficiency Factor (When Operating > 40% Load)** – this accounts for part loading of the variable speed drive, typically ranging from 90%–98%. This factor can be obtained from the VSD manufacturer. Default value is 0.95
- **Motor Efficiency Correction Factor for VSD Operation** – this accounts for the interactive effects between the motor and the variable speed drive when part loading, with values typically ranging from 80%– 95%. Default value is 0.82.

Note: *Sometimes these factors are difficult to obtain. If this information is not available, pick a reasonable value from the ranges indicated above. Note that the worksheet will use the efficiency correction factors when the flow is more than 60% of design. Various diminishing factors are applied in place of the values entered by the user when the flows are less than 60%.*

In the box to the right of the **Pump and Motor Efficiency** information, the **Conventional & VSD Energy by Operating Point** graph will automatically display when the Pump and Motor Efficiency information is entered. The blue bars indicate the expected energy consumption with the conventional system (that is, throttle) and the red bars indicate the energy using a VSD.

5.5 Unitary Air Conditioning (A/C) Engineered Worksheet

The energy performance of unitary roof-top and ductless split A/C systems is largely defined by their energy efficiency ratio (EER). How much energy is saved over the course of a year for a high efficiency unitary system is determined by the annual cooling delivered by the system and the EER rating. This Engineered Worksheet calculates the savings associated with retrofitting an existing inefficient unitary A/C with an energy efficient unit, as well as the impacts of a change in unit capacity.

5.5.1 Applicant and Space Information

In the **Applicant and Space Information** section, information about the unitary A/C project description, worksheet description, worksheet number, total number of worksheets, account number and facility description is entered. Figure 42 shows a sample of this section filled in for a hypothetical Restaurant. Lastly, a reference facility should be selected from the dropdown list.

Figure 42 – Reference Facility

APPLICANT AND SPACE INFORMATION	
Project Description:	Unitary A/C replacement at Building A1
Worksheet Description:	A/C savings
Worksheet Number:	1
Total Number of Worksheets:	4
Account Number:	12345
Select Reference Facility:	Restaurant
Facility Description:	Dining area

There are 8 reference facilities listed in the dropdown list: Office, Big Box Retail, Strip Mall Retail, Ice Pad Arenas (excluding Pad cooling), Community Centre, Food Retail, Hotel and Restaurant. These reference facilities were developed using a database of whole building energy models developed over 15 years. These models were created using EE4 software, a software developed by NRCan as a compliance checking tool for the Model National Energy Code for Buildings (MNECB) and NRCan's own validation. Table 2 shows the assumed characteristics for the various reference facilities.

Table 1 – Archetype Data for the Reference Facilities

REFERENCE FACILITY	DESCRIPTION	AREA (m^2)	YEAR COMPLETED
Big Box Retail	Store with 1-6 Roof Top Units	10,485	2008
	Store with 1-15 Roof Top Units	13,166	2008
Strip Mall Retail	Stripmall 1 with 11 units (pet store, restaurants – subs, pizza, pita, hair salon)	3,500	2008
	Stripmall 2 with 8 units	2,500	2008
	Stripmall 3 with 6 units in Bldg. A and 7 units in Bldg. B (grocery, pharmacy, clinic, dentist, salon, coffee shop)	4,500	2008
Office	1-2 units each serving one floor of office	2,000 (2 floors of office space)	2005
Community Centre	Systems 2,3,8,9 are Roof Top Units. Other zones are Variable Air Volume	2,500 served by RTUs out of 7,300 m^2 total building	2008
Ice Pad Arenas	5 units (units serving ice pad areas are not included)	10,250 (building area)	2008

In 2014, three reference facilities, namely, food retail, hotel and restaurant, were added to the engineered worksheet. The following describes the assumptions used in generating the energy models for these reference facilities:

Food Retail

Two food retail models were used to generate the cooling load profiles for this building type. Focus was placed on only the systems which serve the sales areas of the buildings. The models that were used to generate these curves did not initially have open refrigerated/freezer casework loads included. These aspects were incorporated into the model based on average loads found in grocery stores based on information obtained from the National Renewable Energy Laboratory Council[6]. The table below summarizes the loads added to each model.

Table 3- Loads Added to the Food Retail Models.

Case Type	Capacity Btu/h/ft	Length/Area ft/1000 ft²	Sensible Heat	Temp (°F)	Auxiliary (kW)
Island Single Ice Cream	740	0.972	0.853	-13.0	3.0
Island Single Deck Meat	770	4.508	0.639	28.5	1.9
Multi-Deck Dairy/Deli	1500	7.859	0.759	41.0	22.0

Grocery Store 1 is assumed to have a total area of 2,333 m² (25,112 ft²) with the following assumed spaces: 81% Sales (served by a single roof top unit); 2% Produce/Preparation (served by a unit heater); 13% Receiving (served by a unit heater); and 4% Office (served by a single roof top unit).

Grocery Store 2 is assumed to have a total area of 4,527 m² (48,729 ft²) with the following breakdown of spaces: 72% Sales (served by 5 single roof top units); 26% Stock/Preparation (served by a unit heater); and 2% Office (served by a single roof top unit).

Hotel

The amenity and public spaces in the hotel were the focus of this building type. The analysis of this building type was done by extracting the amenity spaces in the building and assigning single-zone unitary systems to each of the applicable zones. The total area of the amenity/common spaces is assumed to be 6,164 m² (66,330 ft²) equipped with 20 unitary systems. The space is assumed to consist of 21% Meeting Rooms; 32% Ballroom; 27% Lobby; 7% Amenity; 3% Fitness; 2% Storage; and 8% Office.

Restaurant

The Restaurant/Dining building type assumed that the make-up air for the kitchen and washroom exhaust is served by air supplied to the dining spaces. The total area of the space is assumed to be 537 m² (5,780 ft²) equipped with one unitary system and consists of 70% Dining, 20% Kitchen and 10% Washroom.

5.5.2 Load Duration Curve

Once the reference facility has been selected, the Engineered Worksheet produces a default Load Duration Curve based on the chosen reference facility. The Load Duration Curve indicates the

[6] Leach, M., Hale, E., Hirsch, A., & Torcellini, P. (2009, September). Grocery Store 50% Energy Savings Technical Support Document . *Technical Repor tNREL/TP-550-46101*. Golden, Colorado, United States of America: National Renewable Energy Laboratory.

percentage of time the unit operates at each partial load. This load duration information is also presented in format on the right hand side of the table.

Note: *The Load Duration Curve method is only accurate when the system operation schedule entered corresponds to the times when cooling is typically needed within the building (generally 9am - 5pm from June to September for the archetype load duration curves). Significant deviation from this period may result in significant overestimation of energy consumption*.

5.5.3 System Operating Schedule – Cooling Season Only

Since the Unitary A/C Engineered Worksheet is for air conditioning, the system operating schedule that is entered is for the cooling season only. Up to three (3) periods during the cooling season can be entered. To ensure that the number of operating hours is properly entered, when entering dates and time it is important to always use the drop down menus. An example is shown in Figure 43.

Figure 43 – System Operating Schedule – Cooling Season Only

SYSTEM OPERATING SCHEDULE - COOLING SEASON ONLY								
Season 1			Season 2			Season 3		
From:	June	1	From:			From:		
To:	September	30	To:			To:		
Average	On Time	Off Time	Average	On Time	Off Time	Average	On Time	Off Time
Monday	10:00 AM	8:59 PM	Monday			Monday		
Tuesday	10:00 AM	8:59 PM	Tuesday			Tuesday		
Wednesday	10:00 AM	8:59 PM	Wednesday			Wednesday		
Thursday	10:00 AM	8:59 PM	Thursday			Thursday		
Friday	10:00 AM	8:59 PM	Friday			Friday		
Saturday	10:00 AM	4:59 PM	Saturday			Saturday		
Sunday	10:00 AM	4:59 PM	Sunday			Sunday		

Annual Holidays (#days)	3
Annual Operating Hours	1176

Using a schedule that includes many hours when the A/C unit would be off introduces significant error into the calculation method. The unitary A/C Engineered Worksheet assumes that the unitary A/C operates during the cooling season only. If there is only one operating schedule for the cooling season, enter the schedule only under Season 1. If there is more than one operating schedule for the cooling season (e.g. different On Time and Off Time for the cooling months) as in the case of some schools, enter the schedule under Season 2 and Season 3.

5.5.4 Floor Area and Climate

The floor area served by the A/C unit in square meters is entered next, as shown in Figure 44. The amount of cooling per square area is compared with the ASHRAE cooling check loads.

Figure 44 – Floor Area and Climate

FLOOR AREA			
	Floor Area Served By AC Unit (m^2):	400	

CLIMATE			
	Select the region which best represents the climate at the building location:	Eastern Ontario - (eg Ottawa)	

Another important input for the Unitary A/C Engineered Worksheet is the selection of the climate region. This selection determines which set of weather data is used within the calculations. The weather data comes from the files used by the software EE4 by NRCan and contains an hourly wet and dry bulb temperature that is used in the analysis. There are 4 climate regions to choose from in the dropdown list: Southern Ontario - West (e.g. Windsor), Southern Ontario (e.g. Toronto), Eastern Ontario (e.g. Ottawa), and Northern Ontario (e.g. Sault Ste Marie).

5.5.5 Proposed (retrofit/replacement) Unit

In addition to providing the manufacturer, series, and model of the existing and replacement A/C units, the user is asked to provide the unit quantity, equipment type, equipment type subcategory, heating type, unit capacity (Btu/hr) and the Energy Efficiency Ratio (EER) for the retrofit (replacement) A/C units. The user can add up to 3 A/C unitary systems which are differentiated by capacity and EER. Despite the condition of the existing A/C unit on site, the base measure minimum efficiency is automatically displayed based on the user entered capacity, equipment type, subcategory and heating type of the retrofit unit. The base measure minimum efficiency requirement is derived from ASHRAE 90.1-2013. The quantity of the existing system is assumed to equal the quantity of the replacement system. Figure 45 shows an example of this information filled in.

Figure 45 – Proposed Units

Proposed AC Units					
Complete the data entry fields below for each proposed AC unit type. The minimum energy efficiency ratio (EER) for the baseline unit, as defined in ASHRAE 90.1 2013, will display in the "Minimum EER" field based on your inputs for the proposed unit(s).					
Unit Type 1					
Manufacturer / Series / Model:				Quantity:	1
Equipment Type:	Air cooled	Heating Type:	None	EER:	13
Subcategory	Single Package				
Capacity (BTU/h):	72,000			Minimum EER:	11.2
Unit Type 2					
Manufacturer / Series / Model:				Quantity:	
Equipment Type:		Heating Type:		EER:	
Subcategory					
Capacity (BTU/h):				Minimum EER:	0.0
Unit Type 3					
Manufacturer / Series / Model:				Quantity:	0
Equipment Type:		Heating Type:		EER:	
Subcategory					
Capacity (BTU/h):				Minimum EER:	0.0
12,000 BTU/h = 1 Ton Database of equipment with EER ratings: http://oee.nrcan.gc.ca/residential/business/manufacturers/search/large-air-conditioners-search.cfm					

5.6 Horticultural Lighting Worksheet

5.6.1 System Operating Schedule

The operating hours for the lighting system in the facility are entered in the **Lighting System Operating Schedule** section of the Engineered Worksheet using the 24 hour 7 day table as shown in Figure 12. If there is only one operating schedule for the whole year, enter the schedule only under Season 1. If there is more than one operating schedule for the year (e.g. different On Time and Off Time for the different stages of plan growth) enter the schedule under Season 2, Season 3, and Season 4. To ensure that the number of operating hours is properly inputted, when entering dates and time it is important to always use the drop down menus. The dates and time entered for each season should not overlap. If one or more hours are entered in multiple seasons an error message will appear.

5.6.2 Zone Information

Enter the zone description and the zone area. A zone can be described as a combination of rooms or spaces that have the same lighting schedules. Enter the zone multiplier if there are multiple identical zones. This will eliminate the need to use multiple iterations of the worksheet.

5.6.3 Base Case and Retrofit Case Lighting System

User must enter the following information for each fixture style for both Base Case and Retrofit Case fixtures:

- Type of Fixture – Drop down selection of HPS, Metal Halide, Fluorescent T8 or Fluorescent T5
- Stacked / Vertical application – Drop down select Yes if lighting is installed for a stacked / vertical application. Fixture types of T8 or T5s can only be selected if stacked / vertical application is 'Yes' or else an error message will appear. Both Base Case and Retrofit Case must have the same application type.
- Lamp manufacturer and model
- Number of fixtures
- Photosynthetic photon flux PPF (umol/s, per fixture)
- Input Watts per fixture – total input power to the fixture including lamp watts and ballast losses. The Base Case must have a minimum photon efficacy PPF/input watts of at least 1.5 umol/J to be eligible unless a stacked / vertical application is specified. An error message will appear if the minimum efficacy is not met.
- Average PPFD – Base case growing surface (umol/s/m^2) – this is the average light output on the growing surface. Get this number from your lighting design drawing. The average PPFD for the Base Case and Retrofit Case must be within 10% difference of each other or else an error message will appear.

The Engineered Worksheet will automatically calculate the photon efficacy, total connected lighting power, connected lighting power density, aggregate PPF, aggregate efficacy and total connected lighting power per zone.

5.7 Project Cost Breakdown Information

All Engineered Worksheets require the user to enter data on economic values and project costs under the *System Design Assumptions* tab. Inputting the Project Cost Breakdown information allows for calculation of **Total Eligible Costs for the Project.**

5.7.1 Economic Values

The last section under the *System Design Assumptions* tab requires information on Economic Values and Project Cost Breakdown. This information is needed to describe the economics of the project as indicated under the *Outputs* Tab. **Economic Values** inputs include the Blended Cost of Power ($/kWh) and an Estimated Monthly Demand ($/kW). These values may be obtained from utility bills. Figure 46 provides an example of the Economic Values and Project Cost Breakdown sections filled in.

Figure 46 – Economic Values and Project Cost Breakdown

ECONOMIC VALUES			
$ 0.11	Blended Cost of Power ($/kWh)	$ 6.00	Estimated Monthly Demand ($/kW)

PROJECT COST BREAKDOWN	
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 as applicable.	
$ 5,000.00	Actual costs of the equipment purchased and installed
$ 1,000.00	Actual costs of labour for the installation of the equipment by suppliers
	Actual costs to dispose of or decommission the replaced equipment
	Actual costs of inspections of the Project as may be required pursuant to Laws and Regulations
$ 6,000.00	**TOTAL ELIGIBLE COSTS FOR THE PROJECT**

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

5.7.2 Project Cost Breakdown

The **Project Cost Breakdown** relates to the following information related to the procurement and implementation of the eligible equipment or measure:

- Actual total costs of the equipment purchased (not including spare parts)

- Actual total costs charged by suppliers of labour for the installation of the equipment
- Total costs to dispose of or decommission the replaced equipment
- Total costs of inspections of the Project as may be required pursuant to Laws and Regulations

Note: *The Project Cost Breakdown information for the Commercial Lighting Engineered Worksheets does not make use of the Zone Multiplier but, instead, should reflect the actual eligible project costs of all the retrofit lighting fixtures included in the Worksheet. For example, a retrofit lighting project required the submission of two Commercial Interior Lighting Worksheets for a single zone. The first worksheet contained a total of 120 retrofit lighting fixtures while the second worksheet contained a total of 60 retrofit lighting fixtures. The Project Cost Breakdown that must be reflected in the first worksheet must correspond to the total costs of the 120 fixtures. Likewise, the Project Cost Breakdown for the second worksheet must correspond to the total costs of the 60 fixtures.*

6) OUTPUTS TAB

The *Outputs* tabs on the Engineered Worksheets present the Project Engineering Estimates, the Project Economics, and the Quality Control (QC) and Diagnostics for the retrofit project.

6.1 PROJECT ENGINEERING ESTIMATES

The **Project Engineering Estimates** box highlights the Maximum and Average Summer and Winter Peak Demand in kW and the Annual Electricity Consumption in kWh for both the base and retrofit case. It also presents the Average to Maximum Ratio peak demand for both summer and winter. The Retrofit program recognizes the summer peak as the basis for its Demand Savings. Figure 47 shows an example of this information.

Figure 47 – Project Engineering Estimates

PROJECT ENGINEERING ESTIMATES

This section highlights the demand and energy consumption for the Base Case and Energy Efficient Case. From this data, the Energy Savings and Demand 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)	43.8	15.8	28.0	(Occurs During Summer On-Peak Period)
Average Summer Peak Demand (kW)	40.2	14.5	25.7	(Summer On-Peak Energy/On-Peak Hours)
Average to Maximum Ratio (%)	92%	92%	92%	
Maximum Winter Peak Period Demand (kW)	43.8	15.8	28.0	(Occurs During Winter On-Peak Period)
Average Winter Peak Demand (kW)	29.8	10.8	19.0	(Winter On-Peak Energy/On-Peak Hours)
Average to Maximum Ratio (%)	68%	68%	68%	
Annual Electricity Consumption (kWh)	118,041	42,689	75,352	

The Maximum Summer Peak Period Demand (kW) is the Total Connected Load for the base and retrofit system occurring during the summer on-peak period (June 1 – August 31) between 1 pm and 7 pm on business days. Likewise, the Maximum Winter Peak Period Demand (kW) is the Total Connected Load for the base and retrofit system occurring during the winter on-peak period (Dec. 1 – February 28) between 6 pm and 8 pm on business days.

The Average Summer Peak Demand (kW) is the amount of electricity consumed in kWh divided by the available number of hours (assumed to be 510 hours) during the summer on-peak period. Likewise, the Average Winter Peak Demand (kW) is the amount of electricity consumed in kWh divided by the available number of hours (assumed to be 588 hours) during the winter on-peak period.

The Average to Maximum Ratio is calculated by dividing the Average Peak Demand by the Maximum Peak Period Demand. This ratio provides information on the degree of coincidence of the average peak demand to the total connected load or maximum peak demand of both the base and retrofit system given the system schedule.

The Annual Energy Consumption (kWh) is the amount of electricity consumed for the year based on the equipment schedule, including adjustments for statutory, civic or other holidays, as entered in the *System Schedule* tab.

In the following sections, the algorithm or methodology for calculating the maximum summer peak and winter peak period demand (kW) and energy (kWh) savings is discussed for the various types of measures.

6.1.1 Compressed Air

The calculation of the Annual Energy Savings and Annual Demand Savings for implemented measures under the Compressed Air Engineered Worksheet is discussed in Section 5.3.8.

6.1.2 Variable Speed Drive Compressed Air

Power demand for the fixed speed and VSD compressed air are estimated based on the generated linear and polynomial equation, respectively. This calculation is done for each of the 11 bins representing different percentage flows.

For each of the 11 bin, power demand for the fixed speed compressor is assumed to follow a straight-line relationship with the flow and is represented by the equation y = mx + b where:

$$y = \text{Power demand (kW) for a given flow}$$

$$x = \text{Given flow (acfm)}$$

$$m = \frac{\text{Total Package Input @ Rated Capacity and Full Load Operating Pressure} - \text{Total Package Input Power @ Zero Flow}}{\text{Rated Capacity @ Full Load Operating Pressure}}$$

$$b = \text{Total Package Input Power @ Zero Flow}$$

The total power demand for the fixed speed compressor is then averaged according to the given operating profile.

Likewise, for the VSD compressor, power demand is assumed to have a polynomial relationship with the flow and represented by $y = ax^2 + bx + c$ as discussed in Section 5.4.5. Power demand is calculated for each of the 11 bin and the total power demand is then averaged according to the given operating profile.

Power demand for both fixed speed and VSD compressor is adjusted depending on the intended compressor operating pressure. This power adjustment correction factor is used to normalize the expected power to the intended operating discharge pressure conditions so that an equitable comparison can be made between the fixed speed and VSD compressor options. It is assumed that the power requirements for both the fixed speed and VSD compressor are reduced by 0.5% for each 1 psig reduction in discharge pressure.

Demand (kW) savings is calculated as follows:

$$\text{Demand Savings (kW)} = \text{Power Demand of Fixed Speed Compressor} - \text{Power Demand of VSD Compressor}$$

Energy savings takes into account the lesser of the Fixed Speed Compressor Rated Capacity at Full Load Operating Pressure value (acfm) and the VSD Compressor Rated Capacity at Full Load (acfm). It is calculated by multiplying the demand savings (kW) by the Annual Operating Hours.

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

6.1.3 Variable Speed Drive on Fans

Savings calculations for Variable Speed Drive on Fans start with the calculation of the Annual Energy Savings (kWh), which is the difference between the annual energy consumption (kWh) of the conventional fan system (base) and the fan system with the VSD (retrofit). This calculation is done for each of the 10 bins representing 10 different percentage flows.

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

$$FHP_b = \frac{Q_b \times P \times \rho}{\eta_{fan} \times 6356}$$

where:

FHP_b	=	Fan horsepower (hp)
Q_b	=	Average air flow rate for bin range in cubic foot per minute (CFM)
P	=	Design head for the bin range in inches of water ("WG)
ρ	=	Density ratio of the gas to air in lbs/ft^3; air is assumed to have a density of 0.075 lbs/ft^3
η_{fan}	=	Fan efficiency at flow rate (decimal)
6356	=	Conversion constant

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

$$kWh_b = \frac{FHP_b \times 0.746 \times H}{\eta_{motor} \times \eta_{belt/coupling}}$$

where:

kWh_b	=	Energy consumption in the bin range
FHP_b	=	Fan horsepower (hp) calculated for the bin range
H	=	Number of operating hours in the bin range; this is calculated by getting the percentage hours for the bin range as dictated by the Operating Profile
η_{motor}	=	Motor full load efficiency (decimal) x Motor efficiency correction factor (decimal)
$\eta_{belt/coupling}$	=	Belt/Coupling efficiency factor (decimal)
0.746	=	Conversion constant from horsepower to kilowatt

The total annual energy consumption for the base case is the sum of all the energy consumption in the 10 bins.

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

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

where:

P	=	System head for the bin range in inches of water ("WG)
P_s	=	Static head for the fan system in inches of water ("WG);
P_d	=	Design head (at X) in inches of water ("WG)

where: P = System head for the bin range in inches of water ("WG)
Q = Average air flow rate for bin range in cubic foot per minute (CFM)
Q_d = Fan design flow rate in cubic foot per minute (CFM)

$$FHP_r = \frac{Q_r \times P \times \rho}{\eta_{fan} \times 6356}$$

where: FHP_r = Fan horsepower (hp)
Q_r = Average air flow rate for bin range in cubic foot per minute (CFM)
P = System head for the bin range in inches of water ("WG)
ρ = Density ratio of the gas to air in lbs/ft^3; air is assumed to have a density of 0.075 lbs/ft^3
η_{fan} = Fan efficiency at damper fully open
6356 = Conversion constant

$$kWh_r = \frac{FHP_r \times 0.746 \times H}{\eta_{motor} \times \eta_{VSD} \times \eta_{belt/coupling}}$$

where: kWh_r = Energy consumption in the bin range
FHP_r = Fan horsepower (hp) calculated for the bin range
H = Number of operating hours in the bin range; this is calculated by getting the percentage hours for the bin range as dictated by the Operating Profile
η_{motor} = Motor full load efficiency (decimal) x Motor efficiency correction factor for VSD operation (decimal)
η_{VSD} = VSD efficiency factor (when operating with greater than 40% load)
$\eta_{belt/coupling}$ = Belt/Coupling efficiency factor (decimal)
0.746 = Conversion constant from horsepower to kilowatt

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.

6.1.4 Variable Speed Drive on Pumps

Savings calculations for Variable Speed Drive on Pumps are similar to the savings algorithm for the fans. It starts with the calculation of the Annual Energy Savings (kWh), which is the difference between the annual energy consumption (kWh) of the conventional pump system (base) and the pump system with the VSD (retrofit). This calculation is done for each of the 10 bins representing 10 different percentage flows.

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

$$PHP_b = \frac{Q_b \times P \times \gamma}{\eta_{pump} \times 3958}$$

where:
- PHP_b = Pump horsepower (hp)
- Q_b = Average flow rate for bin range in U.S. gallons per minute (USGPM)
- P = Pump head for the bin range in feet
- γ = Specific gravity of the fluid; assume 1.0 for water
- η_{pump} = Pump efficiency at flow rate (decimal)
- 3958 = Conversion constant

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

$$kWh_b = \frac{PHP_b \times 0.746 \times H}{\eta_{motor}}$$

where:
- kWh_b = Energy consumption in the bin range
- PHP_b = Pump horsepower (hp) calculated for the bin range
- H = Number of operating hours in the bin range; this is calculated by getting the percentage hours for the bin range as dictated by the Operating Profile
- η_{motor} = Motor full load efficiency (decimal) x Motor efficiency correction factor (decimal)
- 0.746 = Conversion constant from horsepower to kilowatt

For Variable Speed Drive on Pumps, 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.

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

where:
- P = System head for the bin range in feet
- P_s = Static head for the pump system in feet
- P_d = Design head (at X) in feet
- Q = Average flow rate for bin range in US gallons per minute (USGPM)
- Q_d = Pump design flow rate in US gallons per minute (USGPM)

$$PHP_r = \frac{Q_r \times P \times \gamma}{\eta_{pump} \times 3958}$$

where:	PHP_r	=	Pump horsepower (hp)
	Q_r	=	Average flow rate for bin range in US gallons per minute (USGPM)
	P	=	Pump head for the bin range in feet
	γ	=	Specific gravity of the fluid; assume 1.0 for water
	η_{pump}	=	Pump efficiency at design flow rate (decimal)
	3958	=	Conversion constant

$$kWh_r = \frac{PHP \times 0.746 \times H}{\eta_{motor} \times \eta_{VSD}}$$

where:	kWh_r	=	Energy consumption in the bin range
	PHP	=	Pump horsepower (hp) calculated for the bin range
	H	=	Number of operating hours in the bin range; this is calculated by getting the percentage hours for the bin range as dictated by the Operating Profile
	η_{motor}	=	Motor full load efficiency (decimal) x Motor efficiency correction factor for VSD operation (decimal)
	η_{VSD}	=	VSD efficiency factor (when operating with greater than 40% load)
	0.746	=	Conversion constant from horsepower to kilowatt

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.

6.1.5 Unitary A/C

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 (watts) is calculated by dividing the capacity (Btu/hr) by the energy efficiency ratio (EER). This amount is then converted to kilowatts.

Power consumption at part load is calculated using 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 it yields the percentage (%) of peak power consumed at part load. This calculation is done for each hour of the year that operation is scheduled.

These hourly power consumption (kW) results are then simply summed to give the energy consumption (kWh) over the desired period.

6.1.6 Horticultural Lighting

The Maximum Summer Peak and Winter Peak Period Demand Savings are calculated using the following equation:

Maximum Peak Period Demand Savings (kW)	=	Total Connected Lighting Load per Zone (Base)	-	Total Connected Lighting Load per Zone (Retrofit)

In normal cases, the Maximum Summer Peak and Winter Peak Period Demand savings will be equal. There will be situations when either the Maximum Summer Peak or Maximum Winter Peak Period Demand Savings will be zero. This happens when there is no operation during the hours within the summer or winter peak period.

The Annual Energy Consumption (kWh) is the sum of all electricity consumed for the year based on the operating schedule.

6.2 PROJECT ECONOMICS

The **Project Economics** section summarizes the estimated total annual savings in $/year based on the cost information entered by the user. It also generates the amount of Participant Incentives that are calculated based on the greater of $ 1200.00/kW of Demand Savings or $ 0.13/kWh of Energy Savings for lighting projects and the greater of $ 1200.00/kW of Demand Savings or $ 0.13/kWh for non-lighting up to a maximum of 50% of the total eligible costs for the project.

There are two highlighted cells (dark green) on the *Outputs* page that show the Demand Savings and Energy Savings. The values in these two cells need to be entered in the Save on Energy Retrofit program Application under the *Site and Project Details of the Engineered Approach – Demand (kW) and Energy (kWh) Savings*.

The **Project Economics** section also automatically calculates the simple payback period with, and without, the calculated incentive amount based on the total eligible project costs ($), the estimated total annual savings ($/year) and the estimated Participant Incentive amount. Figure 54 shows an example of a completed Project Economics section.

Figure 54 – Project Economics

PROJECT ECONOMICS	
Based on cost information, entered by the user, along with incentive amounts, the project economics are summarized.	
Assumed Blended Electricity Rate ($/kWh):	$ 0.10
Assumed Demand Rate ($/kW)	$ 6.00
Estimated Annual Energy Savings ($/year):	$ 2,938
Other Savings (Cost) ($/year):	$ 639
Estimated Total Annual Savings ($/year):	$ 3,577
Demand Savings[1] (kW) for the purpose of calculating the Participant Incentive	8.9
Energy Savings[2] (kWh) for the purpose of calculating the Participant Incentive	29,382
Total Eligible Costs for the Project($):	$ 17,000
Calculated kW Participant Incentive ($1200/kW of Demand Savings)	$ 10,680
Calculated kWh Participant Incentive ($0.13/kWh of Energy Savings)	$ 3,820
Estimated Participant Incentive Amount[3,4]:	**$ 10,680**
Simple Payback (without Participant Incentive)	4.8
Simple Payback (with Participant Incentive)	1.8

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

6.3 Quality Control (QC) and Diagnostics

The **Quality Control (QC) and Diagnostics** section shows validations that can be used to help identify whether the Energy and Demand Savings calculated are realistic with respect to the facility consumption and maximum demand. To ensure the accuracy of the results, it is important that the billing data found on the *Applicant and Facility Info* tab be completed. Figure 55 shows an example of the **QC & Diagnostics** section filled in.

Figure 55 –QC & Diagnostics

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	
Annual operating hours warning	No concern
Proposed case capacity warning	No concern
Proposed case EER/SEER warning	No concern
Baseline case cooling power per sq. ft of cooled floor space warning	No concern
Proposed case cooling power per sq. ft of cooled floor space warning	No concern
Calculation methodology warning	Warning - Significant difference between calculation methodologies

Included in this section is an analysis of how the average to maximum ratio compares to an average to maximum threshold level.