Policy Guidelines for Integrated & Build-in fans

Promoting high efficiency fans optimized towards application dependent pressure, promoting integration flexibility through adjustability and promoting a method to estimate the input power and overall fan efficiency can help protect our environment more safely.

By Sham Morten Gabr, Multi-Wing, Danish ISO / CEN Fan National Expert, member of "Danish Ventilation" and active participant to Eurovent Product Groups, smg@multi-wing.com. January 2015.

Forming policies for fans integrated and build-in other products can be uncertain and risky, especially when fan efficiency optimization and system efficiency optimization are uncoupled. Policy makers developing efficiency policies for protection of our environment universally express that adverse and unwarranted effects on the environment must be avoided. However, policy makers are rarely aware of this disconnection between optimization of fan efficiency and system efficiency optimization. The generally accepted assumption in EU and other countries considering the EU approach appears to be that the better the sub-system (fan) at its best efficiency point the better the overall system efficiency (other products).

There is a widespread belief that pressure losses and noise generation in aerodynamic systems can be pre-calculated with a fair degree of accuracy. So, policy makers and fan experts don't address potential adverse and unwarranted effects on our environment. However, the publication "Eurovent 1/12 Sources in Aerodynamic System Resistance and Acoustic Calculation" expresses that this is not the case and flow patterns are much too complicated to allow this. The study expresses that in most installations the flow is neither laminar nor fully turbulent but at an intermediate state. That the resistance coefficients given in literature, which form the basis of all calculations, do not normally take different flow modes or patterns into account at all and therefore cannot be expected to be very accurate. That impellers not integrated in a simple fan alone is strongly impacted by the aerodynamic interaction of components involved within the system. Obviously, forming policies for fans integrated and build-in other products is uncertain and risky when there is a disconnection between fan efficiency optimization and system efficiency optimization, which may lead to unwarranted and adverse outcomes.

Most European Fan experts focus on assessing the contribution to the protection of our environment from incorporated fans by suggesting to extract, cut out or create equivalent geometrical representation of fans defined by a configuration of impeller, stator (aerodynamic part), electrical motor, transmission or direct drive and possible a variable speed drive. In those cases where the products with fan integrated are too big for testing experts suggests scaling down a replica or doing in situ testing. As a result contributions tend to converge along the same basic assumption that the better the fan the better the non-fan product system efficiency delivering for example cooling or heating as its main functionality.

In addition, most European Fan experts focus on the same assessment dimensions for unhoused driven fan impellers build-in such that the system into which they are inserted acts as a housing. That means to cut out the stator component / "fan housing section" part of the housing of a non-fan product or use a geometrical equivalent. Again, in those cases where the products with driven axial impellers are too big for testing experts suggests scaling down a replica or doing in situ testing. Obviously, how unhoused driven impellers performs depends on the system they are inserted. This is similar to how stand-alone fans performs is a question of not only the fan product but also of its implementation in ventilation systems, of which the most import one is the ducting in buildings, including filters, grids, balancers, heat exchangers and so on. As a result from their focus on the housing of non-fan products may represent unwarranted and significant regulatory issues. This is due to

the fact that, while the housing of stand-alone fans are within the boundary of the European Fan Regulation 327/2011, that is unlikely the case for the boundary of other products not regulated by the EU Fan Regulation. That would imply that the EU Fan Regulation could enforce redesign of non-fan products without a product specific regulation. I.e. a super regulation cutting across other product designs.

Furthermore, besides the technical sub-optimization issues and that the housing boundary of non-fan products are unregulated by the fan regulation, a change in "housing" design may make some applications unfit for incorporation into applications upstream. The commission in accordance with the implementing measures expressed in the overall Eco design Framework Regulation has not yet adequately addressed these risky and unwarranted implications.

Furthermore, most European Fan experts focus on only promoting calculation of fan efficiency through input and output measurement. As a result, from this focus manufacturers of non-fan products with fans incorporated or driven impellers built in developing tailor made and/or a large range of products will experience a test cost burden, which may reduce tailor made products and available product ranges adequate for different required operational duty points. One is that producers of non-fan products with fans incorporated and/or driven impellers build in generally have test equipment for testing their products final functionality but not for fans incorporated/build-in. Another is that complete fan package manufacturers typically have 1-2 bare shaft fan options for each and limited diameter size within their standard range (i.e. 315-355-400-450-500…). However, by assembling driven fan impellers there is the option to tailor multiple configurations (i.e. different nr. Of blades. Different fan/hub type, different blade angles, different materials. In addition, with the same fan multiple motor types are necessary in some situations. While, direct measurement of fan system performance is preferred, the large variety of fan system configurations makes this impractical.

The more that European Fan experts focus on the sub-level for fans incorporated and/or build-in, unfortunately the greater likely hood that the expressed technical, regulatory unwarranted and adverse effects remain together with reduced offerings for users covering a wide range of operational duty point different from an medium pressure best efficiency point.

Ensuring the protection of the environment and avoiding "super regulatory outcomes" in the case of fans incorporated or build-in requires a different pattern of thinking about efficiency and regulation. Instead of, only looking within the boundaries of a fan definition, fan experts and policy makers should also look to ensure promotion of high efficiency fans optimized towards application dependent pressure, promote integration flexibility through adjustability and promote a method to estimate the input power and overall efficiency. This will help protect our environment more safely.

The remaining of this document will describe how policy makers may meaningful address the situation with fans incorporated and build-in other products. These guidelines for fans integrated & build-in other products aim to provide assistance to policy makers who wish to design and implement energy efficiency requirements for the good of our environment.

Policy Guidelines for fans incorporated & Build-In

The following table suggests how policy makers can meaningful address the situation with fans incorporated and build-in fans into other products:

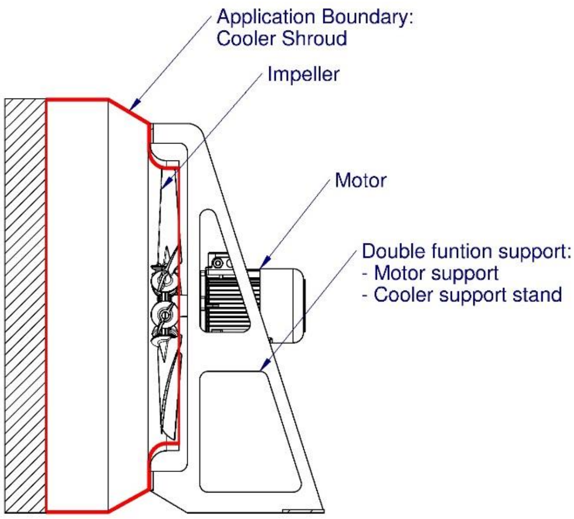
SITUATION WITH INTEGRATED & BUILD-IN FANS*		
SITUATION & ISSUE**	RELEVANT APPROACH	TRANSLATED ACTION
• Aerodynamic and acoustic system effects of axial fans installed in other products can be quite significant. The effects may be both negative and positive. System components may both deteriorate and improve flow conditions. • This means that even a careful pre-calculation of the expected pressure losses in a system may lead to results that differ considerable from the actual values found in the system when built. • This may have negative or positive effects on power consumption and the noise levels of the installation. • So, not only axial fans with or without aerodynamic / acoustic parts within the system need to be optimized towards a requested design point but should also make allowance for optimization towards the actual operating point. • Axial fans may be optimized towards either high, medium or low pressure***	• Minimum efficiency requirements linked to the final functionality and exemptions or allowance of difference in testing and installation set-up for fans. This to counter the complexity of system effects and promote system optimization. • The fan alone with or without aerodynamic / acoustic parts installed must in its optimal configuration be able to meet regulated minimum efficiency requirements. • The fan that in its optimal configuration can meet regulated minimum requirements with or without aerodynamic / acoustic parts installed should be allowed to be corrected within the system (i.e. change of pitch angle, speed and other characteristics) • Using either peak / range efficiency for different fan types combined with exemptions for justified application dependent high and low pressure operating requirements or using a baseline efficiency that varies with both airflow and pressure, universally applied to all fan categories****.	• Promote high efficiency fans with or without additional aerodynamic or acoustic parts optimized towards application dependent pressure • Promote integration flexibility through adjustable: ○ Pitch angle ○ Impeller diameter ○ Hub to tip ratio ○ No of blades ○ Housing geometry ○ Additional aerodynamic or acoustic parts ○ Motor ○ Drives ○ Speed controlling

* See appendix A
**Source: "Eurovent 1/12 Sources in Aerodynamic System Resistance and Acoustic Calculation" and test displayed in appendix B of fan with and without engine mock up. And "Cooling Towers", EUROVENT Position Paper, PP – 2014-12-11
***See appendix C.
**** Note: Such a metric expressed as a Fan Efficiency Ratio (FER), an energy efficiency metric for fans have recently been developed by AMCA international (http://www.amca.org/).

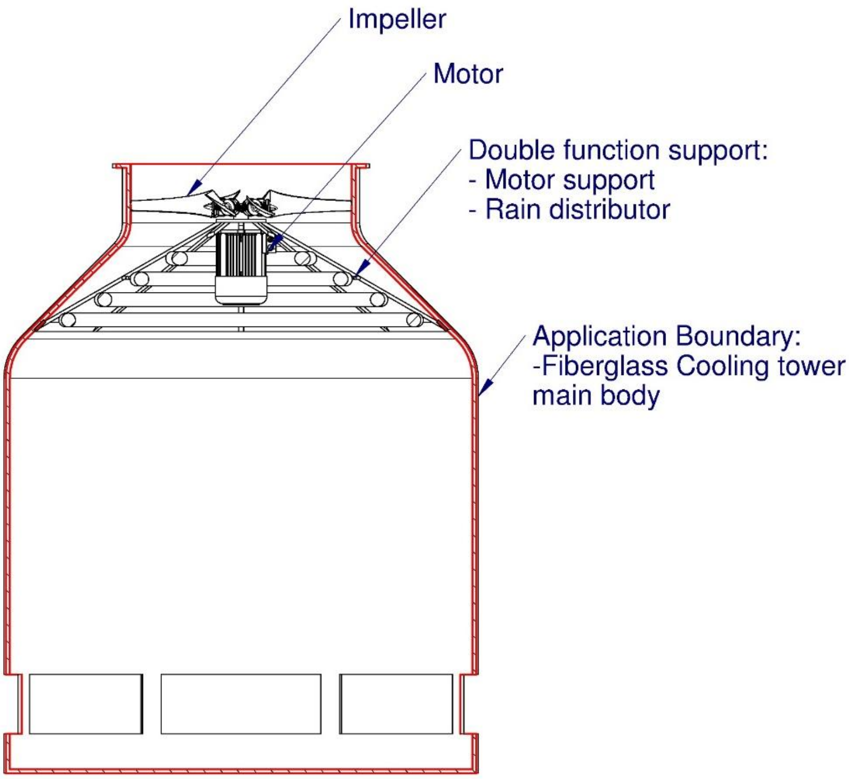
Ideally, other products both with fans incorporated and build in should be assessed in front of their specific machinery´s unique and final function. However, it is possible to assess the conformity of build-in driven impellers based on a test-set up relevant for fan efficiency. See appendix D. So, a unique way for non-fan products is to associate available fan impeller data and motor data from supplier. This by calculating overall fan efficiency and determine input power based on a defined lab inlet set-up, together with the actual motor data and its own efficiency when available. That by taking into account the real motor data and motor shaft load. This in order to ensure a proper matching of the fan impeller and motor integrated solutions. See appendix E.

Appendix A: Fans Build-in

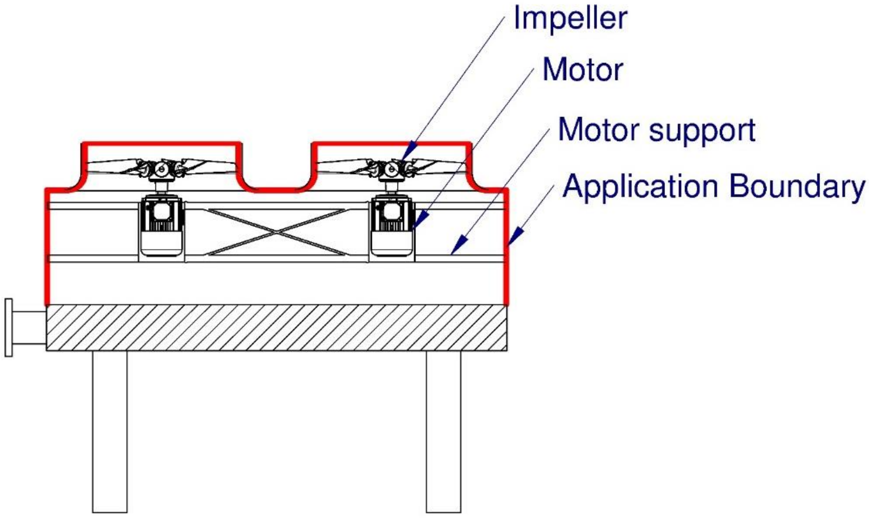
Build-In fans is used to express the situation where an driven impeller is arranged such that the system into which it is inserted acts as a housing, which is unregulated by the EU Fan Regulation (i.e. the housing is part of a product different from an fan). The following give example of some non-fan products. Application examples are for guidance and are not exhaustive.



Cooler where the axial driven impeller and motor are significant elements within the fan boundary and where the housing is an signifant element of the product unregulated by the fan regulation



Cooling tower where the axial driven impeller and motor are significant elements within the fan boundary and where the housing is a significant element of the product unregulated by the fan regulation



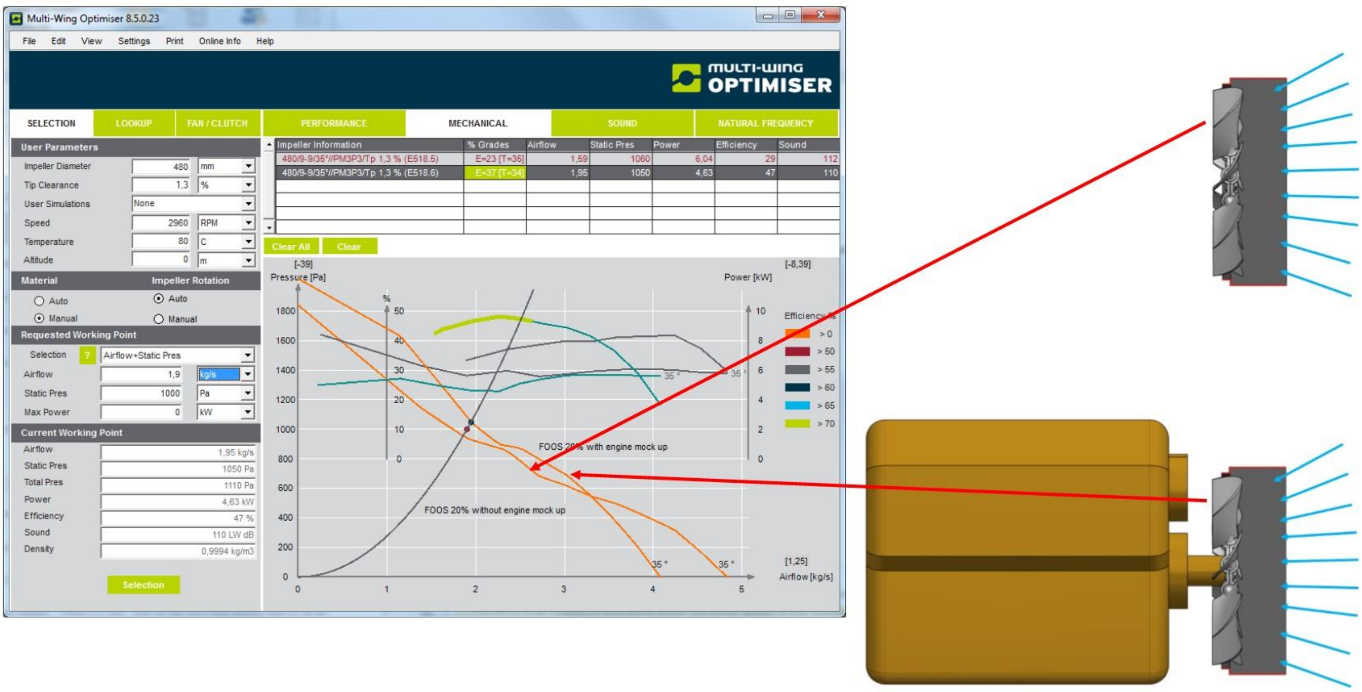
Condenser where the axial driven impeller and motor are significant elements within the fan boundary and where the housing is a significant element of the product unregulated by the fan regulation

Appendix B: System Component developing the flow conditions

System components may both deteriorate or strengthen the flow conditions in the impeller compared to those encountered in an “undisturbed” standardized test installation.

To complement publication “Eurovent 1/12 Sources in Aerodynamic System Resistance and Acoustic Calculation” expressing the situation with deterioration, an example is provided with the opposite outcome.

The example captures a test of an impeller optimized towards the high pressure area with and without a big engine body inside the airflow. Tests expressed that the given high pressure impeller was not compliant with the requirements of the EU Fan Regulation without engine but was compliant with a big engine body inside the airflow. That expresses a positive interaction effect from an impeller coupled to a big engine body. Test results are expressed in below picture:



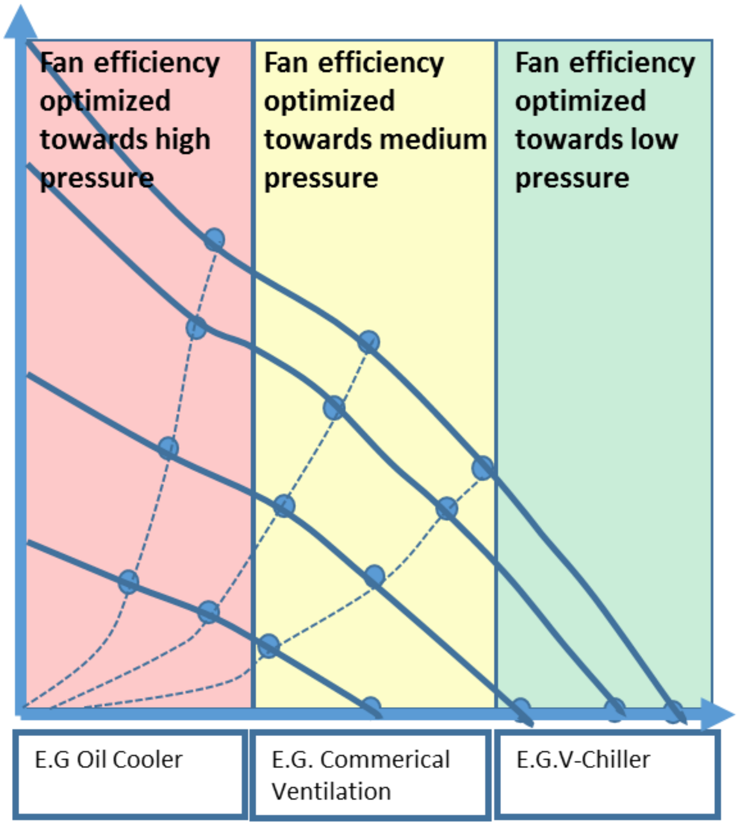
Appendix C: Different Pressure Application Areas

A fan curve may be expressed by different pressure areas i.e. high-, medium- or low pressure. Fans and axial impeller design may be optimized towards these areas. Obviously, different fan types cater for different pressure duties, though axial and centrifugal ranges overlap at moderate pressures. However, it is not always practically possible to change from for example an axial fan impeller to a centrifugal fan impeller due to design space constraints.

Within a given pressure area, fan design may either be optimized towards a peak or a range. As always there is tradeoffs. However, by optimizing towards a range instead of a peak system effect sensitivity is reduced for fans integrated into other products.

A fan may be optimized toward different pressure areas though adjusting the fan design (e.g. pitch angle). Different fan designs together with speed controlling offers an instrument to match fan design and the actual operating points. That means higher performance and lower power consumption. That again, means protection of our environment.

The graph below shows how the fan curve of a fan can capture different pressure areas and how the fan curve can be shifted downwards by reducing the speed.



Appendix D: Test-Setup Suggestion for Driven Axial Impellers build-in for 327/2011 Verification

The performance of axial impellers shall be determined on a test setup that conforms to ISO 5801 and AMCA 210. In addition, axial impellers fitted to electrical motors within the scope of 327/2011 shall follow the guidelines in the following or ensure that it is comparable with that in order to ensure comparability, fair competition, and to facilitate market surveillance activities.

The following instructions shall be used for 327/2011 compliance verification covering axial impellers distributed as not-final assembly to the end user and/or to manufacturers integrating axial impellers into a non-fan product.

Test Category

The test setup is a type A inlet chamber configuration.

Inlet shape

A bell mouth inlet shall be used and the axial impeller may be tested with an R/D between 0.15 and 0.05 applying the associated comparability factor as expressed in table xx to support comparison and balanced assessment.

R/D	**Inlet test set-up Comparability factors** (flow resistance coeffficents inlet shape)
0.15	-0.10
0.14	-0.07
0.13	-0.06
0.12	-0.04
0.11	-0.02
0.10	0.00
0.09	0.03
0.08	0.05
0.07	0.09
0.06	0.13
0.05	0.17

327/2011 Inlet test set-up comparability factors for axial impellers

To account for axial impeller manufacturers different standard inlet shape test-setup the effect of differences in fan inlet shape may be accounted for by applying the comparability factor on the fan static pressure measurement (FSP).

$$FSP_{corrected} = FSP_{ideal} + \sum \Delta p_i$$

The correction is a function of the characteristic air velocity through the test housing area:

$$v_i = \frac{Q}{\frac{1}{4}\pi\left(D_{fan}{}^2\right)}$$

The pressure correction terms then have the structure of a flow resistance term:

$$\Delta p_i = k\frac{1}{2}\rho {v_i}^2$$

$FSP_{Adjustedd}$	Adjusted fan static pressure	[Pa]
$FSP_{Reference}$	Reference fan static pressure	[Pa]
Δp_i	Pressure correction term	[Pa]
v_i	Characteristic air velocity through fan	[m/s]
Q	Air volume flow rate	[m^3/s]
D_{fan}	Fan diameter	[m]
k	Correction factor	[-]
ρ	Air density	[kg/m^3]

The bell mouth shape used for test and related comparability factor shall be stated on the performance documentation.

Axial Impeller positioning
The axial impeller positioning may be chosen by the impeller manufacturer for test but shall clearly be expressed on the performance documentation together with the outlet dimension.

Tip clearance test set-up
Tip clearance test-set up shall be 0.5% of the axial impeller on each side. That means a total clearance of 1% of the axial impeller.

Driving system suggestions for testing axial impellers
Impeller power shall be determined from the rotational speed and beam load measured on a reaction dynamometer, from the rotational speed and Torque measured on a Torsion element, or the electrical input measured on a calibrated motor.

The first method is expressed as the direct drive jig method and the another as driving system method.

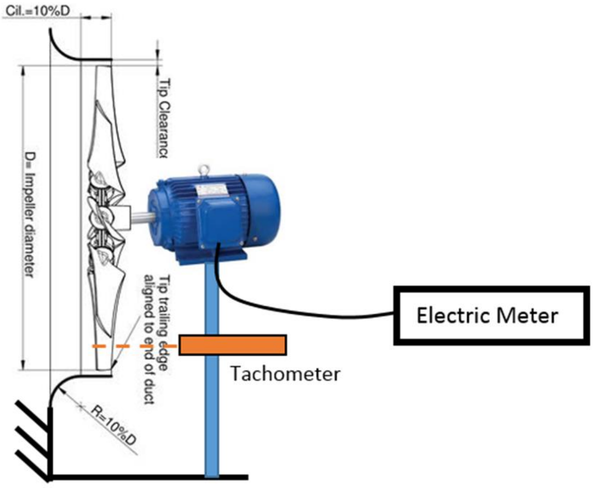
The direct drive jig method is suitable for testing of standard products and for calibrating the second method.

The driving system method is suitable for testing of flexible custom or engineered to order products.

[SOURCES: ISO 5801:2008-12-15 & AMCA 2010-07]

The direct drive jig method

Schematic Diagram of testing method:



Jig with direct driving

The motor support shall be stiff enough to support motor and loads but with a drag as low as possible to provide minimum resistance on the outlet air flow from the impeller. The motor diameter should be within the hub diameter to avoid drag force.

The power output of an electric motor for direct drive shall be deduced from its electrical power input, employing a reliable, accurate and reproducible method, which takes into account the generally recognized state-of-the-art methods, and whose results are deemed to be of low uncertainty i.e. IEC standards.

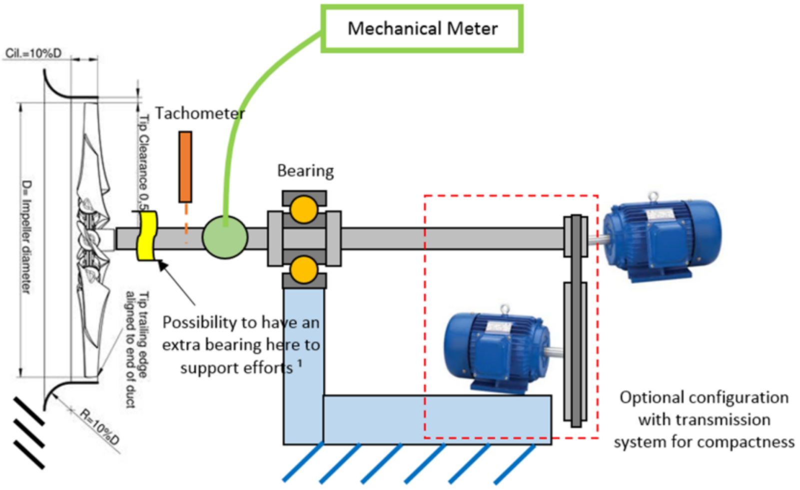
One of the following methods shall be used to measure the electrical power input to an AC or DC motor during the fan tests using the direct drive jig method:

a) For AC motors, by the two-wattmeter method or by an integrating wattmeter;
b) For direct current (DC) motors, by measurement of the input voltage and current.

The equipment used for standardized airway tests shall be of class index 0.5 in accordance with IEC 60051-2 and IEC 60051-3 to which calibration corrections are applied or, alternatively, of class index 0.2 for which calibration corrections are unnecessary.

The driving system test method
This method is recommended for non-standard products like Modular Axial Impellers.

Schematic Diagram of testing method:



The driving system test method

NOTES If the driving shaft is not strong enough and vibrations are too high an extra bearing shall consequently be added. The interposition of a transmission system between the fan and the point of power measurement should be avoided unless it is of a type in which the transmission losses under the specified working conditions can be reliably determined, or the specified power input is required to include those losses. With a large variety of testing conditions and range, a unique mechanical sensor cannot be used. Hence, the sensor shall be changed unless several driving system sizes are used.

The driving system shall be fixed on the floor, including dampeners inside the structure such as for the motor to avoid vibration transmission (incl. dampeners inside the structure like for the motor to avoid vibration transmission)

Noise isolation should be made of the driving system especially if AMCA300 is requested for testing.

To determine power input to the impeller it is necessary to deduct an allowance for bearing losses and for the losses in any flexible coupling, unless the impeller is mounted directly on the motor shaft like in the direct jig method. This deduction can be determined by running a further test at the same speed with the impeller removed from the shaft and measuring the torque losses due to bearing friction. If considered necessary, the impeller may be substituted by an equivalent mass (having negligible aerodynamic loss) to provide similar bearing loadings.

In other words, dues to friction in the different mechanical elements of the driving system, it is strongly advised to perform the test in two steps to measure Impeller Power Consumption:

1. Test the full package
2. Disconnect the impeller and measure the power consumption of the driving system only at same tested conditions

When the power to be determined is the input to the fan shaft, acceptable methods include the following.

a) Reaction dynamometer
b) Torsion meter

Impeller power measurements & calibrations

Measurement of rotational speed

The impeller speed shall be measured at regular intervals throughout the period of test for each test point, so as to ensure the determination of average rotational speed during each such period with an uncertainty not exceeding ± 0.5 %. No device used should significantly affect the rotational speed of the fan under test or its performance.

Instruments should have an uncertainty of not more than 0.5 % (i.e. accuracy class index of 0.5 in accordance with IEC 60051-4).

Revolution counter and chronometer, with a stroboscope and chronometer, with a precision instantaneous tachometer, or with an electronic counter-timer are acceptable.

NOTES The impeller speed can be measured by setting up the system on the driving shaft. However, if available space is not enough the device can be set on impeller blade directly. If a transmission system is used like belt driving, the rotation speed shall not be measured before transmission due to potential loss or slides in this type of mechanical system.

Reaction dynamometer
The torque is measured by means of a cradle or torque-table type dynamometer. The weights shall have certified accuracies of ± 0.2 %. The length of the torque arm shall be determined to an accuracy of ± 0.2 %.

The zero-torque equilibrium (tare) shall be checked before and after each test. The difference shall be within 0.5 % of the maximum value measured during the test.

Torque meter
The torque is measured by means of a torsion meter having an uncertainty no greater than 2.0 % of the torque to be measured. For the calibration, the weights shall have certified accuracies of ± 0.2 %. The length of the torque arm shall be determined to an accuracy of ± 0.2 %.

The zero-torque equilibrium (tare) and the span of the readout system shall be checked before and after each test. In each case, the difference shall be within 0.5 % of the maximum value measured during the test.

Calibrated motor
Impeller input power can be determined by measuring the electrical power input of the impeller’s motor only if the motor is calibrated. Calibrated motors shall have a demonstrated accuracy of ±2%.

A motor shall be calibrated through its range of use against an absorption dynamometer except as provided in if it is an IEEE calibration. The absorption dynamometer shall be calibrated by suspending weights from a torque arm. The weights shall have accuracies of ±0.2%. The length of the torque arm from rotational center to any given point of weight suspension shall be determined to an accuracy of ±0.2%.
The electrical meter shall have a certified accuracy of ±1.0% of observed reading.

The motor input voltage during the test shall be within 1% of the voltage observed during calibration.

For IEEE calibration, a polyphase induction motor may be calibrated by using the IEEE Segregated Loss Method.

The power output of an electric motor for direct drive is determined from an efficiency calibration acceptable to both manufacturer and purchaser. The motor should be run on charge for a time sufficient to ensure that it is running at its normal working temperature. The electrical supply should be within the statutory limits, i.e.

- Voltage: ± 6 %;
- Frequency: ± 1 %.

Power accuracy
The power input to the impeller over the specified performance range shall be determined by a method, including the averaging of a sufficient number of readings at each test point, which achieves a result with an uncertainty not exceeding ± 2 %.

Averaging
The torque measured on any instrument will fluctuate with time. In order to obtain a representative reading, either the instrument must be damped or the readings must be averaged in a suitable manner. Averaging can be accomplished mentally if the fluctuations are small and regular.
Multi-points or continuous-record averaging can be accomplished with instruments or analyzers designed for this purpose. The user is cautioned that this latter type of equipment may yield unreliable readings for an impeller operating in an unstable region of its performance curve, and care must be taken to ensure that the impeller operates without pressure/airflow instability.

Appendix E: Calculation of input power and efficiency for fans Incorporated or Build-In

$$\eta e = \eta r \,.\, \eta t \,.\, \eta m \,.\, Cm \,.\, \eta c \,.\, Cc$$

Where:

ηe is the overall efficiency

ηr is the impeller efficiency according to $\eta r = \frac{Pu}{Pr}$ according to measurement category i.e. static or total impeller efficiency. RPM axial impeller speed shall be equal to the customers requested speed.

ηt is the efficiency of the driving arrangement for which the following default values shall be used:

- For direct drive $\eta t = 1$
- If the transmission is a low-efficiency drive and
  - $Pr \geq 5kW, \eta t = 0.96$, or
  - $1kW < Pr < 5\ kW, \eta t = 0.01$ * Pr + 0.93, or
  - $Pr \leq 5kW, \eta t = 0.94$

- If the transmission is a high-efficiency drive and
  - $Pr \geq 5kW, \eta t = 0.98$, or
  - $1kW < Pr < 5\ kW, \eta t = 0.0175$ * Pr + 0.8725, or
  - $Pr \leq 5kW, \eta t = 0.89$

ηm is the nominal rated motor efficiency at the specific load at the axial impellers best efficiency point

ηm shall either be

- The following calculations are for any motor or motor with integrated controller where data for different loads and efficiency meets the general measurement requirements
  - If $Pr < 0.75\ kW$ and the drive arrangement is different from direct drive then
    - ηb that is the bearing efficiency shall be calculated following ISO 12759 Annex B. Otherwise it shall be assumed that $\eta b\ = 1$in the following calculation
    - L_M motor load ratio = $Pr/(PN * \eta t * \eta b)$ Where PN is the nominal rated motor output
    - If the motor load is equal to one of the tested data points then this is to be used, otherwise;
    - The motor or combined motor and controller efficiency is calculated by linear interpolation between the test point just above and below the motor load (No extrapolation beyond test points is allowed) by

$$\eta_m = \eta_{mi} + (\eta_{mi+1} - \eta_{nmi}) \left(\frac{L_m - L_{mi}}{L_{mi+1} + L_{mi}}\right)$$

    - Where $-L_{mi}\ and\ Lmi + 1$ are the consecutive test points on either side of the required motor load ratio

- If the motor is un-regulated the calculation of efficiency for fans supplied as "non-final assembly" parts or spare parts may be used.

Cm is the correction factor to a account for matching of components = 0.95

Where the value is 0.95 compared to 0.9 for the calculation covering parts and spare parts to the end user covers that the load association between factors has been taken into account. The remaining correction factor is to take into account a default flow obstacle at either inlet or out let.

ηc is the nominal rated variable speed drive controller efficiency

- For a motor without variable speed drive controller $\eta t = 1$

Cc is the variable speed drive controller compensation factor

- For a motor without variable speed drive controller $Cc = 1$
- For a motor with variable speed drive controller and $Ped \geq 5\ kW\ then\ Cc = 1.04$
- For a motor with variable speed drive controller and $Ped < 5\ kW\ then\ Cc =$ -0.03 ln(Ped) + 1.088
- For a motor with variable speed drive controller and $Ped \geq 5\ kW\ then\ Cc = 1.04$

Pe shall be calculated by $\mathrm{Pr}/\ (\ \eta m * \ \eta t\ )$

Ped is calculated by $\mathrm{Pr}/\ (\ \eta m * \ \eta t * \ \eta c)$