Info	
Subject:	EU 327/2011 Comments regarding proposed efficiency slopes
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Introduction
Howden Netherlands [HNL] is a manufacturer of industrial low pressure axial cooling fans. These fans are mainly used in air-cooled condensers, air cooled heat exchangers and cooling towers to provide cooling for power plants and (petro) chemical industries. Due to the nature of the application these fans are operated in, these fans are designed to move a relatively large volume of air against a relatively low pressure difference (50-200 Pa).

Low pressure cooling fans (especially large diameter cooling fans) are nearly always employed in a rotor-only configuration; this means without the use of inlet or outlet guide vanes.

Because many applications that use this type of fan exhaust directly into free atmosphere the relevant efficiency figure for these fans is usually the static (free outlet) efficiency. This is the static efficiency as determined on a type-A ISO5801 test setup [1]. This efficiency is sometimes also referred to as the "total-to-static efficiency".

Proposed minimum efficiency values for 2018 and 2020
The proposed minimum requirements for fan efficiency for 2018 and 2020 as documented in the VHK discussion document dd. 21/11/2014 are too high and would require impeller efficiencies which are unrealistic for a rotor-only axial cooling fan. In the table below the minimum fan efficiency requirements for 2013 and 2015 for axial fans (static and total) are shown together with the propose requirements for 2018 and 2020. Especially above 10kW the requirements are too high.

Power [kW]	Fan efficiency (axial) [%]							
	2013		**2015**		**2018**		**2020**	
	static	**total**	**static**	**total**	**static**	**total**	**static**	**total**
	36	**50**	**40**	**58**	**44**	**62**	**48**	**66**
0,125	24,0	38,0	28,0	46,0	28,7	46,7	28,5	46,5
0,25	25,9	39,9	29,9	47,9	31,3	49,3	32,6	50,6
0,5	27,8	41,8	31,8	49,8	34,0	52,0	36,6	54,6
1	29,7	43,7	33,7	51,7	36,6	54,6	40,6	58,6
2	31,6	45,6	35,6	53,6	39,2	57,2	43,2	61,2
5	34,1	48,1	38,1	56,1	42,7	60,7	46,7	64,7
10	36,0	50,0	40,0	58,0	45,3	63,3	49,3	67,3
25	36,6	50,6	40,6	58,6	48,8	66,8	52,8	70,8
50	37,2	51,2	41,2	59,2	51,5	69,5	55,5	73,5
100	37,7	51,7	41,7	59,7	54,1	72,1	58,1	76,1
200	38,3	52,3	42,3	60,3	56,7	74,7	60,7	78,7
300	38,6	52,6	42,6	60,6	56,7	74,7	60,7	78,7
500	39,0	53,0	43,0	61,0	56,7	74,7	60,7	78,7

Table 1: Minimum requirements axial fan efficiency 2013, 2015 and proposed requirements for 2018 and 2020

Diversity within fan type axial fan in relation to requirements for minimum fan efficiency
The defining characteristic of an axial fan is that the main direction of flow is parallel to the axis of rotation of the impeller (the fan shaft). Although all axial fans share this property there are also many important differences between different axial fans which makes it very difficult to directly compare efficiency values for these different axial fans.

A very striking example of these differences can be shown using the example of the Howden axial fan mentioned by Mr. Kemna during the 2nd stakeholder meeting. During the meeting in Brussels Mr. Kemna mentioned that he had found a brochure of a Howden axial fan stating a 89% fan efficiency.

This example specifically refers to the fan efficiency of a Howden Variax® fan (measured according AMCA 802).

- ID fan / Booster fan
- Over 7 MW motor power
- Minimized tip clearances
- Variable pitch control
- Optimized inlet and outlet guide vanes
- Optimized inlet box and outlet diffuser
- Optimized hub design

Below are some of the main properties of this Howden Variax® fan obtained from the same product brochure:

-	Fan diameter	3.2	[m]
-	Hub diameter	1.6	[m]
-	Fan speed	990	[rpm]
-	Air volume flow rate	550	[m3/s]
-	Fan static pressure	11600	[Pa]
-	Air temperature	135	[ºC]
-	Fan power consumption	7075	[kW]
-	Fan efficiency	89	[%]

<u>Typical cooling fan properties</u>
(At equal air volume flow rate but with pressure rise typical for a cooling fan application):

-	Fan diameter	9	[m]
-	Hub diameter	1	[m]
-	Fan speed	125	[rpm]
-	Air volume flow rate	550	[m3/s]
-	Fan static pressure	150	[Pa]
-	Air temperature	20	[ºC]
-	Fan shaft power	120	[kW]
-	Impeller static efficiency	68	[%]
-	Impeller total efficiency	86	[%]
-	Motor efficiency (IE3)	95	[%]
-	Transmission efficiency	98	[%]
-	Correction for system losses	0.9	[-]
-	Fan static efficiency	57	[%]
-	Fan total efficiency	72	[%]

As can be seen the Variax fan operates in a totally different regime than a cooling fan with regard to air velocity and fan pressure rise. The average air velocity through the Variax fan is in the order of 35 m/s, for the cooling fan this is 10 m/s. The pressure rise developed by the Variax fan is roughly a factor 100 higher than the pressure rise developed by a cooling fan.
In the case of an ID fan such as the Howden Variax® fan a (very large) part of the fan pressure rise is developed by the regain of static pressure through the use of a highly optimized diffuser and guide vane system. Note that these components make up the vast majority of the entire machine with regard to volume. For an ID it makes sense to use these components to regain velocity pressure; for cooling fans however this is not the case. Due to the very low air velocities and pressures involved the increase in cost and the huge space these components would require vastly outweighs the benefits of applying these components.

Because regulation 327 does not really account for these differences all axial fans are put into the same category and are regulated based on the same efficiency requirements. If this remains to be the case it would not be realistic to base minimum requirements regarding axial fan efficiency on the highest values possible with an axial fan without taking into consideration the engineering restrictions involved in some axial fan applications such as industrial cooling fans.

Effect of proposed efficiencies on required impeller efficiency

The overall efficiency of a cooling fan is a combination of the motor efficiency, the efficiency of the transmission, the impeller efficiency and system losses (tip clearance, motor support, fan guard etc.). The latter is expressed by the component matching factor in the non final assembly calculation in the current version of EU 327. Assuming values for motor efficiency, efficiency of the transmission and system losses one can derive the impeller efficiency that would be required to meet the proposed limits for 2018 and 2020.

Assumed values:

Motor efficiency taken as nominal minimum efficiencies for IE3 efficiency level (50 Hz) EU regulation 640.

Transmission efficiency	98	[%]
Component matching	90	[%]

Resulting requirements on impeller efficiency

Power	**Motor efficiency (IE3)**	**Impeller efficiency [%]**			
		2018		**2020**	
		static	**total**	**static**	**total**
[kW]	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**
0,125	65,1	50,0	81,3	49,7	81,1
0,25	73,5	48,3	76,1	50,2	78,0
0,5	80,0	48,1	73,6	51,8	77,4
1	84,0	49,4	73,7	54,8	79,1
2	86,7	51,3	74,8	56,5	80,1
5	89,4	54,2	77,0	59,2	82,1
10	91,0	56,5	78,9	61,5	83,9
25	93,5	59,2	81,0	64,1	85,9
50	94,4	61,8	83,4	66,6	88,2
100	95,0	64,6	86,0	69,3	90,8
200	96,0	67,0	88,3	71,7	93,0
300	96,0	67,0	88,3	71,7	93,0
500	96,0	67,0	88,3	71,7	93,0

Table 2: Resulting requirements on impeller efficiency

Especially the increase in required impeller efficiencies above 10kW towards 200kW is much too great and eventually leads to efficiency requirements which cannot be achieved by a cooling fan (*or in some cases any axial fan*).

Using some typical values with regard to average air velocity through a cooling fan etc. one can obtain a reasonable estimate of the associated impeller diameter based on the fan power consumption.

P	**D_{fan}**
[kW]	**[m]**
9	2
20	3
35	4
55	5
80	6
110	7
140	8
180	9
220	10
270	11
320	12

Table 3: Estimated industrial cooling fan diameter based on power consumption

One can then use Ackeret's formula to obtain an estimate of the effect of the increase in Reynolds number on the efficiency of the impeller.

Ackeret:

$$\frac{1-\eta}{1-\eta_{model}} = \frac{1}{2}\left[1 + \left(\frac{Re}{Re_{model}}\right)^{-0.2}\right]$$

Here the "model" fan is taken to be a 2 meter fan operating at 9kW with an impeller total efficiency that would be required to match the 2018 requirements. The obtained results can then be directly compared to the proposed requirements.

D_{fan}	**P**	**Re/Re_m**	**2018**	
[m]	**[kW]**		**total**	
2	9	1	78.9	"Model fan"
3	20	1,5	79.7	
4	35	2	80.3	
5	55	2,5	80.7	
6	80	3	81.0	
7	110	3,5	81.2	
8	140	4	81.5	
9	180	4,5	81.6	
10	220	5	81.8	
11	270	5,5	81.9	
12	320	6	82.1	

Table 4: Estimated effect of Reynolds number on fan efficiency (using Ackeret)

For comparison the results obtained from applying Ackeret's formula and the proposed efficiency values for P>10kW (2018) are shown together in the following graph.

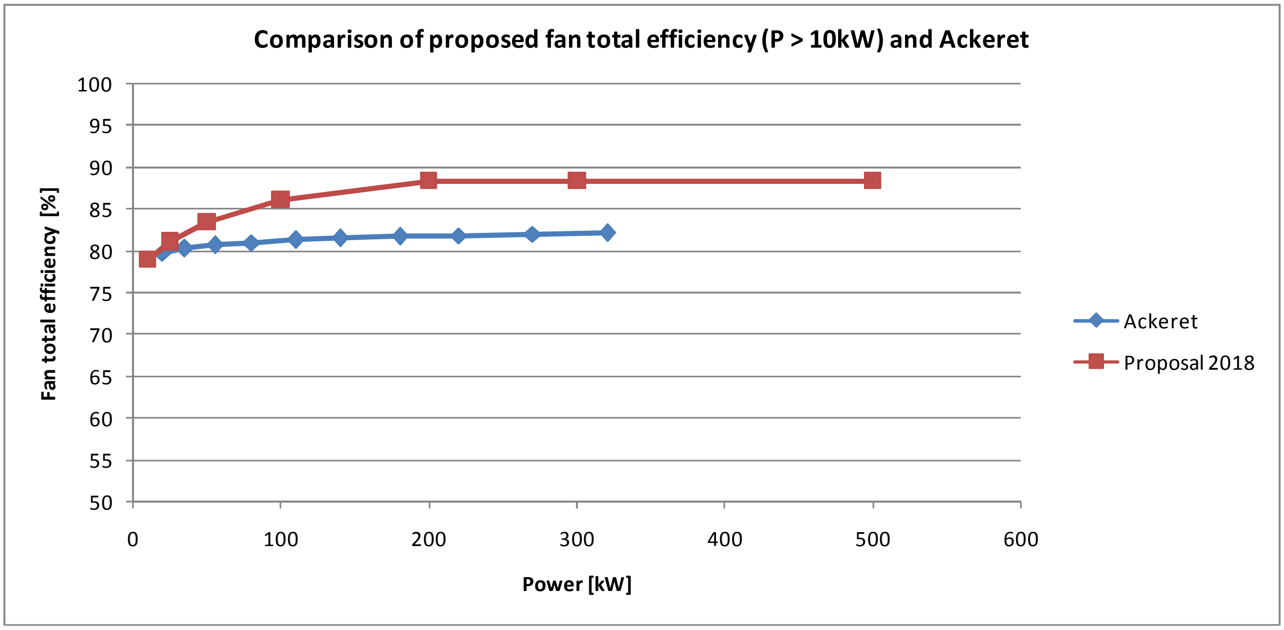

Figure 1: Comparison of fan efficiencies based on Ackeret and proposed requirements for 2018

The comparison clearly shows that the proposed increase in required fan efficiency for fans with a drive power of more than 10kW is too steep. As can be seen in figure 1 and from the results in table 4 the difference in Reynolds numbers leads to an estimated efficiency increase in the order of 4% between 10kW and 200kW. The currently proposed increase in required minimum efficiency between 10kW and 200kW is in the order of 10%.

This is a clear indication that the proposed efficiency curve for P>10kW is far too steep.

Low noise cooling fans

The factor that has by far the biggest influence on fan noise is the fan operating speed. The basic design principle of a low noise cooling fan is therefore that this type of cooling fan can achieve a certain air volume flow rate and pressure rise at a relatively low fan operating speed. This strategy has led to fan designs that generate substantially less noise compared to traditional fan designs. This design strategy does however have a downside, the static efficiency of a low noise fan is inherently lower. This can be made insightful by looking at (a simplified form of) Euler's equation for turbo machinery:

$$\Delta p_{total} = \rho u \Delta c_u$$

Δp_{total}	*Total pressure rise*	*[Pa]*
ρ	*Air density*	*[kg/m^3]*
u	*Blade velocity*	*[m/s]*
Δc_u	*Change in tangential air velocity*	*[m/s]*

For rotor-only fans under swirl-free inlet conditions this means that to achieve the same total pressure rise a fan running at a lower operating speed will need to generate a higher tangential air velocity component (generate more swirl) at the fan outlet than a fan running at a higher operating speed.

This illustrates the classic trade-off one needs to make between efficiency and noise. If a highly efficient cooling fan is required one typically ends up with a fan with narrow chord blades at a low blade angle setting which operates at high operating speed. This will give a very efficient yet noisy fan. If fan noise is the main issue one should use a fan with forward swept large chord blades set at a relatively large blade angle running at a low operating speed.

If no provision is made to adjust the minimum efficiency requirements for low noise fans this will mean that these fans are no longer allowed to be sold on the EU market. This would mean that customers would need to fall back on standard fan designs and would need to use noise dampers and other noise attenuating methods to avoid noise issues. These dampers add a significant amount of resistance to a cooling system which then leads to a significant increase in overall fan power consumption.

This last item is in fact the main selling point of these low noise fan designs. Very often the energy consumption of a unit employing a low noise fan is equal to or even lower than the energy consumption of the same application using a standard fan type combined with noise dampers.

It is important to note that in the current proposal a definition for "stator" is included that would further damage the position of low noise fan types.

Quote from proposal document:

*" 'Stator' is the stationary part of the fan which interacts with the air stream passing through the impeller and, within the geometrical air-stream envelope between defined fan inlet- and outlet sections, **includes any part that may increase**, and **excludes any non-fan component that may decrease**, the fan efficiency, following manufacturer's instruction. For compliance testing the physical component that contain the stator may be Instead of the stator-component that is part of the product placed on the market, the manufacturer may use a geometrical equivalent"*

This loop hole will lead to a situation where the stated efficiency of a standard fan will be as determined without any noise attenuation. The actual efficiency of this fan will be significantly lower due to the noise dampers that will be required to keep the fan within site noise requirements. The final result of all this will often be an increase in net power consumption compared to a situation where a low noise fan is used without the need for dampers.

Also note that these fans are sold mainly within Europe due to the very strict requirements on noise and the high population density.

Example case study low noise fans: Fan retrofit power plant
A highly illustrative example of the effect of low noise fans can be shown using the following case study involving a fan retrofit on a power plant.

4x 345 MW combined-cycle power plant
4x 10 cell hybrid cooling tower

Figure 2: Pictures of noise driven fan retrofit project

The fans used in the cooling tower were of a standard design and each fan unit was equipped with a noise damper due to strict noise restrictions. The goal of the retrofit was to increase cooling capacity (more air flow) without increasing plant noise emissions. This was achieved by removing the dampers and installing a low noise fan type.
The results of this retrofit project are shown in table 5.

	Standard fan type	Low noise fan type	
Air volume flow rate	465	500	[m^3/s]
Fan static pressure	163	147	[Pa]
Fan speed	90	90	[rev/sec]
Fan shaft power	122	133	[kW]
Fan static efficiency	62	55	[%]
Fan sound power level	101.3	93.7	[dB(A)]
Sound reduction due to dampers	7	-	[dB(A)]
Resulting sound power level	94.3	93.7	[dB(A)]
Performance of standard fan (with dampers) scaled to 500 m^3/s			
Air volume flow rate	500		[m^3/s]
Fan static pressure	188		[Pa]
Fan static efficiency	62		[%]
Fan shaft power	151		[kW]

Table 5: Final results noise drive fan retrofit project

Note that to achieve the same increase in air volume flow rate with the standard fans in combination with the dampers would require a higher fan shaft power than the low noise fan due to the additional resistance caused by the dampers.

HNL proposal regarding low noise fans
HNL strongly believes that a revision of the current regulation must not lead to a situation where low noise fan designs are banned from the EU market. The benefits these fan design offer with regard to their noise characteristics outweighs their lower efficiency figures.

HNL proposes a compensation for low noise fans of 10 percentage points with regard to the minimum required efficiency. Where low noise fans are defined as a fan having a characteristic noise emission value C ≤ 32 dB(A).

Where [2, 3]:

$$C = PWL_{impeller} - 30\log u_{tip} - 10\log\frac{Q\,FSP}{1000} + 5\log D_{impeller}$$

C	*Characteristic noise emission value*	*[dB(A)]*
$PWL_{impeller}$	*Impeller sound power level*	*[dB(A)]*
u_{tip}	*Impeller tip speed*	*[m/s]*
Q	*Air volume flow rate*	*[m^3/s]*
FSP	*Fan static pressure*	*[Pa]*
$D_{impeller}$	*Impeller diameter*	*[m]*

At the very least a revision of the current regulation should not be allowed to create an uneven playing field in which excellent low noise fan designs are banned from the market in favour of less suitable fan types. Such a situation would actually lead to the exact opposite of the intended purpose of the regulation; reduction of energy usage.

Effect of proposed minimum values static efficiency on HNL product range
In the graph below the minimum static efficiency requirements for 2015 and the proposed requirements for 2018 and 2020 are shown together with the overall static efficiencies of HNL fans.

The fan efficiencies for the HNL fans have all been calculated using:

- Known impeller static efficiencies
- Motor efficiency taken as nominal minimum efficiencies for IE3 efficiency level (50 Hz) EU regulation 640 (4 pole motor).
- Transmission efficiency 98%
- Component matching 0.9

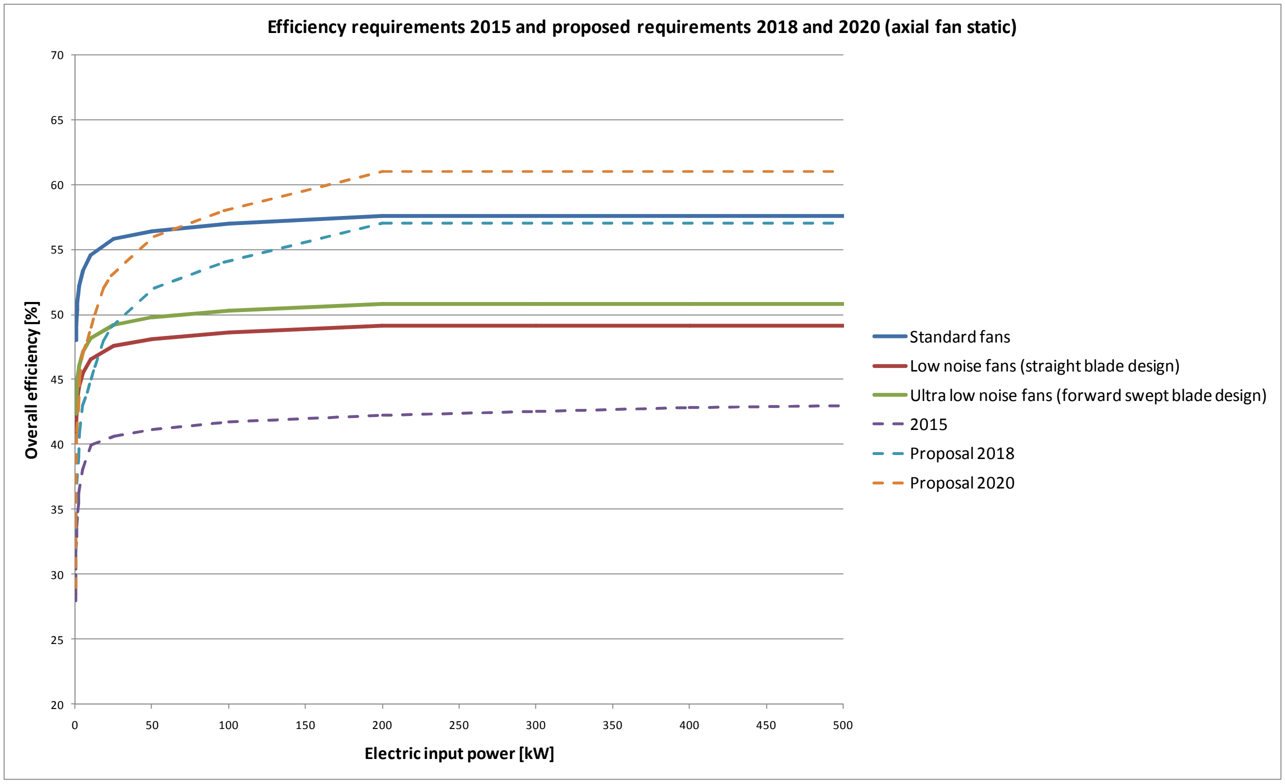

Figure 3: Comparison of proposed minimum requirements on fan static efficiency and HNL product range

The graph shows that with these proposals nearly the entire low noise product range will be cut off in 2018 with the rest of the fans being cut off in 2020. This cannot be the intended effect of this regulation.

References

[1] ISO 5801 Industrial fans - Performance testing using standardized airways
[2] EU commission BREF: Integrated Pollution Prevention and Control (IPPC) Reference document on the application of best available techniques to industrial cooling systems, December 2001.
[3] Spek H. van der, 1993, CTI TP93-03 "Reduction of Noise Generation by Cooling Fans"