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Optimizing Energy Efficiency and Performance in AHUs: Study on Performance of EC Fan with Spiral Guide Vane#

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ABSTRACT

As a core component of Heating, Ventilation, and Air Conditioning (HVAC) systems, the Air Handling Unit (AHU) significantly contributes to energy consumption. With the increasing demand for reduced carbon emissions and enhanced energy efficiency, optimizing the performance of fans within AHUs to lower energy usage has become a primary focus of research. This study aims to investigate the optimal fan type and combination format that can promote higher performance in AHUs. Firstly, groups of experiments were conducted to evaluate the performance of the Electronically Commutated (EC) fans equipped with spiral guide vanes and conventional EC fans. Secondly, fluid dynamic models of these fans' applications in AHU were developed and simulated through Computational Fluid Dynamics (CFD). Finally, the performances comparisons were carried out among AHUs using EC fans with spiral guide vanes and those using traditional EC fans with different layouts. Results revealed that the EC fan with spiral guide vanes exhibited higher energy efficiency, lower energy consumption, and greater pressure head compared to conventional EC fans with the same blade design and dimensions. Furthermore, an array configuration of EC fans with spiral guide vanes generated fewer vortices in the AHU air channel. The pressure loss regions were reduced so that the air velocity in the AHU outlet was increased. Therefore, the selected fans in an array arrangement are more efficient to overcome air flow resistance in an AHU, simultaneously reducing its energy consumption. These findings provide valuable insights into the potential benefits of employing spiral guide vane technology to enhance the energy efficiency and operational performance of AHUs.

Keywords: Electronically commutated fan; Spiral guide vane; Air handling unit; Fan unit configuration; Efficiency improvement.

NONMENCLATURE

Abbreviations	
AHU	Air Handling Unit
CFD	Computational fluid dynamics
EC	Electronically Commutated
HVAC	Heating, Ventilation, and Air Conditioning

1. INTRODUCTION

In modern Heating, Ventilation, and Air Conditioning (HVAC) systems, Air Handling Units (AHUs) play a crucial role in maintaining air quality and thermal comfort. However, their significant energy consumption has prompted ongoing research into optimizing fan performance within AHUs. Fans, particularly Electronically Commutated (EC) fans, are vital in maintaining air circulation within these units. Improving their efficiency could substantially reduce energy use, which aligns with global efforts to reduce carbon emissions [1].

One promising approach is the integration of spiral guide vanes into EC fans. These vanes are designed to streamline airflow, reduce turbulence, and enhance overall performance [2]. While the impact of fan size, shape, and configuration on efficiency has been widely studied, the potential benefits of spiral guide vanes are not yet fully understood.

This paper investigates the performance of EC fans equipped with spiral guide vanes compared to conventional EC fans. Through both experimental testing and Computational Fluid Dynamics (CFD) simulations, the study aims to evaluate the effects of these guide vanes on power consumption, pressure head, and energy

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efficiency within AHUs. The findings are expected to provide valuable insights into fan selection and configuration for enhanced energy savings in HVAC applications.

2. RESEARCH METHODOLOGY

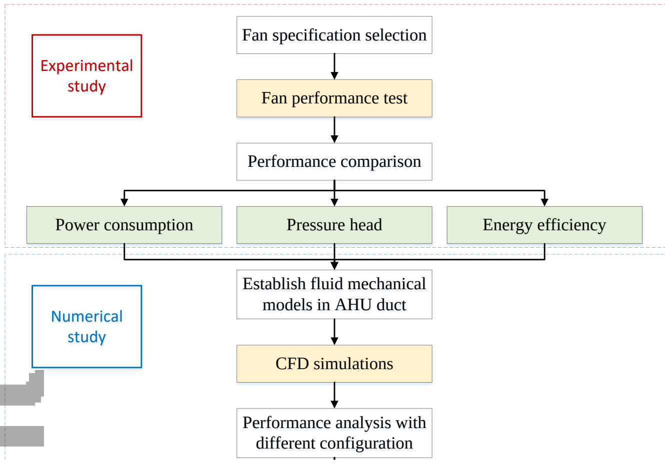


Fig. 1 The research flow chat

The research process for this study is illustrated in Figure 1. To compare the performance differences between EC fans with and without spiral guide vanes, four different EC fan configurations were selected (Figure 2): one equipped with spiral guide vanes, one without spiral guide vanes but of the same size, one with a novel blade shape of the same size, and one with a different blade size. The performance of these four fans was then tested using the fan test unit at The Hong Kong Polytechnic University. The key parameters compared included power consumption, pressure head, and energy efficiency [3].

Fig. 2 Photos of the four EC fans tested in this study (Fan A, B, C, D from left)

Following the experimental tests, a simplified fluid dynamics model of the fans and a simplified model of the AHU duct were developed based on the test results and the structural parameters of the fans. CFD simulations were then conducted to analyze the performance of different fan arrangements within the duct, comparing the performance differences between multiple fan configurations with varying structures [4]. This study aims to provide guidance for the application of fans with spiral guide vanes in AHUs and contribute to energy savings in HVAC systems.

As shown in Figure 3, in the chamber there are 3 numbers of identical nozzles with dimensions as shown in the figure (the diameter of each nozzle is 200mm). While the outlet pressure is set to atmospheric pressure, the fan's ability to generate pressure rise can still be evaluated based on the measured pressure difference between the inlet and outlet of the fan. Positioning the fan at the exit of the system allows for a more realistic evaluation of fan performance, including factors such as pressure rise, airflow rate, and overall energy efficiency. Two DP-Calc™ micromanometers will be used as shown in Figure 6 for static pressure measurements. The data to be collected for each fan test includes input power, static air pressure at plane 5, and pressure difference from planes 3 and 4.

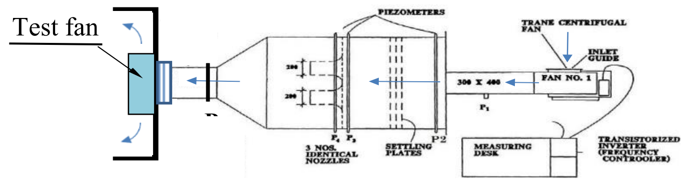


Fig. 3 Test fan and sensor locations on the Fan Test Unit

Fig. 4 Measuring instruments (from left to right: micromanometer, tachometer and power meter)

3. NUMERICAL SETUP

3.1 Modeling and meshing

To investigate the flow field characteristics of fans with and without spiral guide vanes within an AHU duct, physical models of Fan A and Fan D were developed using SolidWorks 2020. A physical model of the AHU duct was also constructed. Since the performance curves of each fan had already been obtained experimentally, and the goal of the CFD simulation was to study the impact of the fans on the flow field within the AHU duct, the physical models of Fan A and Fan D were simplified. This simplification allowed for significant reductions in computational cost while still accurately predicting the flow field characteristics in the AHU duct.

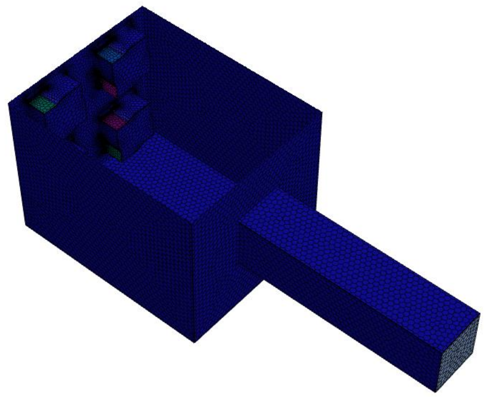


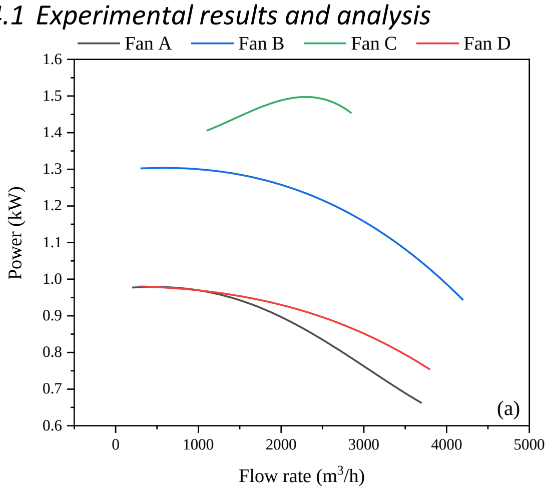
Fig. 5 The final mesh generation of the AHU and fans model

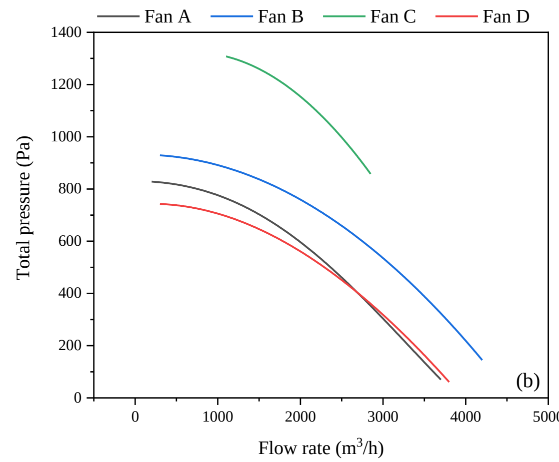
After completing the modeling, the physical models were imported into Ansys Fluent Meshing 2020 for mesh generation Figure 5 shows the mesh generation for the fans and the AHU duct. Polyhedral elements were used for the mesh generation in this study. Compared to tetra or prism meshes, polyhedral meshes were found to be more suitable for the model arrangement, offering higher computational accuracy [5]. Additionally, different mesh resolutions were applied to various parts of the fluid domain. The mesh near the fan outlets was refined to ensure high computational accuracy, while the mesh resolution in regions far from boundaries was kept lower to avoid unnecessarily long computation times [6].

To minimize the uncertainty introduced by mesh generation in the numerical simulations, a mesh independence analysis was conducted. Five different meshing schemes were compared by examining the total pressure at the duct outlet. The results indicate that once the mesh count exceeded 200.4 thousands, changes in total pressure became negligible. Therefore, a mesh scheme with 200.4 thousands elements was selected for this study.

4. RESULTS AND DISCUSSION

4.1 Experimental results and analysis





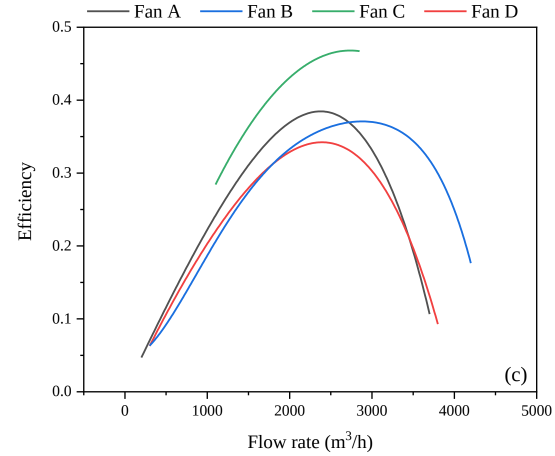


Fig. 6 Variations of fan power, total pressure, and efficiency with flow rate at 3500 r/min

Figure 6 show the trends of power, total pressure and efficiency of the four fans at rotation speed of 3500 r/min with varying flow rates after curve fitting. In general, the trends of four fans are very similar. Specifically, the power of Fan A (with spiral guide vanes) and Fan D (without spiral guide vanes) continuously decreases as the flow rate increases. The power consumption of Fan A is the lowest among the four fans in most cases, although it is slightly higher than Fan D in the low flow range. The pressure produced by Fan A is higher than that of Fan D in most ranges, but only slightly lower than Fan D when the flow rate exceeds 2700 m³/h. The corresponding efficiency values of Fan A are only slightly lower than those of Fan D when the flow rate exceeds 3400 m³/h. Besides, the maximum efficiencies of the fan with spiral guide vanes are 12.4% to 15.8% higher than the one without spiral guide vanes (Fan D). Therefore, it can be demonstrated that guide vanes can reduce the power consumption of the fan while providing the same flow rate and pressure head. In other words, Fan A is more efficient in terms of energy consumption.

Fan B (with a novel blade shape) generally shows a downward trend in power consumption with increasing flow rate. In terms of pressure, Fan B provides the second highest pressure among the four fans, significantly higher than Fan A and Fan D, and outperforms Fan C at high flow rates. Regarding efficiency within the flow rate ranges, from 1500 r/min to 3500 r/min, the peak efficiency of Fan B is between that of Fan A and Fan D. In summary, among the four fans, Fan B is more suitable for high flow rate situations to achieve higher pressure and higher efficiency, which may be attributed to the new blade structure. However, this also results in higher energy consumption.

For Fan C (the EC fan with larger diameter), the power consumption is greater compared to the other three fans, which first increases and then decreases with the increasing flow rate. Within the test range, Fan C can provide higher pressure in the low flow rate range among the four fans. However, as the flow rate increases, the pressure drops the faster. Additionally, due to its impeller diameter being larger than the other three fans while efficiencies remain unchanged during the conversion process using fan laws, it possesses higher efficiency among the four fans. This is because a larger impeller can provide higher airflow and pressure, achieving the same airflow at lower speeds. Lower speeds reduce aerodynamic and mechanical losses during fan operation. After converting to the same diameter and speed as the other three fans, it can be observed that Fan C is more suitable for scenarios requiring higher pressure head at lower flow rates.

4.2 Numerical results and analysis

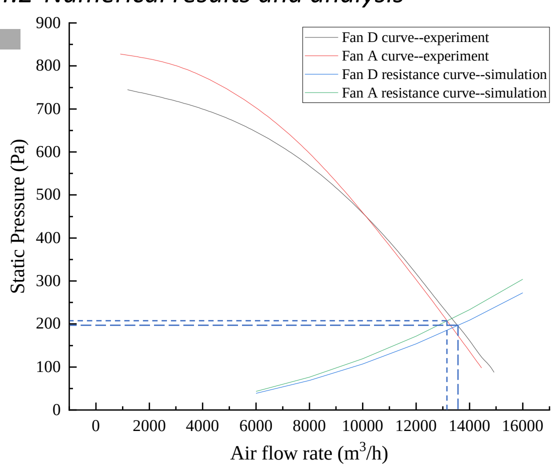


Fig. 7 Resistance curves for the AHU duct with a 2x2 fan configuration

Figure 7 shows the resistance curves for the AHU duct with a 2x2 fan configuration at a rotational speed of 3500 r/min, where four Fan A units and four Fan D units are installed. As seen in the figure, the system resistance in the AHU duct increases with airflow, and the rate of increase becomes more pronounced as the airflow grows. It is also evident that the resistance curves differ between the two fan types. At lower airflow rates, the difference in system resistance is minimal, but as the flow rate increases, the difference becomes more significant. Across all flow rates, the system resistance with Fan A is higher than that with Fan D.

For Fan A, the system resistance is 43.21 Pa at a flow rate of 6000 m^3/h, and it rises to 304.18 Pa at 16000 m^3/h. For Fan D, the system resistance is 38.72 Pa at 6000 m^3/h and 272.74 Pa at 16000 m^3/h. Several factors explain this phenomenon. First, the different system curves result from installing different fan types in the same AHU duct, as the mechanical structure of the fans alters the flow field environment within the duct. This leads to different system resistance curves. Additionally, the spiral guide vane structure on the outer blades of Fan A directs airflow at the fan outlet, while also introducing interference between fans, which increases system resistance. This phenomenon will be discussed in more detail in the flow field analysis later in the study.

By combining the fan performance curves obtained from previous experiments with the system resistance curves, the operating points of different fans within the AHU duct can be determined. From Figure 6, it is observed that Fan A reaches its operating point at a flow rate of 13,220 m^3/h, providing a static pressure of 208.03 Pa. In contrast, Fan D reaches its operating point at a flow rate of 13,601 m^3/h, with a static pressure of 197.24 Pa. This indicates that, within the same AHU duct, the system equipped with four Fan A units can achieve higher static pressure at a lower flow rate compared to Fan D. This suggests that Fan A is better suited to overcome system resistance at lower flow rates, demonstrating superior performance when multiple Fan A units are installed in the AHU compared to multiple Fan D units. Based on the experimental data, Fan A's efficiency at its operating point is 25.9%, with a power consumption of 0.717 kW. Fan D's efficiency at its operating point is 22.4%, with a power consumption of 0.807 kW. Clearly, at the operating point, Fan A not only has higher efficiency but also consumes less power, making it more energy-efficient and delivering better overall performance.

The magnitude of turbulence and the resulting energy dissipation vary in different aspects of the flow. Turbulent Kinetic Energy (TKE) distribution contours provide a more detailed understanding of turbulence intensity and its associated energy consequences. TKE is directly related to turbulence intensity and is commonly used as an evaluation metric in flow field analysis.

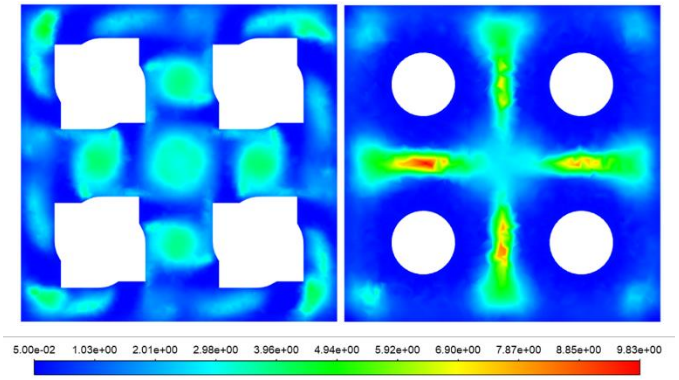


Fig. 8 Turbulent kinetic energy distribution contours on the vertical plane at the fan outlets for the ducts equipped with Fans A and D (2x2)

Figure 8 shows the TKE distribution at the vertical plane of the fan outlets in the AHU duct with Fans A and D. As seen in the figure, there is some turbulence present in the regions between the outlets of multiple Fan A units and between the fan outlets and the duct walls. However, the turbulence intensity is relatively low. This indicates that in this arrangement, Fan A effectively minimizes interference between fans, resulting in low turbulence intensity despite the presence of some vortices in the flow field. In contrast, for Fan D, the absence of the spiral guide structure leads to higher turbulence intensity between the outlets of the multiple Fan D units. This suggests a greater degree of energy loss. These findings further demonstrate that Fan A, in this configuration, outperforms Fan D in terms of efficiency, with better energy performance and reduced energy dissipation due to turbulence.

5. CONCLUSIONS

This study explored the performance of EC fans equipped with spiral guide vanes in comparison to conventional EC fans. Both experimental tests and CFD simulations revealed that the fans with spiral guide vanes demonstrated superior energy efficiency, lower power consumption, and higher pressure head. The addition of spiral guide vanes reduced turbulence and pressure loss in the air channels, resulting in improved airflow and reduced energy consumption.

The results indicated that fans with spiral guide vanes are particularly effective in array configurations, as they minimize airflow interference and turbulence, leading to enhanced overall performance in AHUs. These findings highlight the potential of spiral guide vane technology as an efficient solution for optimizing fan performance and reducing energy consumption in HVAC systems. Future work should consider expanding the scope to different fan types and configurations to further validate the benefits of this technology.

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