## 

**CCT Energy Savings Calculation Tool Manual**

Measure Name: Fan System Upgrades

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***1.1. Description***

Fan and blower systems have been identified as one of the largest end use applications in industrial settings. Under the sponsorship of the DOE Industrial Technologies Program a computer program called FSAT (Fan System Assessment Tool) was jointly developed by the Air Movement and Control Association (AMCA) and Oak Ridge National Laboratory to assist end users in estimating fan system energy saving opportunities. FSAT uses generic fan performance characteristics in conjunction with minimal user inputs to estimate the efficiency and potential savings associated with fan and/or electric drive motor replacements. The FSAT output is limited to an estimate of the potential annual savings associated with single fan operating point and does not attempt to identify how the potential savings can be obtained nor does it characterize savings associated with specific savings measures.

This software tool utilizes some of the information contained in FSAT (fan efficiency based on specific speed) in conjunction with the fan laws to estimate energy and demand savings, and the associated incentive amount. Additionally, this CCT software tool allows for entry of multiple fan operating points as well as installation of a variable frequency drive (VFD); a measure that is not included in FSAT.

This tool currently estimates savings for the following measures, either singly or in combination:

* Direct replacement of a fan or fan and motor with equipment of higher efficiency;
* Installation of an electronic variable frequency drive (VFD) on the fan drive motor;

and

* Installation of a more efficient belt drive on the fan drive motor.

Currently the software will only accommodate measures involving a single fan. Therefore projects involving multi-fan systems should not use this tool to estimate savings.

***1.2. Appropriate Use of the Tool –Program Policy***

The Fan System Upgrades tool is currently only available for use with retrofit applications. The tool can be used for fans and measures having the characteristics shown in Table X-1. Note that fans equipped with variable pitch blades or fans equipped with mechanical drives capable of variable speed operation are not currently accommodated. It is also important to note that this tool utilizes a variety of assumptions related to the condition and operation of fan systems, which are explained in detail in the following sections. This tool provides results representative of “typical” fan systems and may not represent the specific operating conditions present at an individual site/installation. This tool should not therefore be used to design or otherwise specify fan systems or equipment.

Table X-1: Fan Savings Measure Features

|  |  |
| --- | --- |
| **Description** | **Measure Feature** |
| # of Fans | 1 |
| Fan Types | Centrifugal and axial fans with drives of 5 HP or more |
| Fan Drive | Direct drive, belt drive and electronic Variable frequency Drive (VFD) |
| Baseline Fan Efficiency | Generic fan efficiencies are displayed for information purposes. |
| Fan Operating Profile | Daily/Monthly or Total Annual Operating hours accommodated for up to eight (8) modes of operation.  (User may input either fan flow or fan kW) |
| Static Discharge Pressure | Fan total static pressure in the range of 0 – 35 “Wg (recommended) *Increased pressures can be accommodated with some reduction in accuracy due to compressibility effects. Please contact AESC for additional information.* |

#### 1.2.1 Applicable Types of Equipment

The fan types and controls accommodated in the estimation tool software parallel those covered in the FSAT software. The exception is that this software will also calculate savings associated with VFD-equipped fan drives. Table X-2 summarizes the fan type and control options covered by the estimation software. Note that fans deployed as “blowers” may be accommodated subject to the static pressure restrictions noted above.

Table X-2: Equipment Included in Fan Savings Estimation Software

|  |  |  |
| --- | --- | --- |
| **System Type** | **Fan Type** | **Control Type** |
| Centrifugal | Airfoil (SISW, DIDW),  Forward Curved (SISW & DIDW),  Backward Inclined (SISW & DIDW),  Radial (SISW),  Radial Tip (SISW),  Exhaust,  Industrial Commercial Fan (ICF)- Air Handling,  Industrial Commercial Fan (ICF)- Material Handling,  Industrial Commercial Fan (ICF)- Long Shavings | On/off (no control), Outlet Dampers, Inlet Vanes\*\*,  Variable Frequency Drive\* |
| Axial | Tubeaxial,  Vaneaxial,  Propeller,  Exhaust | On/off (no control), Outlet Dampers, Variable Frequency Drive\* |
| *\* -- part of energy savings measure only \*\* -- inlet vane control is not an option for exhaust fan applications* | | |

#### 1.3 User Data Inputs

The fan system upgrades software requires a signficant number of inputs, which can be divided into three basic areas: system requirements, equipment performance (fan, motor, drive) and fan operating modes. Additional information is provided on the inputs related to system pressure requirements and fan performance.

*System Pressure and Flow Inputs:*

The two system inputs of most importance are System Static Pressure at Maximum Flow and the System Maximum Flow. These two inputs (see Figure X-1) are used by the software to develop a simplified system pressure curve[[1]](#footnote-1). The curve is assumed to have a basic quadratic shape with a zero intercept. Thus the system pressure curve can be established using the single maximum flow point. Note that system maximum flow will likely correspond to the maximum fan operating flow for most single fan applications.



Figure X-1: System Pressure and Flow Inputs (not to scale)

The system inputs are located on Input Screen 1 along with the site specific inputs (see Table X-3)

Table X-3: Site/System Inputs – Input Screen 1

|  |  |
| --- | --- |
| **Input Name** | **Description [Purpose]** |
| Location/city | Site location [air density correction for site altitude] |
| Fan System Name | Identifies fan system involved [inspection purposes] |
| Fan System Type | Select either Centrifugal or Axial |
| Exhaust Fan? | Pull down menu; “yes” indicates an unducted exhaust fan |
| Number of Fans | 1 is the only selection currently available |
| Estimate Ambient Air Temperature? | Pull down menu; “yes” indicates that Inlet Air Temperature will be calculated by the software based on the average air temperature for this location/city (CEC weather zone data). |
| Inlet Air Temperature, DegF | Nominal temperature of air entering the fan [air density correction] *If ambient air temperature checkbox is selected then the average ambient for the location/city will be automatically displayed.* |
| System Design (Max) Flow, or Maximum Exhaust Flow, CFM | Maximum flow through system [establish system pressure & flow requirements]or maximum exhaust fan flow (if “yes” is selected on the exhaust fan pull down menu ) |
| System Total Static Pressure @ Max Flow, “Wg | Fan total static pressure requirement at max system flow in inches Water gauge [establish system pressure and flow requirements] *This input does not appear if “yes” is selected on the exhaust fan pull down menu.* |

*Fan Performance Inputs:*

The fan performance inputs of most importance are the fan Total Static Pressure, Static Efficiency and the fan Flow at the fan’s best efficiency point (BEP). The relationship of these inputs is illustrated in Figure X-3 below. These three values are used in conjunction with generic normalized fan curve shapes to develop an estimated fan performance map. Note that the BEP values are taken from manufacturer’s data and will likely be significantly different from the fan operating points (for most fan types).

Figure X-3: Fan Performance Inputs (not to scale)

The fan performance inputs are located on Input Screen 2 along with the site specific inputs (see Table X-4).

Table X-4: Existing Fan Inputs – Input Screen 2

|  |  |
| --- | --- |
| **Input Name** | **Description [Purpose]** |
| Fan ID | Fan identifier [inspection purposes] |
| Manufacturer | Fan manufacturer [inspection purposes] |
| Model | Fan model [inspection purposes] |
| Serial Number | Fan SN [inspection purposes] |
| Type | *See Table X-2 for menu selections* |
| Control Type | *See Table X-2 for menu selections* |
| Drive Type | Direct, V-belt,or Rubber Chain Drive |
| Fan Speed | Fan speed value (RPM) |
| Flow, CFM | Flow at fan best efficiency point (BEP) [establish fan performance curve(s)] |
| Total Static Pressure, “Wg | Total fan static pressure requirement at BEP  [establish fan performance curve(s)] |
| Static Efficiency, % | Fan static efficiency at BEP [establish fan performance curve(s)] *Note that the estimated maximum fan efficiency for this fan type & specific speed (FSAT data) are displayed for comparison purposes* |

The remaining user inputs are summarized in the following tables.

Table X-5: Existing Drive Motor Inputs – Input Screen 3

|  |  |
| --- | --- |
| **Input Name** | **Description** |
| Manufacturer | Motor manufacturer (nameplate data) |
| Model | Motor model (nameplate data) |
| Size, HP | Motor size (nameplate data) |
| Speed, RPM (nominal) | Select from pull-down; 1200, 1800, 3600 |
| FL Speed, RPM | Motor speed at full load (nameplate data) |
| Enclosure Type | ODP or TEFC/TXPL |
| Service Rating | Motor service rating; 1.15 or 1.25 |
| NEMA Nominal  Efficiency @ full load | *EPACT min value is displayed for comparison purposes* |

Table X-6: Fan Operating Information Inputs – Input Screen 4

|  |  |
| --- | --- |
| **Input Name** | **Description** |
| *Fan Operating Conditions:* | |
| Number of Operating Modes | Number of different operating points that will be considered (8 max) |
| Operating Hour Input | Yearly (total annual hours as input) or Daily (days/month as input) may be selected |
| Operating Data Type | Flow (CFM) or Power (kW) |
| *Operating Mode Information:* | |
| Operating Mode Number | Selections are 1 through the number of modes entered above (8 maximum). |
| Description | Name or description of operating mode (i.e., process air, etc.) |
| On-Peak Operation? | Check this box if *any* fan operation during this operating mode occurs during the on-peak period (as defined by local utility). |
| Average Operating Data | Average fan flow rate (CFM) or fan power (kW) during this operating mode |

Table X-7: Fan Operating Information Inputs – Input Screen 5

|  |  |
| --- | --- |
| **Input Name** | **Description** |
| Annual Operating Hours | Total annual operating hours for each operating mode. This field is only an input if the Operating Hour Input (Sheet 4) selection was “Yearly Total”. If “Daily/Monthly Totals” was selected previously (Sheet 3) then these fields will update with the total annual hours calculated from the “Daily” inputs. |
| Days per Month | Table only appears if “Daily/Monthly Totals” Operating Hour Input (Sheet 4) was selected previously. Enter the number of days of operation for each operating mode for each calendar month. |
| Hours per Day | Table appears if “Daily/Monthly Totals” Operating Hour Input (Sheet 4) was selected previously. Enter the number of daily hours of operation for each day of the week for each operating mode for each calendar month. |

Table X-8: Proposed Measure Inputs – Input Screen 6

|  |  |
| --- | --- |
| **Input Name** | **Description** |
| Fan Replacement / Mod. | Select “Fan” and/or “Motor” checkboxes (or neither) |
| Fan Drive Replacment | Select “VFD added to existing drive” or “Rubber Chain Drive (or equivalent)” (or neither) |
| VFD Full Load  Efficiency, % | VFD efficiency at full load @ 100% speed [used to calculate overall efficiency] *(input only appears if VFD checkbox is selected)* |
| VFD Minimum Operating  Speed, % | VFD minimum operating speed [used to check for violation of min speed during operation ] *(input only appears if VFD checkbox is selected)* |

### *Additional Inputs*

Additional input screens are provided to define the performance and operating characteristics of the proposed fan and associated drive motor. These forms / inputs (Screens 7 & 8) will only appear if a fan replacement has been selected in the measure specification page (Screen 6). These forms are identical to the forms used to enter existing fan (Sheet 2) and motor (Screen 3) details as described previously in Tables X-4 & X-5, respectively.

***1.4. Energy savings explanation***

Annual energy savings is calculated by subtracting the proposed energy usage from the baseline usage. Incentive values are then calculated as the product of the incentive rate and the estimated energy savings value.

Annual Savings (kWh) = Baseline kWh – Proposed kWh

Incentive Amount ($) = Annual Savings (kWh) \* Incentive Rate ($/kWh)

#### 1.4.1 Baseline Energy Use – Power as Operating Point Input

In this case the user has already input a measured fan power value for each of the various operating points (up to 8). If the proposed measure does not include replacement of the electric motor then no correction for minimum electric motor efficiency is required and the the baseline energy use for each operating mode is simply the product of the measured fan kW and the total annual operating hours that have been entered. This process is repeated for each of the operating modes with the sum equal to the annual baseline energy use of the fan. Additionally, the software calculates the weighted average electric demand using data from each operating mode that the user has previously designated as having on-peak operation. This value is displayed as the potential DEER peak demand on the DEER peak demand worksheet. Note that in the event that an electric motor replacement has been specified then it is necessary to correct the baseline data if the existing motor does not meet or exceed the EPACT minimum efficiency standard. The software uses existing algorithms developed for the electric motor measure to accomplish this correction (if needed).

#### 1.4.2 Baseline Energy Use – Flow as Operating Point Input

The electric demand of a fan is calculated using the following expression.

=  (Equation 1)

where:

*QF*  = Fan flow (CFM)

*Ps*= Fan static discharge pressure (inches Wg)

*Kp =* Compressibility Factor (initially set to 1.0)

*ρin =* Air density corrected for fan inlet conditions

*ρstd =* Air density at standard conditions (0.075 lbs/ft3)

*ηF* = Fan efficiency @ operating conditions

*ηe* = Electric drive motor efficiency

*ηd* = Drive efficiency (if applicable)

*Note that fan total static pressure has been substituted for total pressure in the above expression.*

Many of the variables shown in this expression are dependent on operating conditions and must therefore be calculated separately prior to use in Equation 1.

#### Estimating Fan Performance

Fans exhibit dynamic performance characteristics such that fan total static pressure (*PS*), brake horsepower and static efficiency (*ηF*) vary with flow. These performance parameters must therefore be calculated for each operating point (for use in Equation 1). Fan total static pressure and efficiency are typically characterized in a fan performance curve. These curves are generated by the fan manufacturer using test data and are used to determine the fan operating point (pressure and efficiency) under varying flows and speeds.

* ***Generic Fan Performance Curves***

Since fan performance curves can be difficult to locate for older fans the estimation tool software assumes that fan performance will follow one of five generic fan curve shapes[[2]](#footnote-2) based on fan type. See Figures X-11 and X-12 for generic static pressure and static efficiency curve shapes, respectively. Note that these curves are normalized based on fan performance parameters at the Best Efficiency Point (BEP). Fan performance at flows other than BEP is estimated using these curves, fan BEP data provided by the user and the following expressions:

|  |  |  |  |
| --- | --- | --- | --- |
| *QF* | = | *Qnorm \* QBEP* | (Equation 3a) |
| *ηF* | = | *ηnorm \* ηBEP* | (Equation 3b) |
| *Ps* | = | *Pnorm \* PBEP* | (Equation 3c) |

where:

|  |  |
| --- | --- |
| *QF* | = Fan flow (CFM) @ operating conditions |
| *QBEP* | = Fan flow (CFM) @ BEP |
| *Qnorm* | = Normalized fan flow (from curves) |
| *Ps* | = Fan total static pressure (“Wg) @ operating conditions |
| *Pnorm* | = Normalized fan total static pressure (from curves) |
| *PBEP* | = Fan total static pressure (“Wg) @ BEP |
| *ηBEP* | = Fan efficiency @ BEP |
| *ηnorm* | = Normalized fan efficiency (from curves) |
| *ηF* | = Fan efficiency @ operating conditions |

* ***Fan Flow Range Restrictions***

Fans are typically designed to operate at flows exceeding the flow at peak output pressure. This is done to avoid potentially unstable fan operation. This problem is more pronouced in axial fans and in some centrifugal fans. In order to avoid this potential problem the software will only estimate fan performance at flows falling within the stable operating region (i.e., flows exceeding the flow at the maximum static pressure).

Figure X-11: Generic Fan Total Static Pressure Curves   
*(normalized based on Flow and Total Static Pressure at the Best Efficiency Point (BEP))*

#### 

Figure X-12: Generic Fan Static Efficiency Curves   
*(normalized based on Flow, Efficiency at the Best Efficiency Point (BEP))*

* ***Compressibility Factor***

The impact of the compressibility of air is considered negligibly small (less than 1% error) at fan pressures less than 10 “Wg (e.g., compressibility factor, Kp, in Equation 4 is set to 1.0). The potential error associated with compressibility remains below 3% for pressures as high as 35”Wg. It is unlikely that applications involving fans (as opposed to blowers) will involve pressures above this value and as such the software does not account for compressibility effects.

* ***Estimated Fan Speed and Drive Efficiency (if applicable)***

If a belt drive has been specified then the software will calculate and use a drive efficiency based on drive size and type specified by the user (see Table X-10).

**Table X-10: Belt Drive Efficiency[[3]](#footnote-3)**

|  |  |  |
| --- | --- | --- |
| **Drive Type** | **Drive Size, HP** | **Efficiency, %** |
| Standard V-Belt Drive | 5 – 100 | 93.29\*(HPmotor)0.00619 |
| >100 | 96 |
| Rubber Chain Drive | Any size | 98 |

#### Matching System Requirements and Fan Performance

In order to estimate the fan baseline energy use it is necessary to calculate the fan efficiency (*ηF*) at the operating point conditions. This is accomplished by identifying where the fan is operating on its characteristic performance curve. The method used to identify this point varies depending on the control that is utilized. The software provides for three fan control methods: outlet dampers, on/off control and inlet vanes. Exhaust fans represent a special case of unducted fan applications where “inlet vane control” is not a baseline control option (VFD is applicable only as a measure). Figure 14 illustrates the relationships between the various control methods with additional explanation in the following paragraphs.

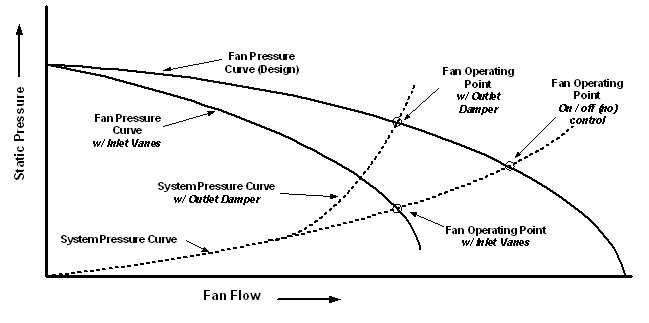


Figure X-14: Fan Operating Point Examples (not to scale)

* ***Outlet Dampers***

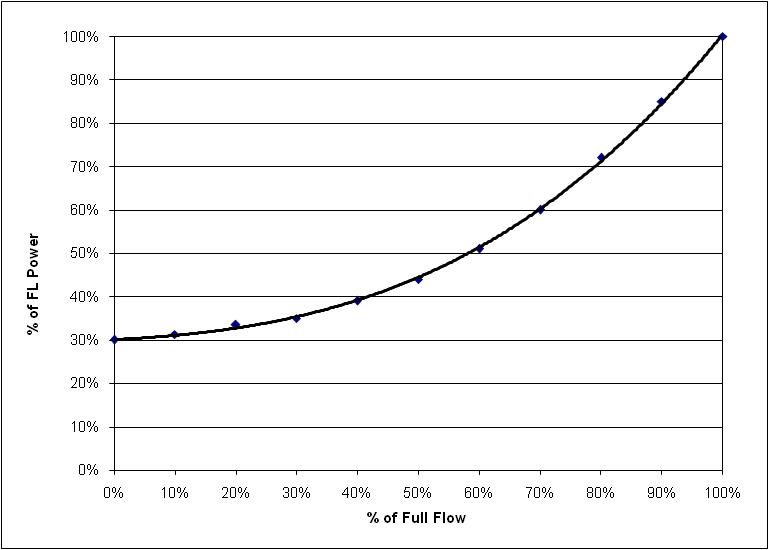
In the case of outlet dampers, a damper located on the fan outlet will increase or decrease the system pressure requirement causing fan flow to decrease or increase (moving to the left or right on the fan performance curve) until the fan flow matches the system requirement. For fan systems that use outlet dampers the fan flow is equal to the system flow while the fan total static pressure will be higher than the system pressure requirement. The shape and location of the fan performance curves are unaffected by outlet dampers so fan performance is estimated using the previously discussed generic performance curves and the operating point flow value (user input). See Figure X-14 for examples of this and other control operating points.

* ***On/off control (no control)***

When there is no control damper the fan flow will only be limited by the system pressure requirements (i.e., fan pressure and flow operating point is equal to system pressure and flow requirement). This situation is represented by the intersection of the system pressure and fan total static pressure performance curves (see Figure X-14). The estimation software must therefore locate this intersection. Site/system information, provided by the user for system flow and pressure (at design flow) is used to generate an expression[[4]](#footnote-4) and associated curve for system pressure. Equating and solving the fan total static pressure and system pressure expressions for flow yields the intersection of the two expressions.

Exhaust Fans -- Note that in the case of unducted exhaust fans the system pressure and flow requirements are assumed to match the fan discharge pressure at the designated operating point flow. The process of identifying the intersection of the fan and system pressure curves is not therefore required for exhaust fan applications.

* ***Inlet Vanes (centrifugal fan types)***

Inlet vanes induce swirl into the inlet of a centrifugal fan, this swirl is normally in same direction as the rotation of the fan impeller and results in reduced fan output. Unlike outlet damper and on/off control, inlet vane controls alter the fan performance characteristic so it is not possible to use the generic fan characteristic curves to estimate fan performance.

Using data from a blower / damper manfucturer, a curve (see Figure X-15) and associated relationship was generated for fan % of full load power and of % of fan full flow[[5]](#footnote-5). The software utilizes this relationship along with the fan full-load power to establish the fan BHP at each operating point flow.

Figure X-15: Inlet Vane Performance Characteristic

**Drive Motor Efficiency & Completion of Baseline kW Calculation**

Once the fan efficiency (for either On/off control or Outlet Damper control types) is determined it is possible to estimate the electric motor load using the following expression:

=  (Equation 5a)

When an inlet vane control is indicated then the software estimates the fan BHP directly using the inlet vane performance characteristic and the electric motor load is subsequently estimated using the following expression:

=  (Equation 5b)

Having established the drive motor load, electric motor efficiency (*ηe*) is calculated using existing CCT software functions (based on DOE MotorMaster). Substituting motor efficiency into the following expression yields the fan kW at this operating point.

=  (Equation 6)

Baseline energy use for each operating mode is the product of the fan kW and the total annual operating hours that have been entered for the operating mode. The estimation software repeats the process of locating the fan operating point, estimating fan, drive and motor efficiency and calculating the baseline energy usage for each of the operating modes (up to eight) specified by the user. The sum of the energy use of all of the operating modes is equal to the annual baseline energy use of the fan.

Calculation of the baseline peak electric demand is accomplished in one of two ways. If only annual operating mode information has been entered then the software calculates the weighted average demand for all operating modes that the user has previously designated as having on-peak operation. This is the value reported as the average demand of the proposed system. However if daily/monthly data has been entered then the software will identify the DEER three-day peak period for the specific city/location and will only utilize information (operating hours and kWh usage) from the month or months of operating data that include this period when calculating the weighted average electric demand.

Note that in the event that the software is unable to locate the estimated fan operating point (intersection of fan and system operating curves) or the estimated operating point is deemed invalid (flow is negative or exceeds system maximum flow) then the calculation will be aborted, and an error window will appear indicating that the specified fan appears incompatible with system requirements and will suggest a possible cause.

#### 1.4.3 Efficiency Measure – Fan Replacement

The estimation software calculates the savings associated with replacement of an existing fan with a fan of the same or different type, having a higher efficiency. If the user provided fan flow information for each operating point then the energy use of the new fan is calculated in the same manner as previously described for baseline energy use . The difference being that the new fan information (fan type, fan efficiency, etc.) is substituted for the existing fan information.

The software provides for input of either a baseline fan flow or fan kW value for each operating point. In the event that the user provided baseline kW values in lieu of fan flow then it is first necessary to estimate the fan flow for each operating point before the performance of the replacement fan can be calculated.

#### 1.4.4 Efficiency Measure – Fan and Drive Motor Replacement

If both the fan and motor are being replaced the estimation software calculates the savings associated with replacement of the existing fan drive motor with a motor having a higher efficiency. The energy use of the new motor is calculated in the same manner as previously described for baseline energy use. The exception being that the new motor efficiency is substituted for the existing motor efficiency.

Unintentional fan speed changes can significantly impact fan energy use. A common problem with motor replacement involves an inadvertent fan speed increase resulting in higher fan energy use, and reduced savings. For this reason, if a VFD has not been specified, the software will warn the user if the full load speed for the new motor is higher than the motor that it replaces.

#### 1.4.5 Efficiency Measure – Rubber Chain Drive (or equivalent) Installation

The electric demand of a fan operating with an improved belt drive is calculated using the same basic expression as the baseline fan calculation with the exception that the new drive efficiency value is used in the drive efficiency term (*ηd*) in the following equation. Note that the software does not provide for direct user input of belt drive efficiency but instead uses the 98% value noted previously in Table 10 for Rubber Chain drives.

=  (Equation 7)

where:

*QF*  = Fan flow (CFM)

*Ps*= Fan static discharge pressure (inches Wg)

*Kp =* Compressibility Factor (initially set to 1.0)

*ρin =* Air density corrected for fan inlet conditions

*ρstd =* Air density at standard conditions (0.075 lbs/ft3)

*ηF* = Fan efficiency @ operating conditions

*ηe* = Electric drive motor efficiency

*ηd* = Belt Drive efficiency

#### 1.4.6 Efficiency Measure – Variable Frequency Drive (VFD) Installation

The electric demand of a fan operating under VFD control is calculated using the same basic expression as the expression used for Rubber Chain Drive installation (see Equation 7) with the exception that the VFD efficiency (𝜂VFD) is included next to the drive efficiency term (*ηd*) in the denominator. However since both fan and VFD performance varies with speed it not possible to utilize this expression without first identifying the VFD (fan) operating speed.

#### Estimating VFD Operating Speed

The fan affinity laws state that with a constant impeller diameter and varying fan speed the following ratios are maintained without any change to fan efficiency.

 (Equation 8)

 (Equation 9)

where:

*Q*  = Fan flow (CFM)

*P*  = Fan total static pressure (“Wg)

n = Fan speed (RPM)

In our case we set P2 and Q2 equal to the system pressure (POPMode) and system flow at the specified operating point (QOPMode), respectively while P1 and Q1 represent the pressure and flow of the existing fan when operating at the same efficiency. Substituting and solving for P1 yields:

 (Equation 10)

To calculate the intermediate flow term (Q1) we equate the above expression to the expression representing the existing fan pressure curve (polynomial expression based on generic curve shape) and solve for the fan flow (Q1). Having solved for Q1 the affinity laws are used to estimate the VFD operating speed (nVFD):

 (Equation 11)

Note that the software checks the estimated VFD operating speed against the minimum speed entered by the user (see Table X-8). If the estimated operating speed is less than the stated minimum:

* The calculation will be paused,
* An error window will appear indicating that “Operating Mode X requires VFD operation below the minimum allowable range.”
* The software will ask if the user would like to continue the calculations using the minimum VFD operating speed.
* If yes then the calculations will proceed with the software adding a note to the reporting describing the action that was taken.
* If no, then the calculations will be aborted.

#### Estimating Fan Efficiency

Fan efficiency at each operating point is calculated using the same process as the baseline calculations , only in this case the intermediate flow, Q1 is used.

#### Estimating VFD Efficiency

The software uses the VFD operating speed with the full load VFD efficiency (user input) to estimate VFD efficiency. The relationship between VFD speed and efficiency utilized by the software is illustrated in Figure X-16 . Once the VFD efficiency has been calculated it is then possible to calculate the electric demand of the VFD equipped fan using Equation 7.



#### Figure X-16: Generic Variable Frequency Drive Performance (derived from EPRI TR-101140 Adjustable Speed Drives Application Guide)

#### Drive Motor Efficiency & Completion of Proposed kW Calculation

Once the fan efficiency (for either On/off control or Outlet Damper control types) is determined it is possible to estimate the electric motor load using the following expression:

=  (Equation 12a)

When an inlet vane control is indicated then the software estimates the fan BHP directly using the inlet vane performance characteristic and the electric motor load is subsequently estimated using the following expression:

=  (Equation 12b)

Having established the drive motor load, electric motor efficiency (*ηe*) is calculated using existing CCT software functions (based on DOE MotorMaster). Substituting motor efficiency into the following expression yields the fan kW at this operating point.

=  (Equation 13)

The proposed energy use for each operating mode is the product of the fan kW and the total annual operating hours that have been entered for the operating mode. The estimation software repeats the process of locating the fan operating point, estimating fan, drive and motor efficiency and calculating the proposed energy usage for each of the operating modes (up to eight) specified by the user. The sum of the energy use of all of the operating modes is equal to the annual energy use of the proposed fan.

Calculation of peak electric demand for the proposed equipment is accomplished in one of two ways. If only annual operating mode information has been entered then the software calculates the weighted average demand for all operating modes that the user has previously designated as having on-peak operation. This is the value reported as the average demand of the proposed system. However if daily/monthly data has been entered then the software will identify the DEER three-day peak period for the specific city/location and will only utilize information (operating hours and kWh usage) from the month or months of operating data that include this period when calculating the weighted average electric demand.

The estimation software calculates the savings associated with replacement of an existing pump with a pump having a higher efficiency. The energy use of the new pump is calculated in the same manner as previously described for baseline energy use. The exception being that the new pump efficiency information is either directly substituted for the existing pump efficiency in equation 20.A (positive displacement pumps) or is used to generate a pump performance curve (dynamic pumps), which in turn allows a pump operating point and efficiency value to be estimated for the new pump.

**CPUC Defined Peak Demand Savings**

The CCT software estimates the CPUC defined peak demand savings by calculating the average demand savings. The average demand savings is calculated by dividing the annual savings by the inputted baseline annual hours of operation. The resulting average demand savings approximates the DEER Peak demand savings because it is assumed the equipments average kW demand is typical during all operating periods. The software will confirm with the applicant the equipment operates during the defined peak period.

1. A system pressure curve is not needed for applications involving unducted exhaust fans and these inputs do not therefore appear when the exhaust fan checkbox is checked. [↑](#footnote-ref-1)
2. Curve data extracted from generic curves shown in AMCA Publication 201-02, “Fans & Systems”. [↑](#footnote-ref-2)
3. See AMCA 203-90, Field Performance Measurement of Fan Systems, Annex L. Estimated Belt Drive Loss. *Belt drives are assumed to be in good working condition.* [↑](#footnote-ref-3)
4. System pressure is assumed to follow a simple quadratic expression of the form: P = mQ2, where m is calculated using the design flow and pressure information provided by the user. [↑](#footnote-ref-4)
5. Source: NYB Engineering Letter 11 -- Selection Criteria for Dampers (www.nyb.com) [↑](#footnote-ref-5)