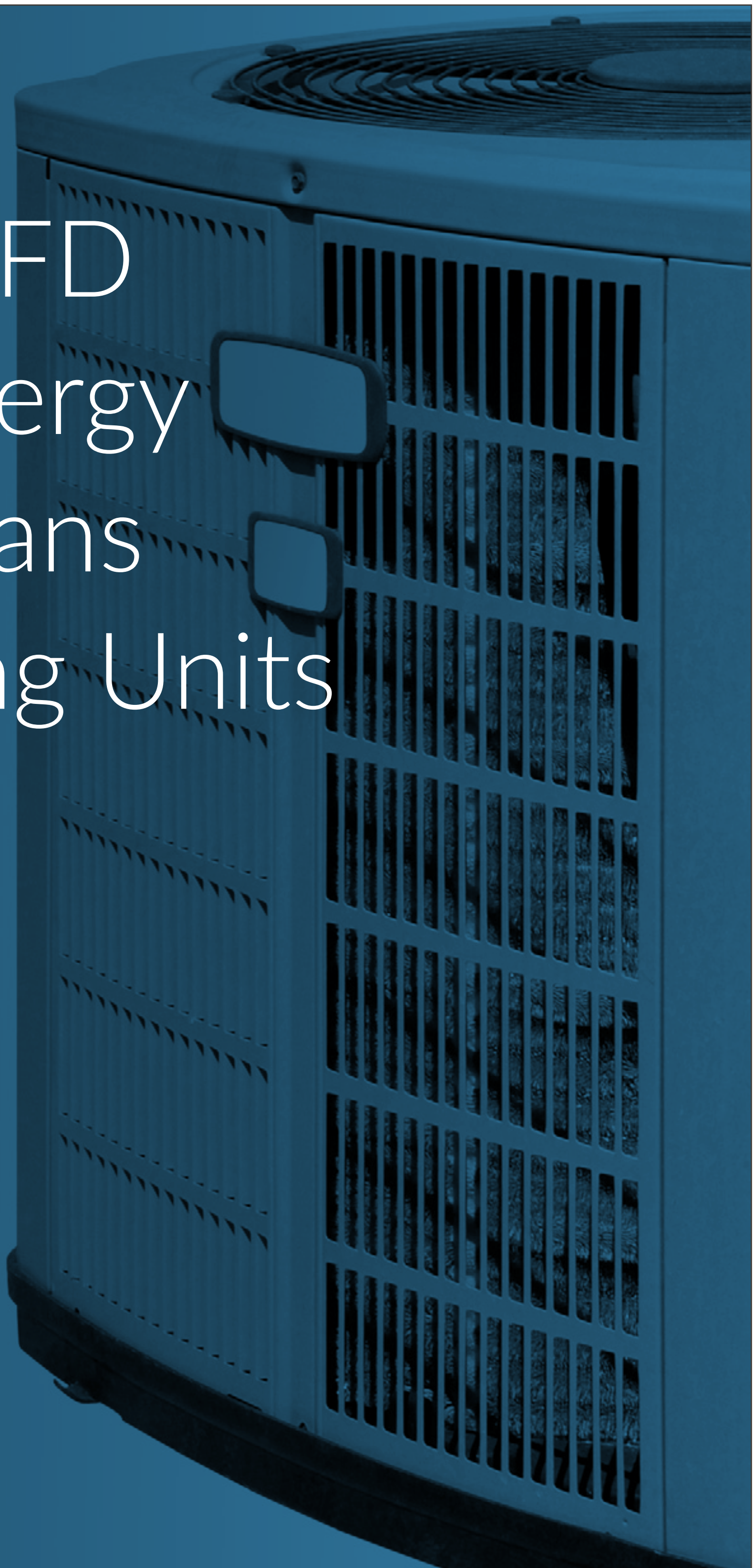
How to Use CFD to Improve Energy Efficiency of Fans for Air Handling Units



Using CFD simulations to analyze and improve HVAC systems.

WhitePaper

SIMSCALE

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How to Use CFD to Improve Energy Efficiency of Fans for Air Handling Units

Energy efficiency of HVAC systems is significantly dependent on fans installed in Air Handling Units (AHUs). According to one estimate, fans account for 8% of total electric power consumption in residential buildings and 17% of total electric power consumption in commercial buildings. For a country like Germany, for example, this means something like 10 TWh of electricity for households and 23 TWh of electricity for commercial buildings, just to run fan motors during a year. The US DOE study has indicated that the potential to save electricity for running fans for AHUs is huge – 81% for domestic consumption and 72% for commercial consumption.

Considering the example for Germany, there is a saving potential of approximately 8 TWh and 16 TWh (total 24 TWh) of electricity for domestic and commercial consumers respectively. Out of the total 24 TWh saving potential, around **40%** may come from proper selection of motors and controls, more than **50%** comes from blade, housing, and fan system design while 2-3 % can be achieved through proper servicing and maintenance during operating life of AHUs.

The question arises – How to tap into this huge energy saving potential. The answer comes partially from the specifications and guidelines conceived in **Commission Regulation (EU) No 327/2011** on fans driven by electrical motors and the **Commission Regulation (EC) No 640/2009** on electrical motors. Additionally, the **Ecodesign directive 2009/125/EC** establishes the overall framework for the setting of community eco-design requirements. This directive is part of the 20-20-20 target setting requirements which energy-related products like fans should meet so that energy consumption can be reduced by 20% and the share of renewable energies increase by 20% by 2020. The principles adapted by the EU are also recognized by the **ISO standard 12759**.

Once we have learnt the requirements from referred EU regulations then comes the step to implement these in our designed systems and certify / report compliance. In EU regulations minimum efficiency requirements have been defined in the perspective of the overall efficiency of the fan, motor and driving arrangement. Thus in order to achieve regulatory compliance, both the fan and motor directives need to be implemented and testing needs to be carried out to determine that the relevant minimum efficiency requirements have been met.

1. U.S. DOE / BTO – Pump & Fan Technology Characterization and R&D Assessment (October 2015)

2. https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts - calculated from values given for Households (residential) and Public Facilities plus Trade and Services (commercial)

3. U.S. DOE / BTO – Pump & Fan Technology Characterization and R&D Assessment (October 2015)

Problem

Under the EU Fan regulation requirements guideline starting from 1st January 2015, designing fans for AHUs call for meeting target energy efficiency (defined in table reproduced below from the Commission Regulations). It is understandable that getting fans for AHUs certified to meet desired specifications through rigorous testing is an essential step before assembly production can start. These requirements vary depending upon both fan type, measurement category for the fan power and the electrical power consumed as tabulated below.

Fan types	Measurement category (A-D)	Efficiency category (static or total)	Power range P in kW	Target energy efficiency	Efficiency grade (N)
Axial fan	A, C	static	$0,125 \le P \le 10$	$\eta_{target} = 2,74 \cdot \ln(P) - 6,33 + N$	40
			$10 < P \le 500$	$\eta_{target} = 0,78 \cdot \ln(P) - 1,88 + N$	
	B, D	total	$0,125 \le P \le 10$	$\eta_{target} = 2,74 \cdot \ln(P) - 6,33 + N$	58
			$10 < P \le 500$	$\eta_{target} = 0,78 \cdot \ln(P) - 1,88 + N$	
Centrifugal forward curved fan and centrifugal radial bladed fan	A, C	static	$0,125 \le P \le 10$	$\eta_{target} = 2,74 \cdot \ln(P) - 6,33 + N$	44
			$10 < P \le 500$	$\eta_{target} = 0,78 \cdot \ln(P) - 1,88 + N$	
	B, D	total	$0,125 \le P \le 10$	$\eta_{target} = 2,74 \cdot \ln(P) - 6,33 + N$	49
			$10 < P \le 500$	$\eta_{target} = 0,78 \cdot \ln(P) - 1,88 + N$	
Centrifugal backward curved fan without housing	A, C	static	$0,125 \le P \le 10$	$\eta_{target} = 4,56 \cdot \ln(P) - 10,5 + N$	62
			$10 < P \le 500$	$\eta_{target} = 1,1 \cdot \ln(P) - 2,6 + N$	
Centrifugal backward curved fan with housing	A, C	static	$0,125 \le P \le 10$	$\eta_{target} = 4,56 \cdot \ln(P) - 10,5 + N$	61
			$10 < P \le 500$	$\eta_{target} = 1,1 \cdot \ln(P) - 2,6 + N$	
	B, D	total	$0,125 \le P \le 10$	$\eta_{target} = 4,56 \cdot \ln(P) - 10,5 + N$	64
			$10 < P \le 500$	$\eta_{target} = 1,1 \cdot \ln(P) - 2,6 + N$	
Mixed flow fan	A, C	static	$0,125 \le P \le 10$	$\eta_{target} = 4,56 \cdot \ln(P) - 10,5 + N$	50
			$10 < P \le 500$	$\eta_{target} = 1,1 \cdot \ln(P) - 2,6 + N$	
	B, D	total	$0,125 \le P \le 10$	$\eta_{target} = 4,56 \cdot \ln(P) - 10,5 + N$	62
			$10 < P \le 500$	$\eta_{target} = 1,1 \cdot \ln(P) - 2,6 + N$	
Cross flow fan	B, D	total	$0,125 \le P \le 10$	$\eta_{target} = 1,14 \cdot \ln(P) - 2,6 + N$	21
			$10 < P \le 500$	$\eta_{target} = N$	

**** Table Reproduced from Commission Regulation (EU) No 327/2011*

Calculating Target Energy Efficiency

Referring to the table above, calculations are pretty simple as provided below for Axial and Centrifugal (Backward curved fan without housing).

For 5 KW Axial Fan,

Static η_{target} = 2.74 x ln (5) – 6.33 + 40 = **38.08 %** *(Measurement Category A & C)*

For 5 KW Centrifugal backward curved fan without housing,

Static η_{target} = 4.56 x ln (5) – 10.5 + 62 = **58.84 %** *(Measurement Category A & C)*

"N" (in the example above N=40 for axial fan and N=62 for centrifugal backward curved fan) is a parameter used by EU directive equation to identify optimum energy efficiency point of a fan of specific type and electric input power.

Understanding η and determining accurate measurement of ηtarget

Referring to terms used in the above table, fan total efficiency $\boldsymbol{\eta_{total}}$ is defined as $Power_{output}$ divided by $Power_{input}$. Where $Power_{output}$ is the static pressure generated plus the dynamic power created through flow and Powerinput are the electricity consumed in watts. More specifically

$Power_{output}$ (watts) = Air pressure (Pascals) x Air Flow (m^3 / sec) ***Metric Units***

$Power_{output}$ (watts) = (Static Air pressure (in of H_2O) x Air Flow (cfm))/8.5 ***Customary Units***

$\eta_{total} = Power_{output} / Power_{input}$

$\eta_{static} = Power_{static\ pressure} / Power_{input}$ (when only static pressure is considered)

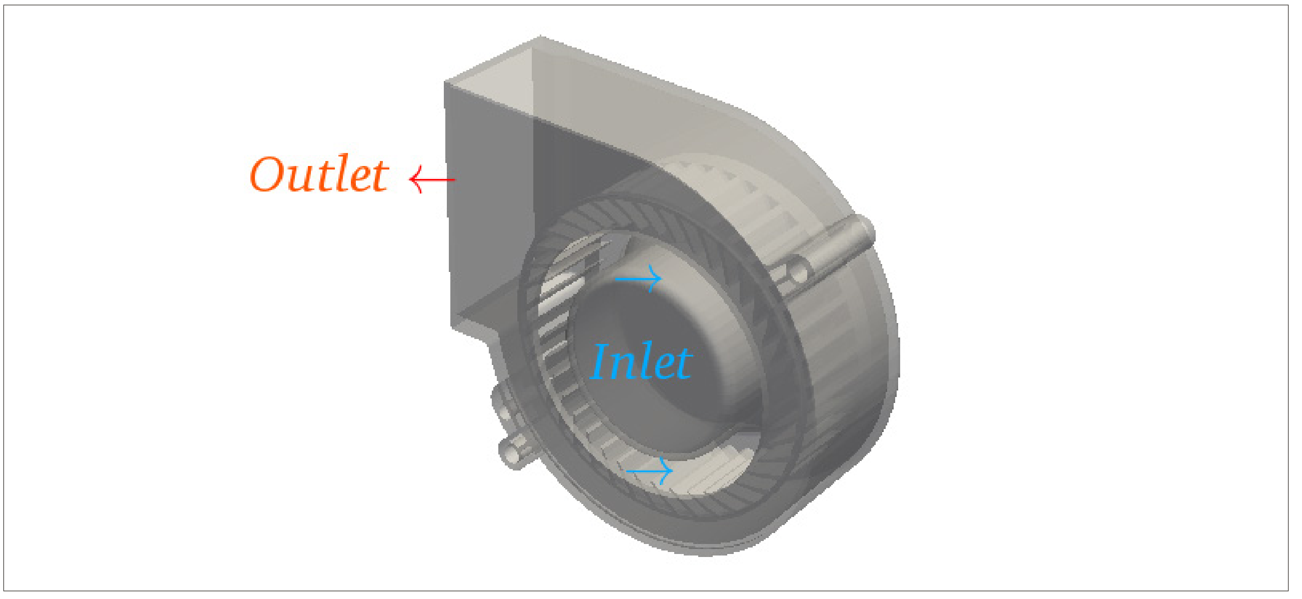
Solution for today's AHU Design Engineer

The testing, documenting, and certification processes for parameters briefly described above are really expensive and time consuming when we follow the conventional engineering approach of Design - Build - Test - Redesign.

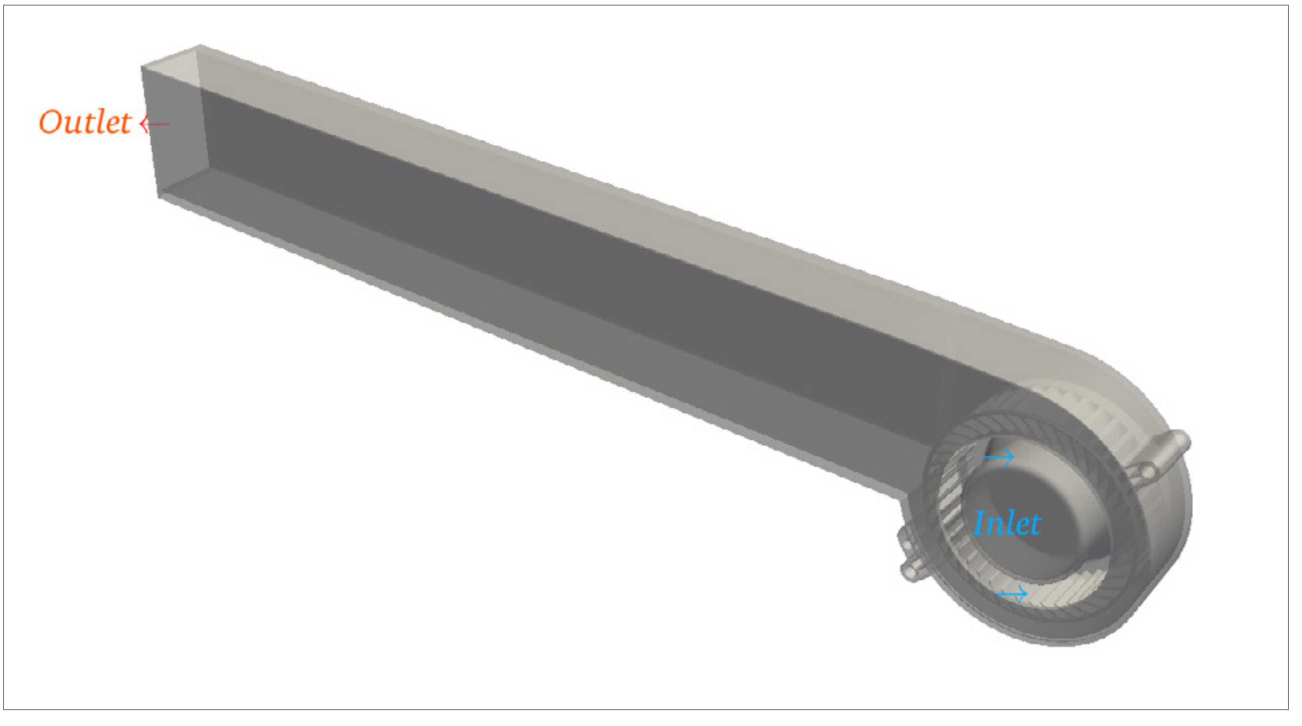
The solution to reduce time, energy, and resource consumption is to perform CFD simulation of designed fans through a software capable of implementing transient analyses. With Computational Fluid Dynamics (CFD), you can analyze the design under varied conditions to optimize before actual prototyping, which result in significant reduction in R&D costs. Making things even easier, the SimScale simulation software is 100% cloud-based, which means you only need a normal computer and Internet connection to perform complex CFD simulations. From CAD model upload to post-processing, everything happens in the browser.

The EU directive provides four measurement categories which identify test, measurement or usage arrangement for inlet and outlet conditions of the fan under test. All these conditions can be easily simulated with CFD, as described in the project done with SimScale:

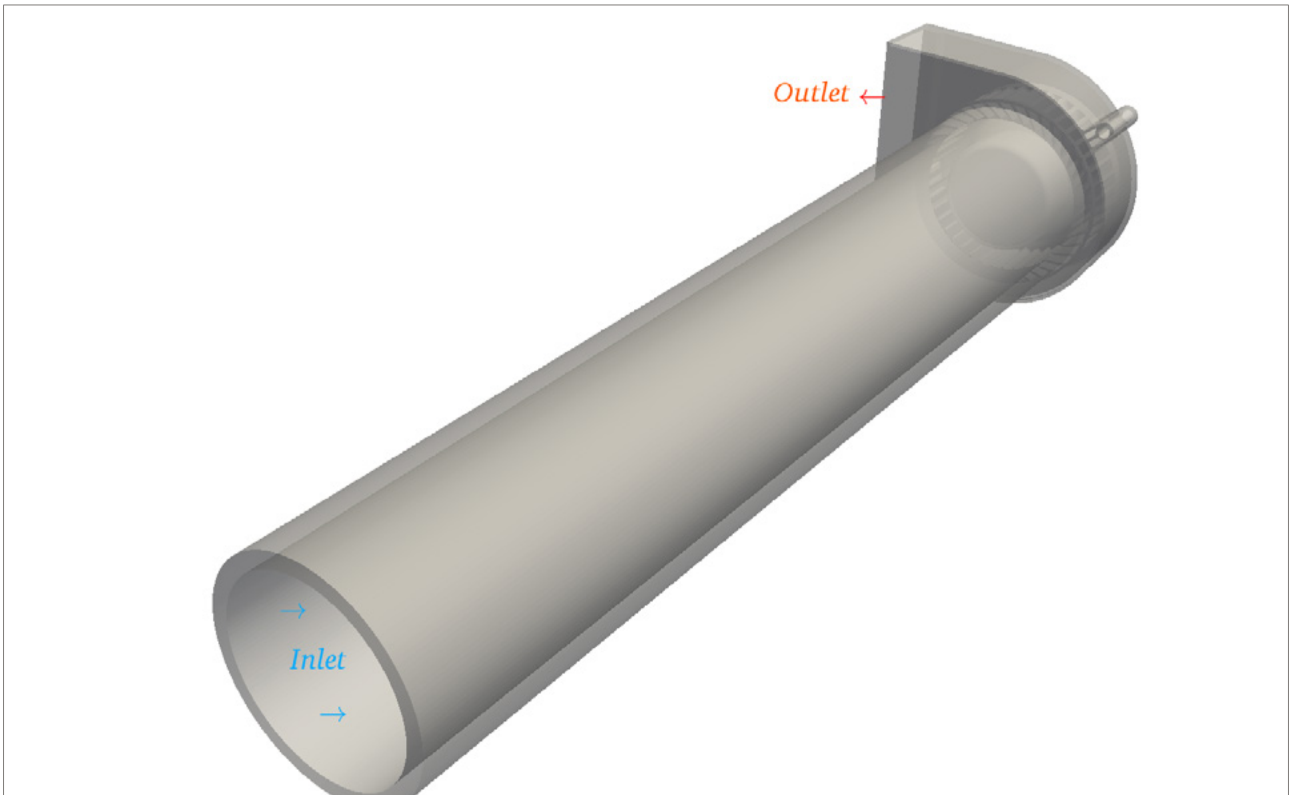
1. 'Measurement category A' means an arrangement where the fan is measured with free inlet and outlet conditions.



2. 'Measurement category B' means an arrangement where the fan is measured with free inlet and with a duct fitted to its outlet.

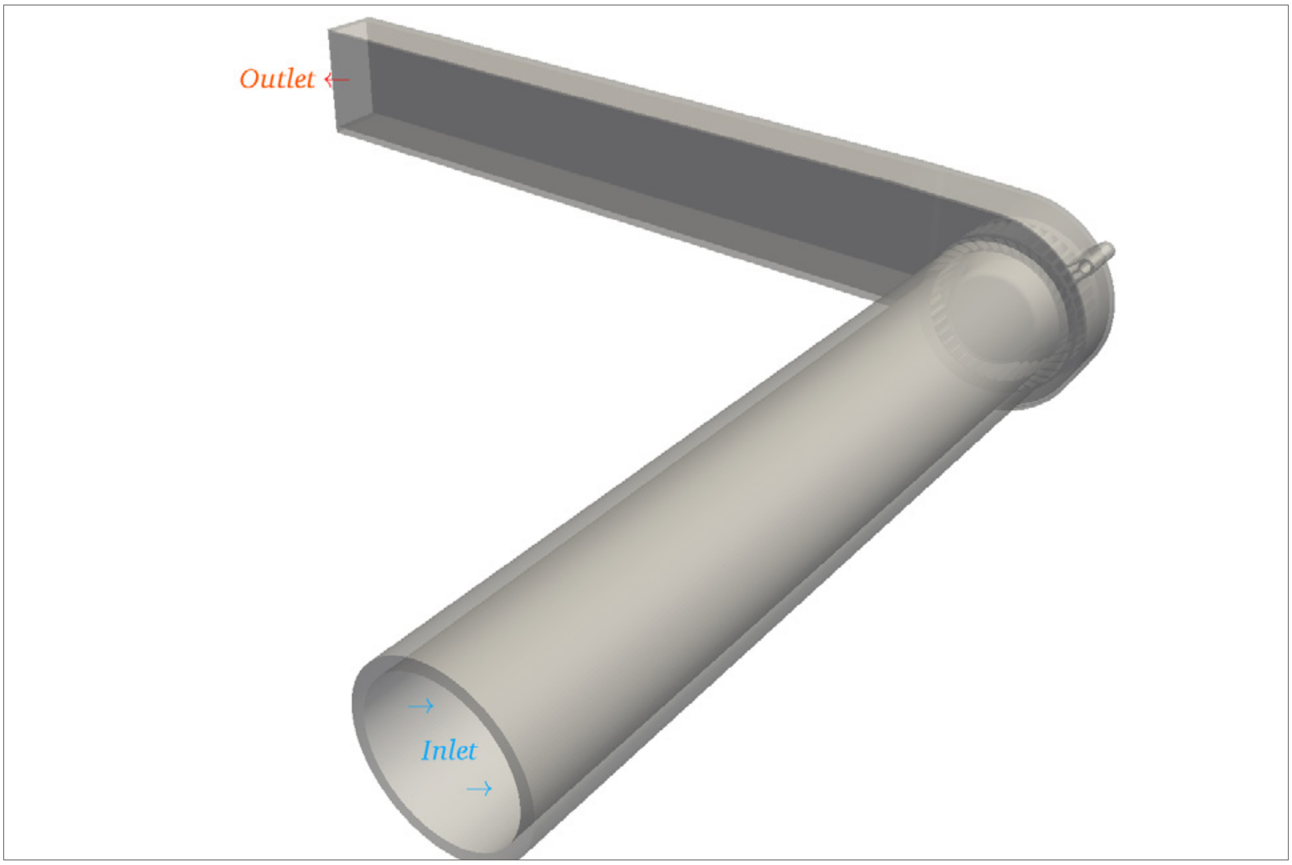


3. 'Measurement category C' means an arrangement where the fan is measured with a duct fitted to its inlet and with free outlet conditions.



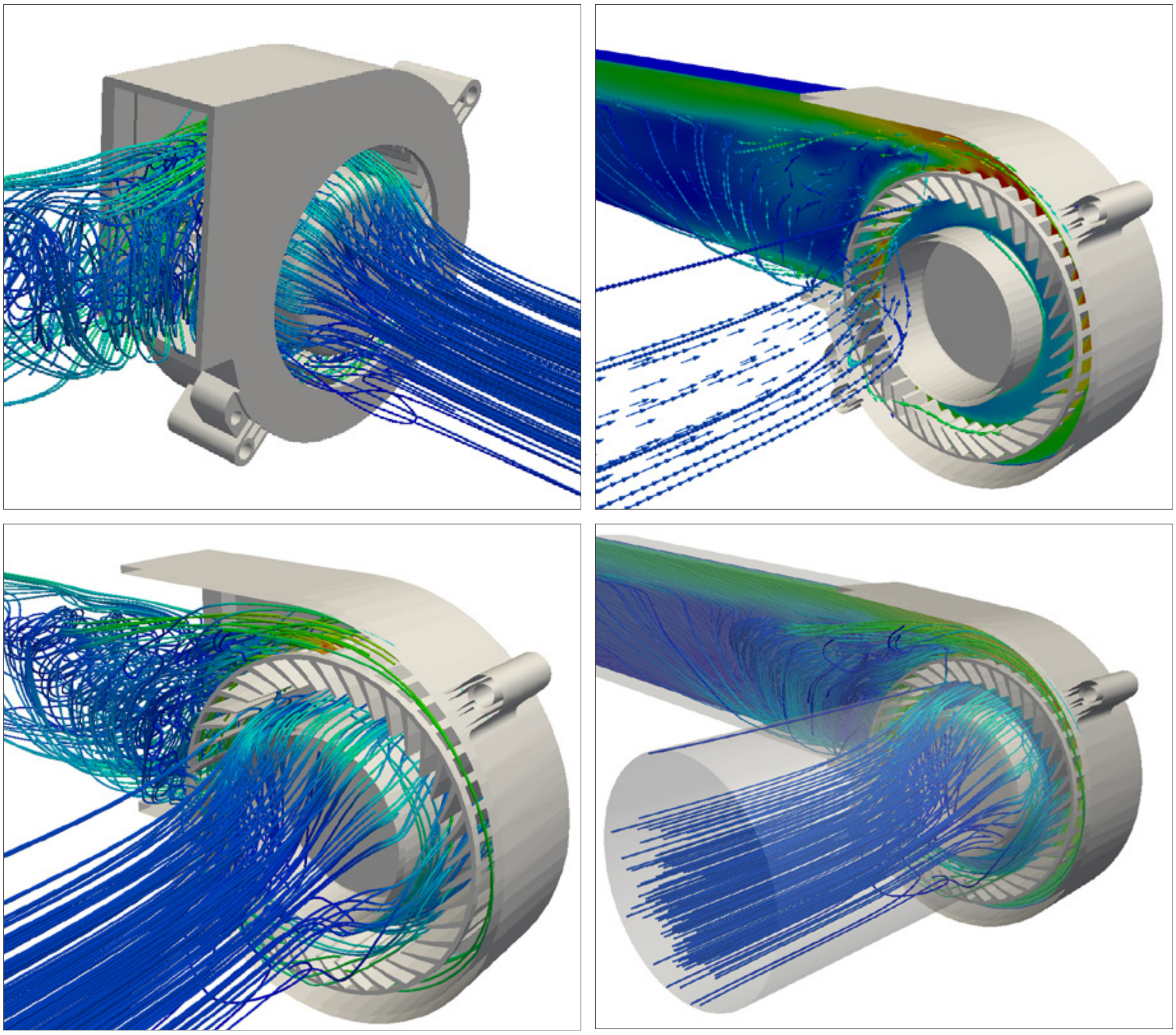
(inlet duct not visible in figure)

4. 'Measurement category D' means an arrangement where the fan is measured with a duct fitted to its inlet and outlet.



For implementing the above four measurement categories identified by the EU directive, HVAC design engineers involved in improving energy efficiency of air handling units have two options. First is the customary approach and a costly one involving designing, prototyping, testing, measuring, documenting and redoing the entire exercise to improve results.

The second option is to design and obtain the output parameters involved in the determination of fan energy efficiency (or AHUs) through engineering simulation, especially CFD. Below you can see the post-processing images of the fourth measurement category, performed with the SimScale cloud-based platform. As it can be seen, the images show the plots of velocity and streamlines in order to visualize the flow.



SimScale give engineers the opportunity to try simulation technology completely for free through the Community plan, which gives access to all the platform's features to be used for public projects and a CAE community of 70 000 engineers open to help. After testing and evaluating it, the subscription of 2000 EUR / year grants access to 3000 computing cores for private projects and dedicated support. Using such software enables design engineers to achieve the required energy efficiency improvements of fans for air handling units as well as necessary regulatory compliance without resorting to the expenditure of capital resources, valuable time, and environment degradation involved in testing and optimizing designs.

The figures above show the CAD model of a fan for AHU which is simulated for the determination of static pressure, total pressure as well as flow under all of the four measurement categories defined in EU directives. The **Static** $\boldsymbol{\eta}_{\textbf{target}}$ as well as **Total** $\boldsymbol{\eta}_{\textbf{target}}$ can be easily determined from the results provided in this fan design simulation which will also help you understand the methodology involved.

Bibliography:

1. U.S. DOE / BTO – Pump & Fan Technology Characterization and R&D Assessment (October 2015)

2. https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts
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