Problem Statement

Fan System Efficiency

Regulation and Standardisation

A recommendation by the European Fan Industry

European Ventilation Industry Association

Summary

This document is a problem statement on a future energy efficiency measure to reduce the impact of fans and increase the efficient use of fans. It is written with consideration of future revisions of European eco-design regulations but could be used by any regulatory authority to regulate the use of inefficient fans and to reduce the power consumption in the use phase of their lifecycle.

The external force demanding change can be summarised as a requirement to consider a System Efficiency Metric and Partial Load operation of the fan. Partial Load is considered as any operating point within the safe operating characteristic of the fan other than that of its peak efficiency. There are an infinite number.

Is operating at any of these points efficient? The short answer is maybe but not a definite yes. Where it operates depends on the match between the fan and the system into which it is fitted. A judgement is required to ensure an optimum match between the fan and the system into which it is incorporated. The key question is can a product regulation ensure a fan is operated at its optimum Partial Load?

Since 2011 the European Union has had an ecodesign regulation for fans, Regulation (EU) 327/2011, that has had a positive impact. It has transformed the market, removing inefficient fans, stimulating innovation, increased the use of higher efficient fans and between 2012 and 2017 saved 46,800 GWh of electricity consumption. But it is noted that it does not consider Part Load operation.

The pressure on the fan industry to adopt an Energy Efficiency Index (EEI) is not the solution and will adversely affect future development.

It is accepted that a reduction of power consumed in the use phase of fans can be achieved with better selection. A factor in forming a better decision is the availability of reliable information of the losses of the fan when operated at Part Load.

The proposal is to follow existing practice introduced in European ecodesign regulation for motors 2019/1781. This includes a requirement to provide data at a number of Part Load operating points. This ensures that components of an Extended Product are provided with reliable data. Developers can then determine the losses of their design. Further they can compare one selection to another.

The Driven Fan is a component in other Extended Products, such as ventilation appliances. Adopting the same approach in future fan regulations as those of motors and VSD regulations will provide reliable data at part Load operation. Developers of appliances using Driven Fans can then determine the impact when used at Part Load and be able to compare one fan to another, selecting the most optimum for their circumstances.

A number of issues need to be addressed in order to reach this goal. Ones such as deciding what is Part Load, and more fundamental ones such as how many operating points and how to interpolate between them.

The existing European ecodesign regulation for fans has proved to be very effective in improving fan efficiency and removing inefficient fans from the market. It is recommended to continue with this approach of setting a minimum efficiency requirement and to add to this the Part Load operating data.

The proposal is to continue with the proven approach under ecodesign. Add to it an accepted method of providing Part Load operating data. This will ensure inefficient fans are removed from the market and the power consumption of the remining fans are minimised through better selection.

Recommendations and requirements

The existing European ecodesign regulation for fans has proved to be very effective in improving fan efficiency and removing inefficient fans from the market. It is recommended to continue with this approach of setting a minimum efficiency requirement and to add to this the Part Load operating data.

The proposal is to continue with what is proven. Add to it an accepted method of providing Part Load operating data. This will ensure inefficient fans are removed from the market and the power consumption of the remining fans are minimised through better selection.

The issues to be addressed to provide this outcome are for the fan industry to decide;

- How many operating points to publish?
- Where those operating points are located?
- How to interpolate between those points?
- What deviation and therefore tolerance is appropriate for when Market Surveillance check the operating point(s)?

In addition, the industry needs to agree some fundamental terms;

- A clear definition of an Extended Product?
- What is a System Metric?
- What is Part Load and therefore Partial Load?

Currently only a direct measurement method is reliable and includes all current technologies. To achieve a calculated approach many aspects need to be clarified or defined, such as;

- Does the industry agree with the methodology of interpolating the load condition data of a motor given in IEC standards?
- Motor losses at higher frequencies, up to 90 Hz.
- Motor losses of other rotating machines.
- Can a simpler method to determine the losses of a VSD be provided by the drive industry?
- Etc.

All items that need to be resolved are collated in Annex 1 of this document.

Contents

Introduction

This document is a problem statement on a future efficiency measure to reduce the impact of fans and increase the efficient use of fans. It is written with consideration of future revisions of European eco-design regulations but could be used by any regulatory authority to regulate the use of inefficient fans and to reduce the power consumption in the use phase of their lifecycle.

The document discusses the current state of European regulations, European standards and International Standards and make comments on issues that need to be resolved to provide am extended efficiency metric for fans.

Future eco-design regulations need to consider many factors. In this case a significant factor is the need to reduce the environmental impact of fans in the use phase. There are a number of players influencing this need and they are discussed and considered.

Two proposals are made. One is to retain what is currently effective. A new one is proposed to assist and to encourage the effective application to optimise the efficient use of fans.

The document describes the short falls of current regulations and standards and sets out the issues that need to be addressed to be able to fully exploit the opportunity to reduce the impact of fans.

Fans are an important component, often hidden and unseen, in our modern society. The obvious solution to reducing energy efficiency is to switch the fan off, but this would have a negative effect on our society. The key is to find the balance between the benefits of moving air and the energy required to move that air.

Fans move air and produce a force to overcome the natural resistance to air movement. The product of the volume of air moved and the force required to move that air can be described in terms of energy, air power. The input energy to meet this requirement can be provided by electricity, typically as an input to an electric motor that drives a rotating impeller to produce the air movement and force. The efficiency, the difference between the electrical input power and air output power, describes the losses that occur in the electric motor, variable speed drive (if used), mechanical drive between motor and impeller and that of the impeller and stator.

The demand for change can be summarised as a requirement to consider a System Metric and the Partial Load operation of the fan.

What is a System Metric? A definition cannot be found in standards for fans. It is assumed to me one for an extended product, but is this correct and what is an extended product?

In this document the term system is defined as the extended system within which the fan is integrated. This extended product is itself considered as a system of impeller, stator and motor. However, in this document it is not considered as a system but as a component consisting of an impeller, stator and motor. This component has the terms; '*driven fan'* and *'a fan driven by a motor'*

What is Partial Load? It could be considered as any operating point within the safe operating characteristic of the fan other than that of its peak efficiency. There are an infinite number.

Is operating at any of these points efficient? The short answer is maybe but not a definite yes. Where it operates depends on the match between the fan and the system into which it is fitted. A judgement is required to ensure an optimum match between the fan and the system into which it is incorporated. The key question is; can a product regulation ensure a fan is operated at its optimum Partial-Load?

Key Terms

Extended Product (EP) and Extended Product Approach (EPA)

The term Extended Product (EP) is understood to have been first defined in standard IEC 61800-9-1 (1) as driven equipment together with its connected motor system (e.g a PDS).

It considers each element as individual components, hence motor, drive and fan (bare shaft fan) are seen as individual components. When combined, for example as a motor and drive, it becomes an EP of a Power Drive System. When a motor, drive and fan are combined they become a EP with the term Driven Fan. See figure 1.

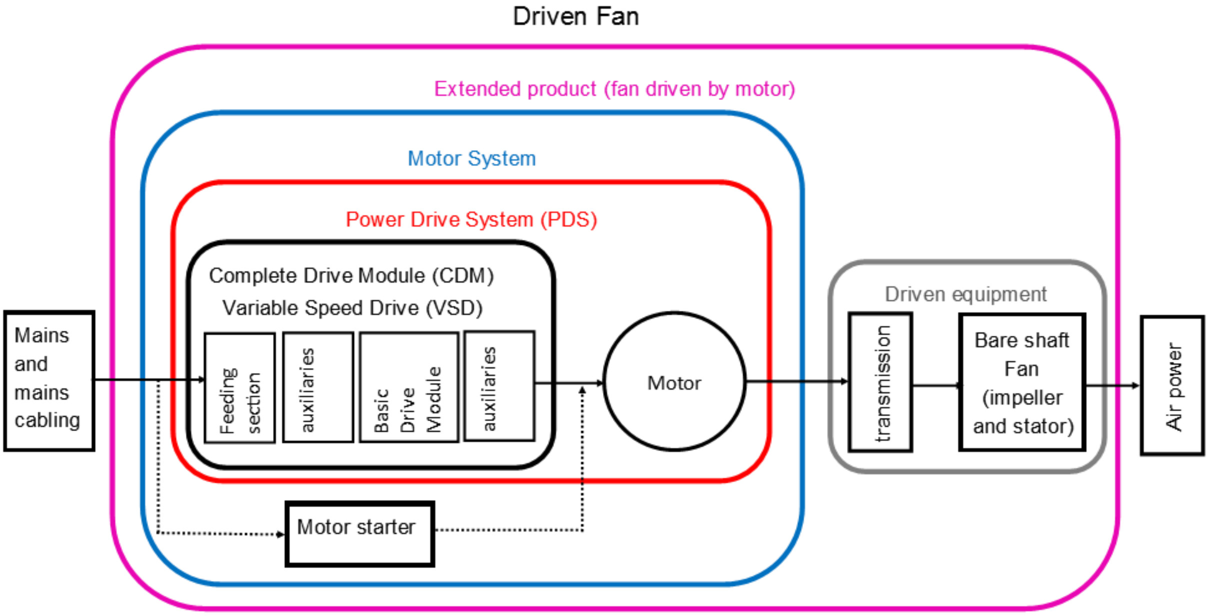

Figure 1 - Driven Fan - an Extended Product - adapted from ISO 61800-9-1

The Extended Product does not stop at the Driven Fan. The system into which the Driven Fan is incorporated is another Extended Product. IEC Guide 119 (2) describes how;

- The components of a pump impeller and housing come together as a pump unit (an EP)
- How a pump and motor combine to a pump system (an EP)
- How the pump is integrated into a Production Plant (an EP)

Components, product and system cascaded up and down.

IEC 61800-9-1 also includes a term Extended Product Approach (EPA) that defines it as a method to determine the Energy Efficiency Index (EEI) of the extended Product (EP).

The EEI is not clearly defined in IEC 61800-9-1 with a vague definition of a *value describing the energy of an application, resulting from the extended product approach*.

IEC Guide 119 gives a clearer explanation of a EPA but does not refer to EEI. It describes the Extended Product Approach as collaboration between various technical committee of individual products cooperating in development of efficiency standards when the products are combined into Extended Products.

See EEI below for further explanation and discussion.

The Fan industry considers the driven fan as a component. This component is integrated into a system, e.g. ventilation units, air-cooled chillers and cold rooms.

Partial Load operation

Part load is described in EN17038-2 (3), a European Standard describing methods of qualification and verification of the Energy Efficiency Index for Rotor Dynamic Pump Units. A pump is a similar fluid flow machine to a fan.

The term Part-Load is not defined within the standard but is used in the title of the standard, the first paragraph of the Introduction, in section 5.2.3 and in section 5.3.

As the term is not defined it is open to interpretation and would indicate Part-Load is any point other that that of maximum 100% point. The standard determines the Best Efficiency Point of the unit to be 100% flow and 100% head pressure.

An analogy can be applied to show that Best Efficiency Point of the fan is its maximum or peak efficiency and therefore operation at any other point is at a point of Part Load.

Energy Efficiency Index (EEI)

The EEI is not clearly defined in IEC 61800-9-1 with a vague definition of *a value describing the energy of an application, resulting from the extended product approach*.

EN17038-1 (4) provides a better definition of EEI as the *ratio between* $P_{1,avg}$ *and* $P_{1,ref}$. This along with section 4 and the figures from EN 17038-2 show that the EEI is a weighted average of a number of Part Load operating points, see examples below.

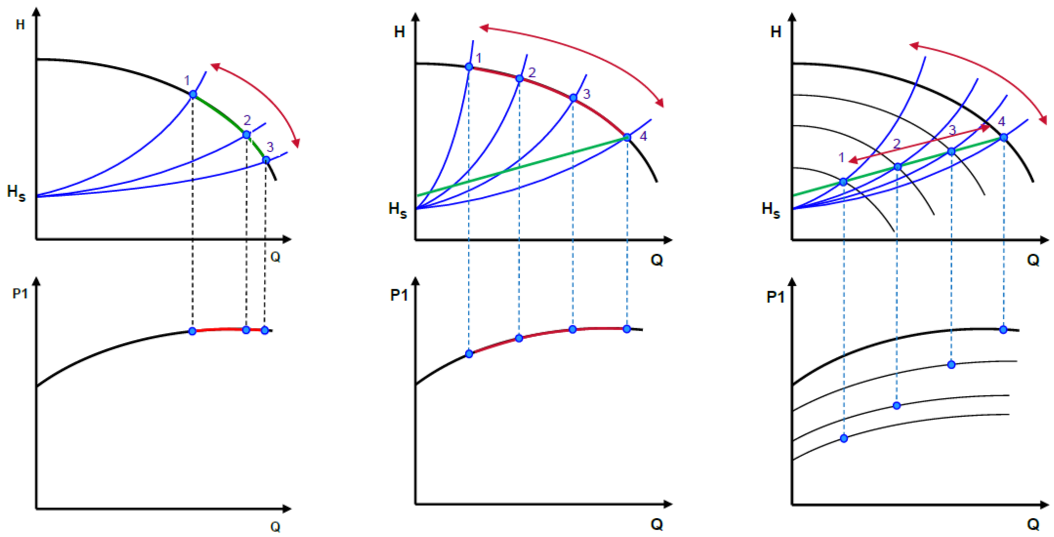

Figure 2 - preproduced figure 1 and 2 from EN 17038-2

There does not exist, at present, an EEI methodology in any fan standard.

System Efficiency Metric

The term System Efficiency Metric is not defined in any standard or regulation. It becomes mixed with the term Extended Product because the IEC guides and standards refer to Motor Systems that are a combination of Motor, Drive and Starter. Also, Power Drive Systems that are combination of Motor and Drive. Both are Extended Products. The Driven Fan is at least an impeller, stator and motor therefore it is an EP and also considered to be a Fan System. The product or application into which the fan is integrated is also referred to as a System.

The words System and Extended Product become intertwined.

IEC 61800-9-1 makes a unilateral statement in section 4 that a number or elements are required to determine an energy efficiency standard. The section concludes with table 1 with a statement that an EEI is required to complete the EP and it is the responsibility of ISO TC117 – fans.

As IEC61800-9-1 links EP and EEI in its definition of EPA and as the word System is intertwined with the term EP, then the assumption is made that a System Efficiency Metric is one that has an EEI. As EEI uses Partial Load operation to determine the its value then the assumption is a System Efficiency Metric is one that considers Partial Load.

Are the assumptions correct?

Current situation

Overview

In Europe there is an existing effective eco-design regulation for fans setting minimum energy efficiency requirements; Commission Regulation (EU) 327/2011 ecodesign requirements for fans driven by electric motors with an electric input power between 125 W and 500 kW (5) (regulation 327/2011).

The fan industry produced a technical standard, ISO 12759:2010 (6), at the international level to support regulation 327/2011.

At a later date the EU issued Mandate M/500 (7) requesting the European Committee for Standardisation (CEN) to produce standard(s) to support regulation 327/2011. Mandate M/500 requests a harmonised standard for the requirements of regulation 327/2011 in the first phase.

CEN technical committee 156, the committee for ventilation of buildings, established working group 17 - fans (CEN TC156 WG17) to answer the Mandate. CEN TC156 WG17 decided ISO12759:2010 did not address some issues with the regulations and decided to draft a new standard, FprEN17166 (8) to address the first phase of the mandate.

Regulation 327/2011 is currently being reviewed. At the Consultation Forum of the review study the EU's consultant presented explanatory notes (9) and in section 2.1 stated 'while the industry was busy transforming large parts of its catalogue to meet the requirements of the Regulation, there have been no major developments in the metric underlying that Regulation. The 'extended product approach' for part load testing, which is part of several other Eco-design-regulated products, has hardly been explored by the sector'.

The second phase of Mandate M/500 requests a System Efficiency Metric. This is understood to mean a metric that is an Extended Product and considers Partial Load operation, but this is not a universally accepted. This is yet to be tackled by CEN TC156 WG17.

The non-government organisation the International Energy Agency (IEA) has commissioned research of existing fan standards and regulations around the world. This research was conducted through one of its' Annexes, the Electric Motor Systems Annex (EMSA). It has produced two Policy Guidelines for Motor Driven Units, Part 1 (10) and Part 2 (11).

The guides influence the formation and revision of fan energy standards. They make reference to IEC guides 118 and 119 and use the terms Extended Product and Extended Product Approach.

Part 2 combines the terms System Efficiency and Extended Product Approach, see glossary for EPA within Part 2.

Part 2 makes a number of recommendations. Within these recommendations are statements regarding Partial Load operation (general recommendation step 5) and 'standardised load profile' and 'standard operating points' (general recommendation step 4).

The Advisory Committee on Energy Efficiency (ACEE) of the IEC has initiated a project in collaboration with ISO to encourage the development of energy efficiency standards for motor driven systems. The initiative proposes to build on the work of IEC 61800-9 series of standard and considers that far greater energy savings are achieved with an extended product when the combination of a motor and its driven equipment are optimised. ACEE has initiated liaisons with other IEC and ISO technical committees (TC's) including TC117.

Technical Group 6 of ACEE has organised a workshop to lay the groundwork for cooperation between ISO and IEC Technical Committees and international standards. The workshop was held in Tokyo in September 2019 with representatives from various IEC and ISO TC's and invited guests, including the Policy Officer of the EU responsible for 327/2011. The objective of the workshop was to facilitate the Coordination and Alignment of IEC & ISO Standards for energy efficient Electric Motor driven Systems. The outcome was a general agreement to continue to find opportunities to align Motor Driven Unit standards.

In response to the USA Department of Energy considering energy performance regulations for fans the Air Movement and Control Association (AMCA International) has developed a new energy use metric. This is described in AMCA 208 (12) (AMCA208)(ISO/DIS 12759-6). The Fan Energy Index (FEI) described in the standard is a ratio of the energy consumed compared to a reference fan at an operation point. As there are an infinite number of operating points of a fan there is not one singular FEI value for a fan.

The AMCA208 standard is supported by AMCA 207 (13) (AMCA207)(ISO 12759-2) that defines the calculation method to determine the power input of the fan system, where the fan system is the Extended Product of at least a motor, impeller and stator.

Regulation (EU) 327/2011

Regulation (EU) 327/2011 was published in 2011 and set ecodesign requirements for fans with electric input power between 125 W and 500 kW. The key measure is a minimum energy efficiency limit. That limit varies with fan type and input power, with the limit increasing with increasing input power. The requirement is for the fan to be higher than the limit effectively meaning the maximum or peak efficiency of the fan is required to meet or be above the limit.

The first limit became effective in January 2013 and then the limits were increased in January 2015.

The European Ventilation Industry Association (EVIA) study published in its position paper of June 2018 (14) that Regulation (EU) 327/2011 has had a positive impact. It has transformed the European market, removed inefficient fans, stimulated innovation, increased the use of higher efficient fans and between 2012 and 2017 saved 46,800 GWh of electricity consumption.

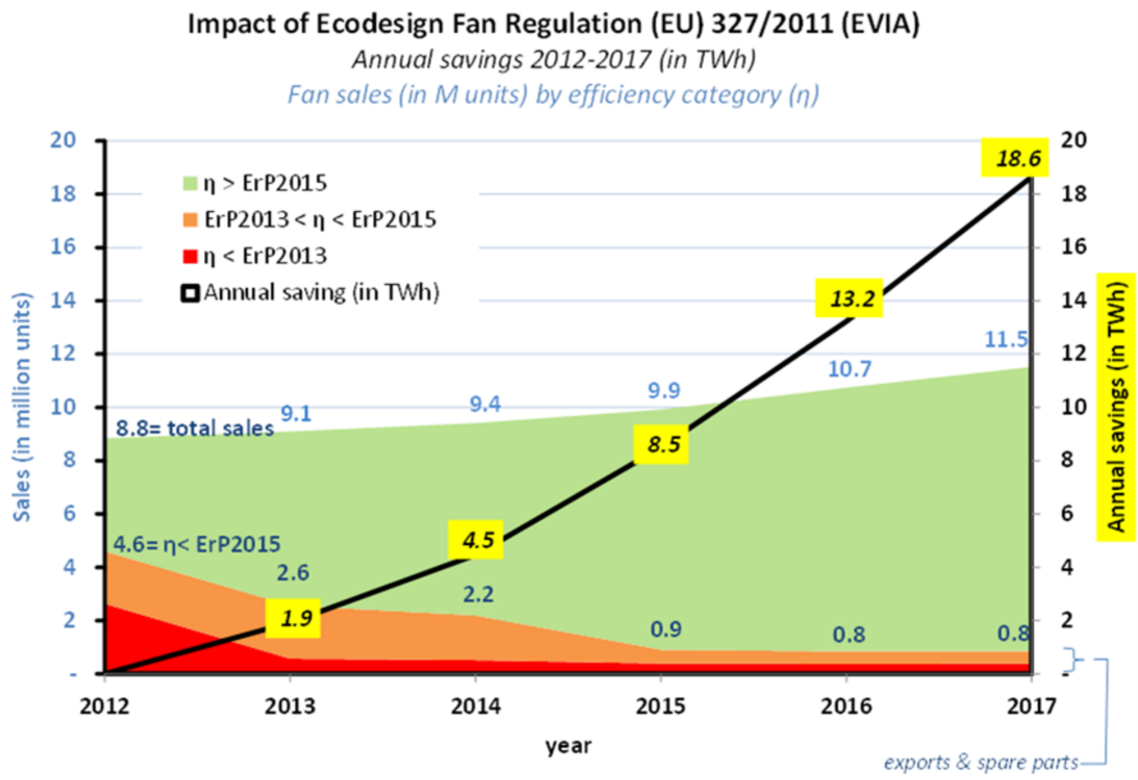

Figure 3 - Impact of Ecodesign Fan Regulation 372/2011 - source EVIA impact study

Regulation (EU) 327/2011 has had a positive impact, but there are issues with the regulation:

- Some definitions are unclear. For example, the scope of the fan is open to interpretation.
- All Jet Fan fail to meet the requirements as the methodology is inappropriate.
- There are issues with the calculation method:
    - Not all component losses are included.
    - The compensation factor (C_m) for the matching of components is challenged by the industry.
    - The default values for unregulated motors are too high.

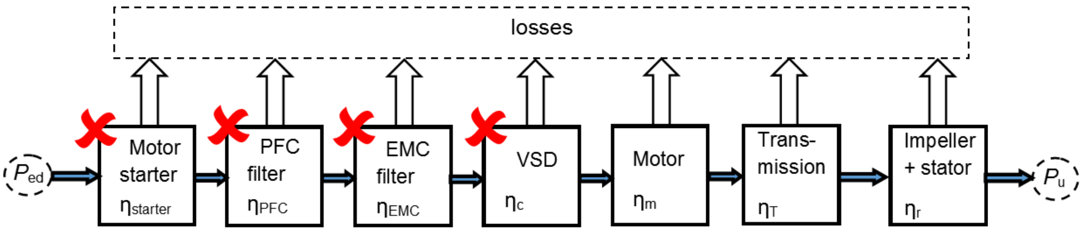

Figure 4 - diagram of losses of fan system showing which elements are not considered in the calculation method

Revision of Regulation (EU) 327/2011

At the time of drafting this document the final draft of the revision document of Regulation (EU) 327/2011 was not published. The following is an assumption based on the draft presented at the EU Commission Consolation Forum of 30th April 2015 and subsequent discussion with the EU Policy Officer.

Considering the issues of Regulation (EU) 327/2011 described above it is anticipated:

- It includes a clear definition of a fan; consisting of at least an impeller, stator and motor.
- Jet Fans may be included and if so the minimum limit will be based on the thrust it produces
- The issues with the calculation method could not be resolved and only a direct measurement method is included, supplemented with a scale model method for large fans.

The minimum efficiency limits will be higher.

Partial Load operation is not included in the limit or requirements

Ecodesign regulation for Motors and Variable Speed Drives (EU) 2019/1781

The revised ecodesign regulation for motors and variable speed drives (VSD), Regulation (EU) 2019/1781, includes a requirement to provide specific product information for motors and VSDs.

From July 2022 the power loss at seven defined operating points of the motor are required to be published. The seven points align with prIEC 60034-2-3, see Elements of the Fan extended product - Motor below.

From July 2021 the power loss at eight defined operating points of the VSD are required to be published. The eight points align with IEC 61800-9-2, See Elements of the Fan extended product – Variable Speed Drive below.

ISO 12759:2010

ISO 12759 was produced in response to a request from European ISO members for a standard to support Regulation (EU) 327/2011. At the time there was no technical committee in CEN representing fans. In parallel, a USA delegation requested a standard for the American market where their focus was on Bare Shaft Fans and not a wire to air metric.

Section 6.2 met the requirements for the USA with a Fan Energy Grade (FEG) for Bare Shaft Fans. Section 6.3 is a Fan Motor Efficiency Grade (FMEG) for an extended fan product and a representation of Regulation (EU) 327/2011.

ISO TC117 is revising standard ISO 12759:2010. The committee has decided to structure the document into six parts as described below.

- Part 1 – General Information for fans
- Part 2 – Standard losses for drive components.
  - Published in 2019.
  - Based on AMCA207.
  - European members have decoupled this part from the Vienna Agreement, and it will not become a harmonised EN standard until revised.
- Part 3 – Fans without drives at maximum operating speed
  - Published 2019
  - Was section 6.2 of version ISO 12759:2010
- Part 4 - Driven Fans at maximum operating speed
  - Due for publication
  - Was section 6.3 of ISO 12759:2010 with some material incorporated from FprEN17166
- Part 5 – Jet Fans
- Part 6 – Fan Energy Index
  - Based on AMCA208

- European members have decoupled from the Vienna Agreement as it related to Part 2, see above.

FprEN17166

Written by CEN TC156 WG17 and at time of drafting this document is in its final draft for voting stage. The draft has been produced in response to the first phase of EU Mandate M/500. It addresses some of the issues found in regulation 327/2011, for example:

- A better definition of a fan
- A clear definition of the scope of the fan by describing its boundary
- Improved definition between fan types axial, mixed flow and centrifugal
- A definition of a Jet Fan
- Includes the term Extended Product and references IEC61800-9-1

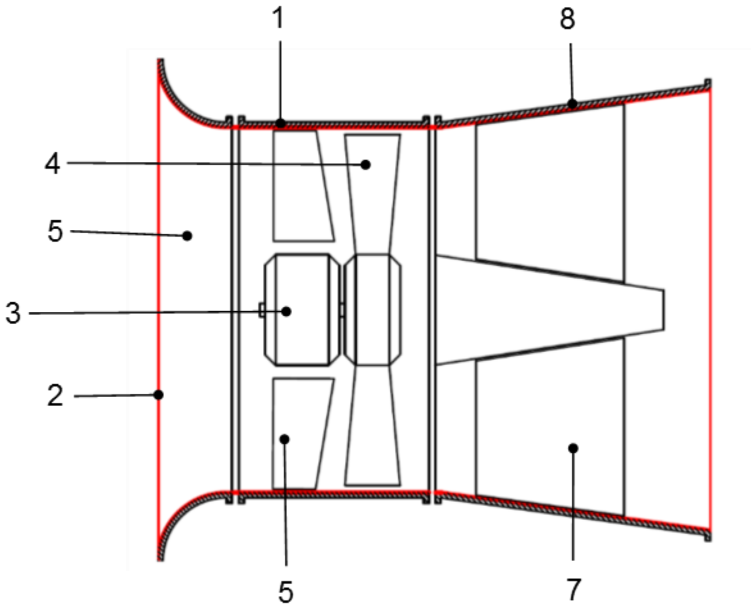

Figure 5 - sketch of fan showing boundary in red - source fig 26 of FprEN17166

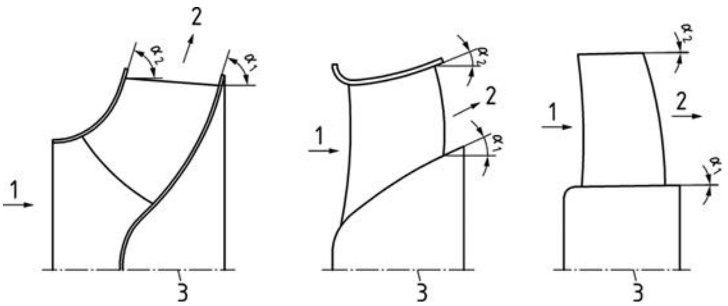

Figure 6 - Differentiation of fans types by use of angle α – source figure 2 FprEN17166

Elements of the Fan Extended Product

A fan in its Extended Product arrangement consists of at least an impeller, stator, and motor. Where a stator is a stationary element that interacts with the air stream passing through the impeller.

In terms of Extended Product, see figure 1, the Driven Equipment is at least the Impeller and Stator and may include the Mechanical Drive. In figure 7 below the wall-ring is the Stator.

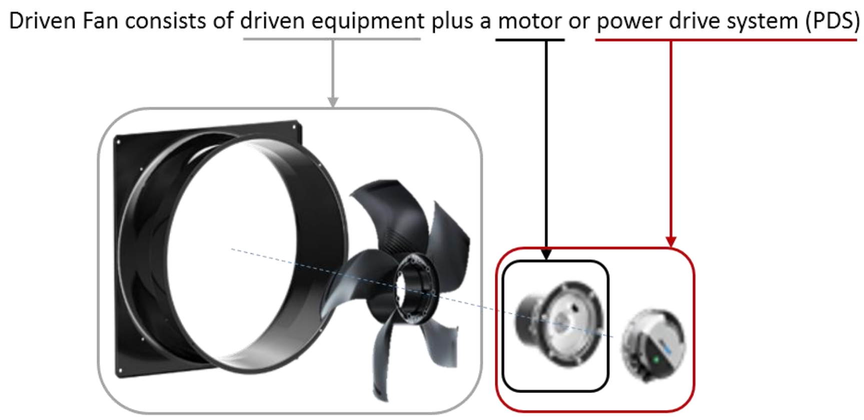

Figure 7 - A Driven Fan consisting of at least an Impeller, stator and motor

Fan efficiency is determined by comparing the electrical input to the air power output measured in Watts. The exception to this rule is a category of fans known as Jet Fans. The efficiency of a Jet Fan is determined by comparing the electrical input to the thrust it produces, measured in Newtons.

Performance based on air power output is assessed by direct measurement according to ISO 5801 (15). The performance of Jet Fans is assessed by direct measurement according to ISO 13350 (16).

There is not a method to calculate the performance in either ISO5801 or ISO 13350, and therefore to determine losses and efficiency.

Impeller and Stator (Bare Shaft Fan)

The performance of the Bare Shaft Fan (impeller plus stator) can only be determined by direct measurement according to the standard ISO5801.

Mechanical Drive (Transmission)

It is unclear what standards exist in determining the losses of mechanical drives. Representatives of the ISO committees responsible for Pulleys & Belts (ISO TC 41) and Gears (ISO TC 60) did not participate in the IEC-ISO workshop, Tokyo 2019.

Regulation (EU) 327/2011 includes equations to determine the losses of 'low-efficiency drives' and 'high-efficiency drives'. The source or accuracy of these losses are unknown.

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has commissioned AMCA International to undertake a research programme for the Experimental Evaluation of Belt Drives for Fans.

In many fan systems a mechanical drive is not required, and the motor is directly connected to the impeller. In such cases there are no mechanical drive losses.

Motor

The efficiency classes of single speed AC induction motors is defined according to IEC 60034-30-1 (17). The efficiency classes of variable speed AC induction motors is defined to IEC 60034-30-2 (18).

The technical committee IEC TC2 WG28 is revising a standard that defines the testing and interpolation of variable speed AC induction motors, IEC TS 60034-2-3 (19). The current standard specifies test methods for determining the losses of converter-fed AC induction motors. The revision, edition 2, will include analytical interpolation formulae to determine the losses at any point between seven defined points, see figure 8

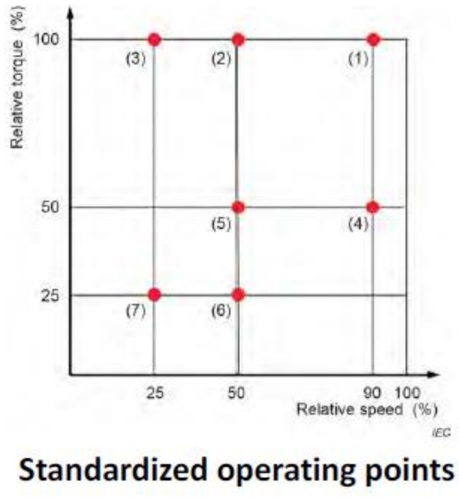

Figure 8 - reproduced from prIEC TS 60034-2-3 showing seven standardised operating points

Variable Speed Drive (VSD)

IEC 61800-9-2 (20) provides a methodology to determine the losses of an operating point of a VSD at any point between eight standardised operating points. The methodology requires analytical two-dimensional linear inter- or extrapolation between the points, see figure 9

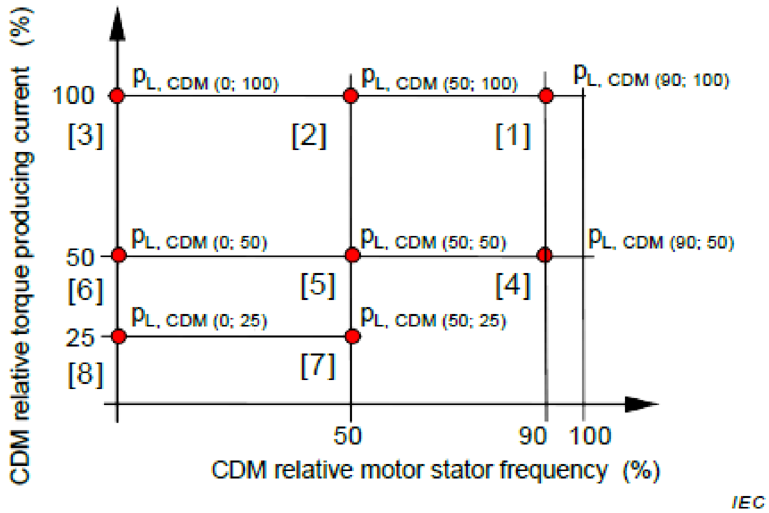

Figure 9 - reproduced from IEC 61800-9-2, figure 21 - order of CDM measurements from 1 to 8

Power Drives Systems (PDS)

IEC 61800-9-2 provides a methodology to determine the losses of an operating point of a Power Drive Module (motor plus VSD) at any point between eight standardised operating points. The methodology requires analytical two-dimensional linear inter- or extrapolation between the points, see figure 10

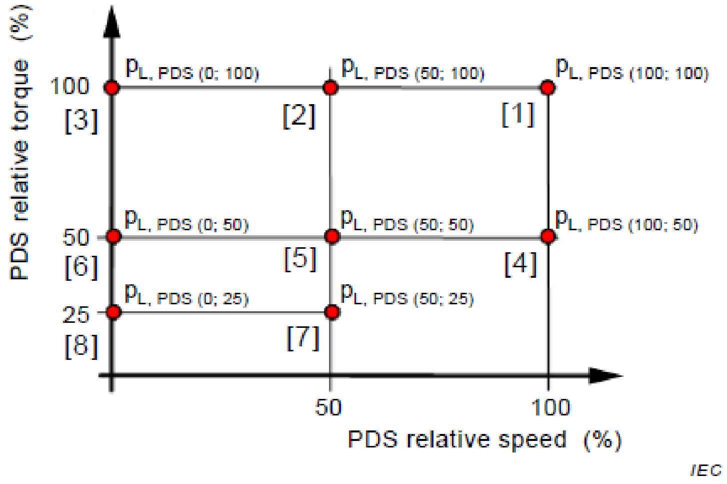

Figure 10 – reproduced from IEC 61800-9-2, figure 22 order of PDS measurements from 1 to 8

Motor Starter

Mr B. Leprette presentation on behalf of IEC TC121 (switch gear and control gear) at the IEC-ISO workshop in Tokyo 2019 (21) demonstrated that the losses of motor starters are negligible and do not change the efficiency of the motor system.

Issues

A review of the current situation shows that there are many issues: inconsistencies, conflicting requirements and missing elements. For example, EU Mandate M/500 request a System Efficiency Metric, but the term System Efficiency Metric is not clear. Another example is the IEC standard 61800-9-1 has stated a EEI is required to complete an EP and that ISO TC117 is responsible. There has been no dialogue between IEC and ISO TC117 on the matter. There are issues as discussed below

Definition of terms

Separate IEC, ISO and CEN committees have produced definitions for the same term. This has been noted on an ISO document ISO-TC117-WG17-N0085 and ISO-TC117-WG17-N0086. Definitions should be aligned.

There is no definition of a System Metric that leads to multiple interpretation and misunderstanding.

Calculated values

The current regulation 327/2011 includes a formulae to calculate the efficiency of the Driven Fan by using the efficiency values of the individual components. The formulae given is:

$$\eta_e = \eta_r \times \eta_m \times \eta_T \times C_m \times C_c$$

Where;

η_e is the overall efficiency

η_r is the impeller efficiency (impeller plus stator, also called Bare Shaft Fan) and is determined by direct measurement according to ISO 5801.

η_m is the nominal rated motor efficiency in accordance with European Regulation 640/2009. It uses the maximum efficiency and does not consider the actual load on the motor from the Bare Shaft Fan. For non-regulated motors and motors outside the scope of 640/2009 a default value is given. There is not relation to the actual motor used or consideration of the load on the motor of the Bare Shaft Fan.

η_T is the mechanical transmission between motor and Bare Shaft Fan. Default values are provided by two formulae for a low efficient drive and a high efficient drive. There is no consideration given for a change in efficiency due to the load of the Bare Shaft Fan.

C_m is a compensation factor recognising the high probability of poor matching of components. It is a fixed fractional value of 0.9. It does not consider instances of correct mating of components, that the effects of mismatching can vary and that the effect varies with load.

C_c is a part load compensation factor. It is a value greater than 1 that compensates for the additional losses of a Variable Speed Drive and encourages the use of a VSD.

The formulae does not include the losses of Variable Speed Drives.

The values for motors only consider a small range of AC induction machines and not alternative technology, small machines, or high pole machines.

The outcome is a method that has resulted in instances of calculated values much lower than reality. However, where power efficient components and default values are used and/or where a there is poor matching of components then a higher value than reality can be declared.

The solution for the revision of 327/2011 was the proposal to remove the calculated approach and only have a direct measurement method.

Energy Efficiency Index (EEI)

An Energy Efficiency Index (EEI) attempts to describe the real-life performance of a system. An example is the EEI for circulators that describes the typical performance of a circulator in a water heating system in a building.

In this example the method takes four defined operating points across the range of a circulator, and calculates an average loss based on a defined operating period, i.e. 10% operation at point 1, 30% at point 2, 40% at point 3 and 20% at point 4.

Is this appropriate for a fan? Many fan manufacturers develop fans for use in multiple applications and market them through promotional catalogues. Often fans are manufactured in volumes of tens of thousands of pieces per year and sold to multiple clients for multiple applications. One fan part number is used in many applications including fixed speed intermittent use, continuous use in a constant volume operation, continuous use in a constant pressure operation, continuous use in a variable volume and variable pressure operation, and any combination of these. 4 operating points does not describe the characteristics of this fan.

A single EEI cannot describe the full variety of real-life applications. Indeed, an EEI would be predicated on a single reference, representing only a small fraction of real-life fan usages.

As minimum efficiency limits are increased research & development teams will concentrate in optimising on these 4 points, although rarely if ever will the fan operate at these points.

With modern technology it can be imagined that manufacturers will optimise, with other detrimental effects, the efficiency of these points to meet market surveillance requirements.

Motor Standards

The technical committee IEC TC2 WG28 is revising a standard that defines the testing and interpolation of variable speed AC induction motors, IEC TS 60034-2-3.

Driven Fans are fitted with many more motors other than AC induction machines. They also use Permanent Magnet machines and other synchronous machines. Standards to determine the efficiency and to provide partial operation of these machines are required for a calculated method.

Some direct driven Driven Fans are operated at high rotation speeds. To achieve the high rotational speed a frequency converter is used to operate the motor to on frequencies up to 90 Hz. Currently motor standards do not consider the motor losses above 60 Hz operation. Losses at operation at high frequencies are required for a calculated method.

Future motor standards must include the efficiency of high pole motors, such as 8, 10 and 12 pole. These machines are used by industrial and large fan manufactures who are typically Small Medium Size (SME) companies. SME do not have the resources to develop their own motor or provide the sales potential to interest motor manufacturers to produce efficient versions of these machines. For SMEs to meet the fan efficiency standard a source of highly efficient components is required.

Variable Speed Drive Standards and Power Drive Systems

It is unclear if standards to determine the losses of VSD and PDS include the losses of the auxiliary items. For example, to meet EU regulations there is a need to meet the Electromagnetic Compatibility (EMC) Directive (EU) 2014/30, potentially requiring the use of filters. These filters are a loss in the system. For an accurate and reliable calculated method these losses must be included.

The method to determine the losses at a operating points between the eight standardised operating points is understood to be difficult, indeed it is understood that only the manufacturer of the VSD can calculate. For and easy, accurate and reliable calculation method this issue needs to be resolved.

Mechanical Drive Standards

Regulation 327/2011 includes two formulae for losses of belt drive. One is for a low efficiency drive and one is for a high efficiency drive. The value of the loss varies with the size of the power being transmitted. These formulae have subsequently been adopted into standards, ISO 12759-4 and FprEN17166.

The source of the formulae is unknown, and the accuracy of the formulae is unknown.

It is unclear what standards exist in determining the losses of mechanical drives. Representatives of the ISO committees responsible for Pulleys & Belts (ISO TC 41) and Gears (ISO TC 60) did not participate in the IEC-ISO workshop, Tokyo 2019.

Fan Energy Index (FEI)

The Fan Energy Index is a ratio of the power consumed at an operating point compared to a reference fan. The operating point can be anywhere within the operating characteristic of the fan. There are two methods of determining the actual losses of the Driven Fan. One is by direct measurement and the other is by calculation of losses of components.

The metric has benefits as it can be used to compare the losses of different fans at an operating point where that operating point can be at Partial Load. Partial Load operation is considered which encourages the better selection of fans.

Further it is understood that European Market Surveillance will not regulate the operating point of a fan. It is difficult to determine in situ the operation of a fan and as such it is difficult to determine what was the original design operating point and what is the actual operating point.

Furthermore, if it is accepted that more energy savings can be achieved by adjusting the fan output to match the load, i.e. speed control the fan to match the load. Many loads are variable and as such the FEI becomes variable and a moving target.

Discussion and proposal

A key question is can a product regulation ensure a fan is operated at its optimum Partial Load? First there needs to be a decision of what is the optimum and a realisation that in the high-volume manufacturing sector general fans are designed and built for use in multiple applications.

There is a possibility that a bespoke fan can be designed whereby its optimum operating point is aligned with the demand on the appliance. In reality this situation is confined to a few very high-volume appliances. The demand on the appliance is variable. In such cases the operating point will vary and rarely if ever align with the optimum operating point of the fan.

In the majority of situations, a standard fan from a catalogue is selected and used in a multiple number of different appliances. The demand of those appliances will vary, from static to variable duty where that variable duty can be constant volume, constant pressure or variable volume and pressure. Rarely if ever will the demand match the optimum operating point.

If it is accepted that rarely if ever the demand on the fan matches the optimum point, then what benefit is a regulation that attempts to ensure a fan is used at its optimum point, or at any operating point?

It is difficult to measure the performance of a fan in situ, that is when installed in a system or integrated within another product. Why then have a regulation that is difficult to measure and difficult to determine a point of operation that is shown to be theoretical?

Is an EEI an appropriate measure? If a unique fan is used in multiple applications and appliances, and the demand from those vary significantly then four arbitrary operation points cannot fully describe the characteristics of the fan.

Future fan developers will design the product to be optimum at these four points. If variable demand applications and appliances mean that rarely if ever the fan operates at these points, then to what benefit is there to optimise these points?

The current eco-design Regulation (EU) 327/2011 has proven to be effective. It has transformed the European market, removed inefficient fans, stimulated innovation, increased the use of higher efficient fans and between 2012 and 2017 saved 46,800 GWh of electricity consumption. The EVIA study shows that inefficient fans were removed from the market.

If this methodology has shown to work what benefit is there in changing from this effective measure to improve fan efficiency and remove inefficient fans from the market?

What is missing is ensuring the fan is optimally installed or integrated in the system or appliance. In real life business clients discuss with fan manufacturers to select the optimum fan for their application. For the best decisions to be made, clear and accurate data at any operating point within the fan's characteristics is required.

Currently most manufacturers provide selection programs that provide data at any operating point within the operating characteristic of the fan. The data provided will include the volume flow and pressure development. It can also include energy loss, efficiency, sound, etc.

The selection programs allow comparison to other fans at the same operating point or a range of operating points. Therefore, developers of systems and appliances can select the optimum based on comparison against their criteria.

A question is: how reliable is the data? Reliable data can be regulated taking the example of the European eco-design regulation for motors, Regulation (EU) 2019/1781 (22). This stipulates a requirement to provide the power losses at 7 defined operating points of a motor and 8 defined operating points of a variable speed drive (VSD). This provides a means for market surveillance to check the accuracy of the declared operating points.

This ensures that users of motors and VSD's are given information informing them of the losses at these points. The IEC standards provide methodology to determine the losses at any point between these regulated points. Users can now predict the impact of operating power drive systems at Partial Load.

The Fan industry could follow a similar approach and provide a set of Partial Load operating points. Thus, providing the data for a more informed decision on the selection and use of fans.

What is missing to achieve this result? The industry needs to decide:

- How many operating points to publish?
- Where those operating points are located?
- How to interpolate between those points?
- What deviation and tolerance are appropriate for when Market Surveillance check the operating point(s)?

Can these operating points be calculated? Considering the number of open questions and unknown sources of data described for each element of the fan, see above, then only a direct measurement approach is currently reliable. To provide a calculated approach the issues described above need to be resolved.

Conclusion

The current European eco-design regulation for fans, 327/2011, has had a positive impact. It has transformed the European market, removed inefficient fans, stimulated innovation, increased the use of higher efficient fans and between 2012 and 2017 saved 46,800 GWh of electricity consumption.

There is strong pressure and a foreseen benefit in providing a future metric that considers Partial Load operation.

The proposal for a fan efficiency metric based on an Energy Efficiency Index (EEI) may provide a comparison between fans but does not compare to the actual use of fans and will adversely affect future fan development.

The three main issues with the Fan Energy Index are:

a) The operating point is often variable, especially over time.
b) The pre-selection calculation to determine the pressure loss is often inaccurate.
c) Determining the in situ operating point of the fan.

The alternative is to follow the lead shown with other component regulation. The fan is just another component of an Extended Product as motors and variable speed drives are components of the Extended Product that is the Driven Fan. The European ecodesign regulation for motors and VSD requires the publication of losses at 7 and 8 operating points, respectively for motor and for VSD. This provides the user and developer of systems and appliances using motors and VSD the means to determine the affect when operated at Partial Load. The fan industry should do the same for fans.

The issues to be addressed to provide this outcome are for the fan industry to decide:

- How many operating points to publish?
- Where those operating points are located?
- How to interpolate between those points?
- What deviation and therefore tolerance is appropriate for when Market Surveillance check the operating point(s)?

In addition, the industry needs to agree some fundamental terms:

- A clear definition of an Extended Product?
- What is a System Metric?
- What is Part Load and therefore Partial Load?

Currently only a direct measurement method is reliable and includes all current technologies. To achieve a calculated approach many aspects, need to be clarified or defined, such as:

- Does the industry agree with the methodology of interpolating the data of a motor given in IEC standards?
- Motor losses at higher frequencies, up to 90 Hz
- Motor losses of other rotating machines
- Can a simpler method to determine the losses of a VSD be provided by the drive industry?
- etc

All items that need to be resolved are collated in Appendix 1 of this document.

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Appendix 1 – Issues that need to be resolved

No.	Description	Issue	Risk	Action
1	Extended Product - definition	Opportunity to clarify difference between elements including Bare Shaft Fan and Driven Fan	Low	A definition was agreed at meeting of 22nd April 2020 see Appendix 2.1
2	Extended Product - EEI	IEC 61800-9-1 states in section an EEI is required to complete an EP and it is the responsibility of ISO TC117	High	A position was agreed at meeting of 22nd April 2020 see Appendix 3.1
3	Partial Load	No definition in Fan standards	High	A definition agreed at meeting of 22nd April 2020 see Appendix 2.2
4	System Efficiency Metric	Unclear meaning and use of the term in EU Mandate M/500.	High	A definition agreed at meeting of 22nd April 2020 see Appendix 2.3
5	Mechanical Drive – low-efficiency drive, high-efficiency drive loss factors in regulation 327/2011	What is the source of these factors? How representative are they of direct measurement?	Medium	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
6	Mechanical Drive	ASHRAE research programme. Is this a source of alternative loss factors for a calculated approach?	-	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
7	Losses of variable speed motors other than AC induction	prIEC 60034-2-3 describes methods of determining the losses of variable speed AC Induction. Currently there is not a standard to determine the losses of other machines	High	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
8	Alignment of definitions	Separate IEC, ISO and CEN committees have produced definitions for the same term, see ISO-TC117-WG17-N0085 & N0086	Low	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
9	A calculation of losses method is not within the main fan standard ISO5801	There is not universal agreement of the correct method. There are no comparisons between methods. There are concerns that losses of some items differ across standards or do not exist	High	A position was agreed at meeting of 22nd April 2020 see Appendix 3.2
10	A number of methods defining motor losses exist	Which method is correct?	High	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2

11	The IEC standard does not provide losses of motor operation >60 Hz	Many use motors up to 90 Hz.	High	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
12	A number of methods defining VSD losses exist	Which method is correct?	High	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
13	The IEC method of determining the Part Load loss of VSD is complicated	How can this be used by the fan industry?	High	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
14	Losses of VSD with EMC filters is required	Fan manufactures need to meet EMC Directive and therefore need to know the losses of additional components such as filters	High	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
15	Belt drive losses	The source of the formulae in 327/2011 is unknown. Are they reliable? Are other sources available. Is there a standard that defines belt drive losses?	High	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
16	Gear losses	There are no standards that define gear losses	High	No longer relevant. EVIA has decided a position that only a direct measurement is possible in regulations. See Appendix 3.2
17	Part Load operating points	How many?		A position was agreed at the meeting of 28th May 2020 - see Appendix 4
18	Part Load operating points	Where are they located?		A position was agreed at the meeting of 28th May 2020 - see Appendix 4
19	Part Load operating points	How to interpolate between those points?		A position was agreed at the meeting of 28th May 2020 - see Appendix 4

Appendix 2 – terms and definitions

The following are new or existing terms and definitions that have been produced or revised by EVIA

2.1 Extended Product (EP)

The term Extended Product (EP) is understood to have been first defined in standard IEC 61800-9-1 (1) as driven equipment together with its connected motor system (e.g a PDS). EVIA proposes an alternative definition.

Extended Product

Is a combination of parts that are combined to form a new item. For example, a Fan can be as simple as an impeller, stator and motor (EN17166 definition 3.1 and note 1 to entry), or can be combination of impeller, stator, motor, mechanical drive, variable speed drive, starter, and aerodynamic elements. The skill and knowledge of the manufacturer combines those elements to obtain the optimum performance for the required application and becomes responsible for providing the technical data.

An extended product can be a combination of products and components leading to a new set of performance parameters. Therefore a fan can become a component in a higher system.

2.2 Extended Product Approach (EPA)

IEC 61800-9-1 also includes a term Extended Product Approach (EPA) that defines it as a method to determine the Energy Efficiency Index (EEI) of the extended Product (EP). EVIA is of the opinion that such an approach is not appropriate for the Fan industry and has agreed the following.

Extended Product Approach

The fan industry does not agree with a strict extended product approach directly linked to an Energy Efficiency Index. We believe it is important to provide reliable data so that others can make informed decisions for the application where the extended product is used.

2.3 Partial-Load

Part-Load is described in EN17038-2 (3), a European Standard describing methods of qualification and verification of the Energy Efficiency Index for Rotor Dynamic Pump Units. A pump is a similar fluid flow machine to a fan.

The term Part-Load is not defined within the standard but is used in the title of the standard, the first paragraph of the Introduction, in section 5.2.3 and in section 5.3.

As the term is not defined it is open to interpretation and would indicate Part-Load is any point other than the maximum 100% operating point. The standard determines the Best Efficiency Point of the unit to be 100% flow and 100% head pressure.

An analogy can be applied to show that the Best Efficiency Point of a fan is its maximum or peak efficiency and therefore operation at any other point is at a point of Part-Load.

Extract from EN17038-2

Introduction

This part of the European standard is the second part of a series of standards describing a methodology to evaluate energy efficiency performance of single pump units, comprising the pump, the motor with or without frequency converter, based on a non-dimensional numerical value called Energy Efficiency Index (EEI). An EEI allows the comparison of different pump sizes and types with one common indicator. Physical influences such as pump size, specific speed, pump unit part-load operation, motor-efficiency characteristic and frequency converter influence are implemented into this metric.

5.2.3 Determination of part load and over load points and reference control curve

The reference flow points of the flow rate Q_i shall be calculated by the following formula:

$$Q_i = \left(\frac{Q}{100}\right)_i \cdot Q_{100\%} \qquad (2)$$

5.3 Calculation of $P_{1,avg}$

5.3.1 General

Measure the values Q_i, H_i and $P_{1,i}$ at each reference part load/over load point.

The term Partial-Load is used in the discussion of energy efficiency metrics for fans, but a definition does not exist in any fan standard or regulation. EVIA agrees the following definition.

Partial Load

Is any point within the safe operating characteristics of the fan away from the optimum point on the performance curve at constant speed or at any point below with reduced speed.

Note Partial Load is not Part-Load. Part-Load is defined in the motor industry to show the real motor efficiency compared to defined load points (75%, 50%, 25%) of the full load efficiency at a constant speed. Different load profiles at reduced speed are not covered by this definition.

Separate definitions (Part-Load versus Partial-Load) are important to avoid possible misunderstandings between motor efficiency values and system efficiency values (like a fan), between a component and a system regulation.

For fans and other systems with not only constant speed, the term "Partial Load" should be used.

2.4 System Efficiency Metric

The term System Efficiency Metric is used in the discussion of energy efficiency metrics of fans, but a definition does not exist in any fan standard or regulation. EVIA agrees the following definition.

System Efficiency Metric

There is not one metric that is appropriate for all conditions. Many fans are embedded within many applications. One metric cannot define the fan operation in all applications as they each have different requirements of the fan. For embedded fans it is important that the metric provides reliable data so that the developer of the application can make informed decisions. For embedded fans partial load data is essential.

Industrial fans are often designed and manufactured for a specific contract requiring a defined duty to be met. In such circumstances the above is superfluous, unnecessary, and not appropriate.

For standalone fans, a defined metric can be beneficial and provide a comparison to other options to the system integrator.

Appendix 3 – position statements

The following are the view of EVIA on specific topics within the general discussion of fan system efficiency.

3.1 Energy Efficiency Index (EEI)

IEC 61800-9-1 states in section 4 that a number of elements are required to determine an energy efficiency standard and concludes with table 1 that an EEI is required to complete the EP and it is the responsibility of ISO TC117 – fans.

EVIA is of the opinion that an EEI is not appropriate for the fan industry and states the following.

Energy Efficiency Index (EEI)

An EEI is not appropriate for the fan industry. An EEI describes a unique operation condition, including weighed average times and loads, for a single application. Fans are used in hundreds of different applications requiring a large variety of different indexes. One index would be completely misleading for all other applications. It will also restrict innovation of fans to this one index.

3.2 Measured versus calculated data

EVIA has requested that the performance of a fan is only determined by direct measurement. It is understood that the revised regulation 327/2011 will remove the 'not-final-assembly' calculation method. EVIA is of view that reliable calculation methods are not available in current standards. EVIA position is described as follows.

Measured vs calculated

A measured value is more accurate than a calculated value of fan performance data. A calculation approach does not always consider the tolerance of the motor, VSD and combination. Further is does not consider aerodynamic losses of component parts, such as the effect of the motor and mechanical drive in the airstream.

An explanation

A Driven Fan (definition 3.1.3 of ISO 13349:2010) is at least an impeller, stator and motor and the term for the electrical input power at the motor terminals is P_e. The Driven Fan may also include a Variable Speed Drive (VSD), in which case the term for the electrical input power at the motor terminals is P_{ed}.

The performance of fans is determined using the testing methodology described in ISO 5801:2017. The efficiency of the fan is determined from the *fan air power* divided by the *electrical input power*. The following equations are examples for the methodology using total pressure (term and definition 3.53 and 3.54 respectively):

Overall efficiency for a fan without variable speed drive; $\eta_e = \frac{P_u}{P_e}$

Overall efficiency for a fan with variable speed drive; $\eta_{ed} = \frac{P_u}{P_{ed}}$

The following diagram shows the inputs and outputs of a fan:

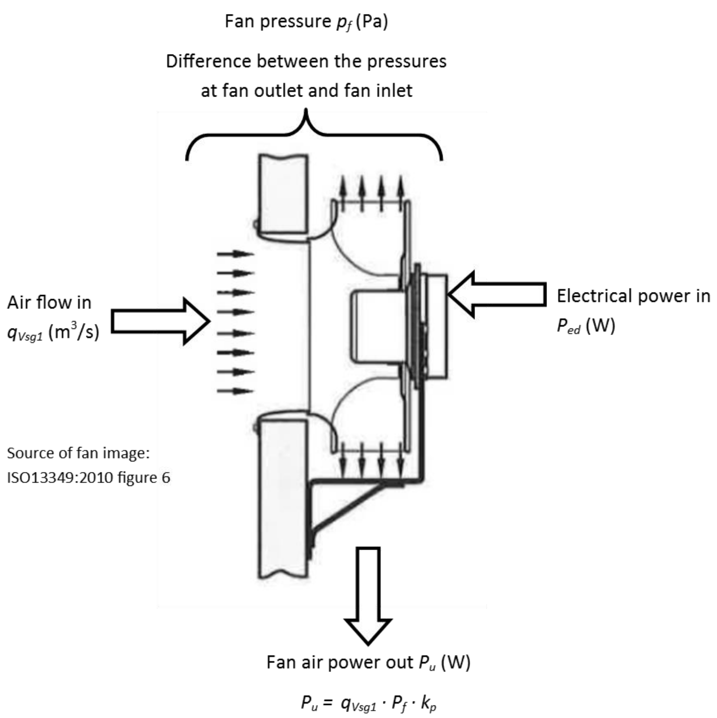


Figure 11 - diagram showing the inputs and outputs of an example of a Driven Fan

The standard ISO 5801:2017 describes the determination of the performance of fans by direct measurement of the input power and the output power. A calculated approach is discussed in an informative Annex E.

Informative Annex E of ISO 5901:2017 notes that ‘there is, therefore, a need for an agreed approach to the calculation to the electrical input power, P_e’. The annex provides a calculation, equation E.8, that includes losses for impeller, bearings, mechanical transmission, motor and VSD, but is does not consider matching the load of each element and does not include all the possible elements that add losses to the fan and that should be included.

The following table lists all possible elements that are a loss within a Driven Fan and highlights where equation E.8 and other approaches falls short and shows how a calculated approach can give a false optimistic overall efficiency.

Element	**Efficiency term**	**Included in a direct measurement of a fan?**	**Included in a calculated measurement of a fan?**	**comments**
Impeller	η_r	yes	yes	The performance can only be determined by direct measurement and shall be measured with its stator; ISO 5801:2017
Bearing, impeller shaft	η_b	yes	Can only be estimated	Determined by direct measurement or estimated;

				ISO8501:2017
Mounting arm	none	yes	no	Note 1
Protection guard	none	yes	no	Note 1
Mechanical drive – belt & pulley	η_T	yes	no	Note 1. η_T is a generic term for all mechanical drives
Mechanical drive – flexi-coupling	ditto	yes	no	Note 1
Mechanical drive – gear box	ditto	yes	no	Note 1
Mechanical drive – aerodynamic loss	none	yes	no	Note 1
Motor, AC induction	η_{mot}	yes	yes	Standard methods for determining the losses and efficiency from test of rotating electrical machines: IEC60034-2-1 Specific test methods for determining the losses and efficiency of converter-fed AC induction motors: IEC60034-2-3
Motor, Other than AC induction	η_{mot}	yes	no	No known standard
Motor – aerodynamic loss	none	yes	no	Note 2
Motor terminal box – aerodynamic loss	none	yes	no	Note 2
VSD	η_c	yes	yes	IEC61800-9-2
VSD – aerodynamic loss	none	yes	no	Note2
EMC filter	none	yes	no	No known standard
Line harmonic filter	none	yes	no	No known standard
Motor starter	none	yes	no	No known standard

		All losses are included	Not all losses are included	Not an equal comparison

Table 1 - direct versus calculated - list of elements of a fan

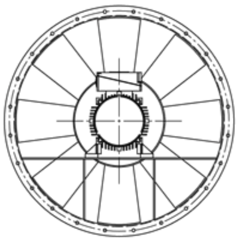
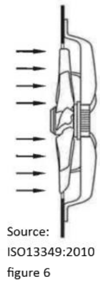
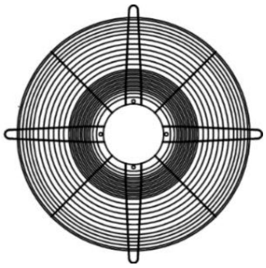
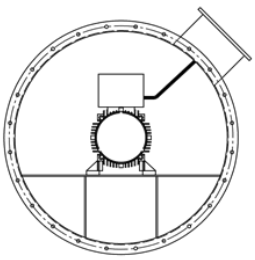
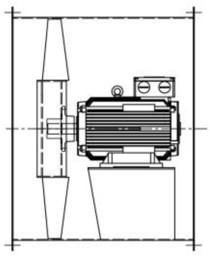
Note	Comment	examples
1	Obstructions at the inlet and outlet of the fan add losses due to restriction and due to adverse aerodynamic effect to the impeller & stator. No known method to calculate losses. Examples are; • Mounting arm • Protective guard • Belts & pulley • Flexible couplings • Gearboxes	   
2	An element located in the airstream can add losses due to adverse aerodynamic effect to the impeller & stator. No known method to calculate losses. Examples are; • Motor • Terminal box • VSD • EMC filters • Line harmonic filter	 

Table 2 - notes supplementing Table 1

Appendix 4 – Product Information

Future ecodesign regulation should continue with a minimum efficiency requirement based on the optimum energy efficiency point at the stated inherent speed (‘inherent speed’ see 7.2 and 16.3 of ISO 5801:2017). To assist integrators or users to make better informed decisions additional product information shall be provided;

1. For series produced fans that have integrated variable speed drives or are designed to be used with a variable frequency drive the additional information shall describe the partial-load operational performance of the fan. This shall be described by a minimum of three performance curves; one at the stated inherent speed, one at the minimum recommended speed, plus an additional one between the other two, see figure 12. More than three curves can be provided.
2. For series produced fans that are fixed speed and are not to be used with variable speed drives the additional product information shall be the performance curve characteristic at the inherent speed.
3. For industrial fans that have been designed to meet a specific duty, or a range of duties, the additional information provide shall be the performance at the specified duty or range of duties.

4.1 Series produced fans

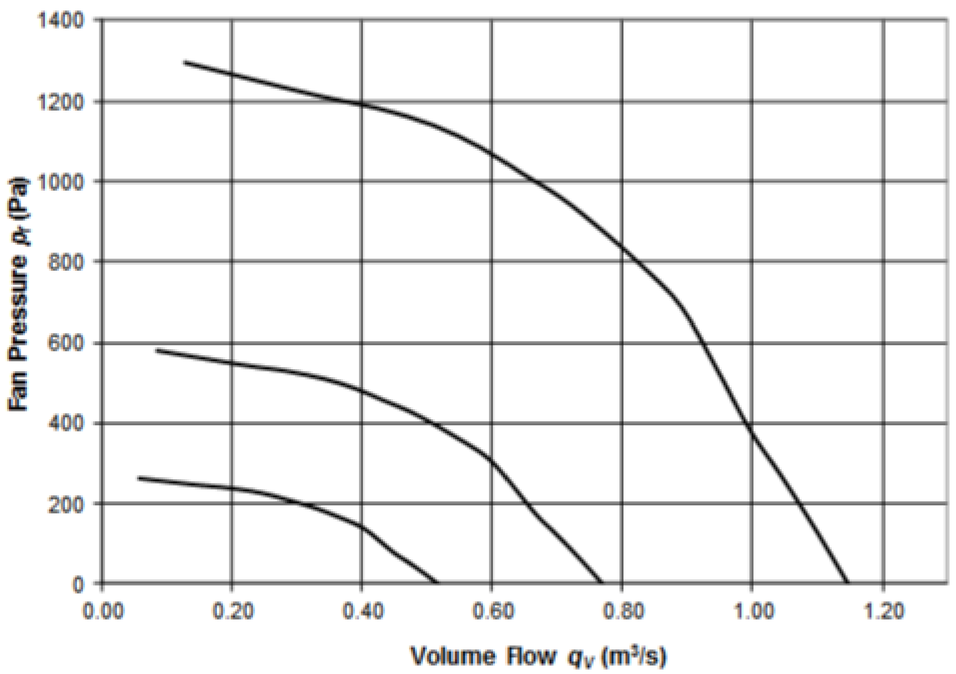


Figure 12 an example of partial-load operational performance described by three fan curves

Test points for determining fan characteristics curves shall comprise a sufficient number of plotted test points to permit the characteristic curve to be plotted over the normal operating range (source 7.7 of ISO 5801:2017).

ly test points and characteristic curve within the operating range are to be provided. For clarity and to assist market surveillance the volume flow, pressure, energy consumption and efficiency of the test points shall be displayed in technical documentation and published via free access websites of the manufacturer. The documentation can be in digital form such as selection software or online catalogue.

4.2 Industrial fans

Where only one operating point has been specified in the contract that point is the test point and is the additional product information.

Where a range of operation has been specified the additional product information shall be a sufficient number to describe the range.

If the Industrial Fan is placed on the market for general use then the requirements described for series produced fans shall be provided.

4.3 Market Surveillance

The additional data can be verified by checking a minimum of two declared test points of any of the characteristic curve