Energy & Buildings 165 (2018) 321–327

Contents lists available at ScienceDirect

Energy & Buildings

journal homepage: www.elsevier.com/locate/enbuild

Efficiency increase of free running centrifugal fans through a pressure regain unit used in an air handling unit

Abdul Azem[a,*], Paul Mathis[a], Frederik Stute[a], Martin Hoffmann[a], Dirk Müller[a], Georg Hetzel[b]

[a] RWTH Aachen University, E.ON Energy Research Center, Institute for Energy Efficient Buildings and Indoor Climate (EBC), Mathieustrasse 10, Aachen, 52074, Germany
[b] TROX GmbH, Heinrich-Trox-Platz, Neukirchen-Vluyn, 47504, Germany

ARTICLE INFO

Article history:
Received 9 October 2017
Revised 19 December 2017
Accepted 22 January 2018
Available online 2 February 2018

Keywords:
Air handling unit
Air transport
Centrifugal fan
Energy efficiency
Pressure drop
CFD

ABSTRACT

In this paper, a free running centrifugal fan inside a rectangular duct is investigated via measurements and CFD. A rectangular cuboid-shaped body is mounted downstream of the free running centrifugal fan, covering most of the space next to the fan wheel, leaving only a small channel for the air near the duct walls to pass through. We call this cube a 'pressure regain unit' (PRU). The cube increases the fan efficiency by reducing vortices downstream of the fan and tranfering a larger part of the kinetic energy into static pressure. Experiments are conducted with several PRU geometry variations. The measurements show that an increase in efficiency of 10% is possible compared to a free running fan in an empty duct. Subsequently, a numerical analysis is performed to analyze the effect which leads to efficiency increase. Comparing the installation with and without PRU shows that the main difference is a recirculation area behind the fan wheel when no PRU is installed. Higher level of turbulence and strong shear layers in the empty duct cause efficiency losses. The turbulence level and the amount of shear layers are reduced by the PRU. Both experimental and numerical data show an energy saving potential by optimizing the downstream region of the free running centrifugal fan.

1. Introduction

1.1. Motivation

Electricity represents a significant energy use in residential and non residential applications. Therefore, energy efficient use of electricity is an essential to save energy. About 40 % of the total energy consumption in the European Union results from the building sector, including heating, cooling and ventilation [1]. About 10 % to 15 % of this amount of electrical energy is necessary to operate the fans [2]. As the energy consumption of fans is solely based on electricity, therefore the operating costs of the fans represent a significant share of the total operating costs. In this paper a free running centrifugal fan inside a rectangular duct is investigated via measurements and computational fluid dynamics (CFD). This investigation provides an opportunity to reduce the electrical power required for the air transport and increase the energy efficiency of free running centrifugal fans.

1.2. Literature review

Anschütz [3] compared the characteristics of free running centrifugal fans with and without a rotating diffuser. His results indicated that the pressure difference and thus efficiency of the free running centrifugal fans can be increased, particularly in part load conditions. These findings have already become accepted in production of commercially available fans.

Meakhail and Park [4] investigated the flow field in a centrifugal fan in a volute shape including the interaction between the impeller and the stationary diffusor vanes. He figured out that there is a low velocity region behind the impeller blade located at the suction side and highly distorted unsteady flow between the impeller and the diffusor.

Zarschler [5] describes manufacturer's methods for developing a centrifugal fan. The goal of the development was to design a free running centrifugal fan with high efficiency. With this method an increased power density, compared to an existing impeller, was achieved by increasing the width of the impeller and the blade discharge angle.

Chunxi et al. [6] compared the influence of an enlarged impeller on the performance to the original one in a centrifugal fan.

* Corresponding author.
E-mail address: aazem@eonerc.rwth-aachen.de (A. Azem).

https://doi.org/10.1016/j.enbuild.2018.01.041

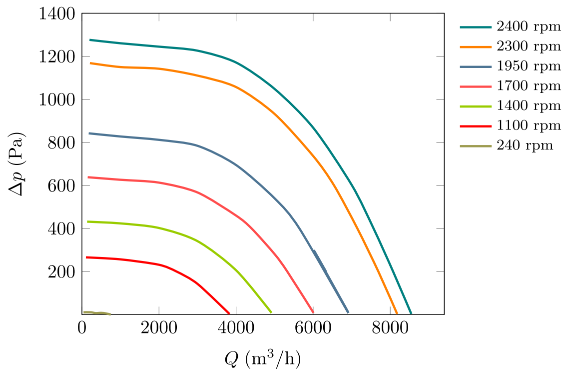

Fig. 1. Static pressure difference plotted against volume flow rate at different fan speeds. Data obtained from [11].

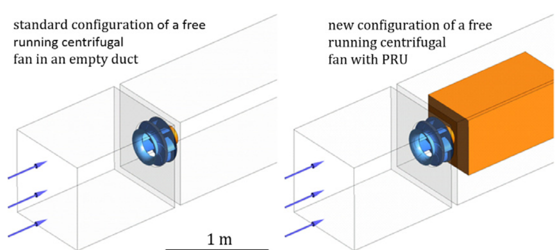

Fig. 2. Sketch of the examined setup; standard variant in an empty duct (left), with PRU (right).

He found that the shaft power and the total pressure increase, as well as the flow rate, but due to the fact that the flow distributes less uniformly in the volute, the losses increase leading to lower fan efficiency.

Bayomi et al. [7] described the effect of flow straighteners at the inlet region of centrifugal fans. Eliminating inlet distortion resulted in a small increase in static efficiency, but the performance of the fan depended mainly on the exit blade angle and the straightener's type and shape.

Ratter [8] quantified the efficiency of a free running centrifugal fan. According to him, the highest losses were at the fan outlet (16.9 %), followed by volumetric losses (7.1 %) and finally the losses of the impeller passage (4.7 %).

Wolfram and Carlous [9] investigated the velocity field at the outlet of a free running centrifugal fan with three-dimensional hot-wire anemometry and quantified the different causes of the losses. With this method, the losses could be differentiated as internal losses (11.9 % of the power supplied to the shaft) and outlet losses (19.6 % of the power supplied to the shaft).

Rong et al. [10] introduced an opportunity to improve the blade aerodynamic performance in a centrifugal fan with slots cut along the pressure side to the suction side. This technique mitigates the boundary layer separation and improves the flow field on the surface. Due to this fact no extra energy is consumed.

As a result of this literature review, we will focus our research on the fan outlet area, this area shows the greatest potential for optimization.

1.3. Problem definition

Based on above objectives, the flow in a free running centrifugal fan under realistic conditions is experimentally examined and then compared with CFD calculation results. A free running centrifugal fan type GR40C-ZID.DC.CR with the fan characteristic diagram (shown in Fig. 1 and a sketch of the setup shown in Fig. 2) is examined [11]. The left side of the examined setup shows a fan assembled in an empty duct and on the right side the new configuration with a 'pressure regain unit' (PRU). The aerodynamic inefficiencies due to mounting the free running centrifugal fan inside a duct result in a lower static pressure difference compared to free flow conditions. In an attempt to minimize this negative effect, an additional component is fitted immediately downstream of the fan, serving as a PRU.

A well-designed fan outlet region with regard to aerodynamic behaviour of the flow is expected to have a positive effect on the overall efficiency. Pressure losses caused by swirling regions with vortices are minimised by achieving a more uniform, unidirectional velocity distribution. This results in an increased static pressure difference at a given flow rate or in an increased flow rate at a given pressure difference. Subsequently, the efficiency of the free running centrifugal fan increases.

Table 1
Overview of measurement equipment and corresponding errors.

Measuring	Sensor	Unit	Error
Temperature	PT 100	°C	0.5 K
Rel. humidity	DRKF 400	%	2.0%
Amb. pressure	DS2	mbar	2.0 hPa
Pressure	SENSIRION 1000	Pa	1.0%
El. power	WT 500	W	0.2%

2. Methods

2.1. Experimental analysis

Fig. 3 shows a schematic overview of the experimental setup and the locations of the measurement equipment. The inflow section of the duct is 1.5 m long and the outflow section has a length of 6.5 m. The free running centrifugal fan is mounted in a square duct with a cross section of 0.75 m · 0.75 m. A secondary axial fan is used to adjust the opera-ting points of the free running centrifugal fan according to the characteristic curve. If necessary the secondary fan supports the free running centrifugal fan or blows in the opposite direction.

Air density is calculated depending on measured temperature, relative humidity and ambient pressure at position 1. The volume flow rate is determined using the differential pressure method with a volume flow control unit (position 2), which has been calibrated by a metering orifice according to DIN ISO 5801 standard [12]. The flow is straightened by a perforated metal sheet before entering the duct section (position 3), where the difference of static pressure is measured between 1 m upstream (position 4a) and 6 m downstream (position 4b) of the free running centrifugal fan. The power consumption of the fan is measured at position 5.

Accuracies of the measurement equipment are given in Table 1. In the investigated case, the grea-test measurement error for the system efficiency and the volume flowrate of the free running centrifugal fans is within 2%.

Measurement results of the empty duct serve as a reference for the optimization with a PRU. Experiments are carried out to evaluate the impact of variations of the PRU geometry. During width/height variation, the width and the height of the PRU cuboid are kept at the same value and are set to 400 mm, 475 mm, and 550 mm at a constant length of 250 mm. For length variation, a variety of measurements are tested, ranging from 20 mm, 250 mm 400 mm and 1000 mm with width and height set to 550 mm. Measurements of the increase of static pressure are conducted at different volume flow rates and fan speeds. The fan efficiency η is calculated from

$$\eta = \Delta p \cdot Q / P_{el} \quad (1)$$