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Research Paper

Design and performance of a direct and continuous ventilation measurement system for variable-speed pit fans in a pig building

Ji-Qin Ni [a,*], *Daniel Kaelin* [a], *Igor M. Lopes* [a], *Shule Liu* [a], *Claude A. Diehl* [a], *Chao Zong* [b,c]

[a] *Department of Agricultural and Biological Engineering, Purdue University, 225 S. University Street, West Lafayette, IN, 47907, USA*

[b] *Department of Engineering, Aarhus University, Blichers Allé 20, 8830, Tjele, Denmark*

[c] *College of Water Recourses and Civil Engineering, China Agricultural University, Qinghua Donglu 17, 100083, Beijing, China*

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Manure pit ventilation is a common design in commercial pig-rearing buildings. However, determining accurate pit ventilation rates is technically challenging. A new pit exhaust airflow measurement assembly (PEAMA) was developed to directly and continuously measure airflow rates for tube-mounting variable-speed pit fans. The PEAMA consists of a PVC pipe, a flow straightener, and an impeller anemometer. A laboratory study revealed good linear correlations between the PEAMA signal outputs and the fan rotational speeds ($R^2 > 0.999$). The ventilation rates measured with the PEAMA were calibrated against those with the standardised traverse measurement with a highly linear correlation ($R^2 > 0.996$). In 2011, 24 PEAMA units were installed in twenty-four 250-mm diameter pit fans in a state-of-the-art pig research building. Multi-year field performance showed that the PEAMA greatly improved data quality during pit fan airflow monitoring compared with previously adopted techniques. This system enabled continuous and real-time ventilation outputs to be determined in volume time^{-1}. It was easy to maintain due to the simple design and outdoor installation. The cost of the 24 units accounted for only a small portion of a comprehensive air quality monitoring setup at the pig research building.

1. Introduction

Manure pit ventilation to evacuate the contaminated headspace air from the under-floor manure pit has been widely adopted in pig-rearing industry. Because manure is the primary source of gaseous air pollutants in pig-rearing buildings, concentrations of the gaseous pollutants are usually higher in the under-floor pit headspace than in the above-floor animal living zone. For this reason, pit ventilation has been

* *Corresponding author*. Tel.: +1 (765) 496 1733.
E-mail address: jiqin@purdue.edu (J.-Q. Ni).

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Nomenclature

A	anemometer rotational speed, RPM
AirDAC	software for air quality data acquisition and control
ANSI	American Nation Standards Institute
C_1	aerial pollutant concentrations at a building inlet, mass volume^{-1}
C_2	aerial pollutant concentrations at the building outlet, mass volume^{-1}
E	aerial pollutant emission rate, mass time^{-1}
HWA	hot-wire anemometer
ID	inside diameter
K_1	coefficient, RPM VDC^{-1}
K_2	coefficient, m^3 revolution^{-1}
OD	outside diameter
OSCS	on-site computer system
PEAMA	pit exhaust airflow measurement assembly
Q	ventilation rate, volume time^{-1}
Q_{PF}	pit fan ventilation rate, m^3 min^{-1}
RPM	revolution per min
SERB	swine environmental research building
V	output of anemometer, VDC
W	wind speed, m min^{-1}

recognised in the USA since the 1970s to be more efficient than wall fans for reducing indoor air pollution in the pig-living zones (e.g., Grub, Foerster, & Tribble, 1974; Keller & Day, 1975; Pohl & Hellickson, 1978). Interest in obtaining better understanding has continued over the intervening decades in many countries, including the USA (e.g., Buiter & Hoff, 1998), Canada (e.g., Choinière, Marquis, & Gingas, 1997; Lavoie, Marchand, & Gingras, 1997), the Netherlands (e.g., van der Wolf, 1996), and Denmark (e.g., Saha, Zhang, Kai, & Bjerg, 2010; Wu, Zhang, Bjerg, & Nielsen, 2012). Recent studies have also confirmed the benefits in using pit ventilation to more efficiently mitigate air pollutant emissions to the outdoor atmosphere (Zong, Li, & Zhang, 2015).

Pit ventilation is usually realised using electric fans. Due to the special pit structures for storing liquid manure in pig-rearing buildings, pit fans are often smaller in diameter and configured differently compared with wall fans or ceiling fans in the same buildings. The inlets of the pit fans can be extended to the headspace of the pits, sometimes connected to in-pit vent pipes (Pohl & Hellickson, 1978).

Ventilation rate is one of the two key variables used to quantify air pollutant emissions from animal buildings because emission rate is a product of the ventilation rate and the aerial pollutant concentration difference between air inlet and outlet of the building [Eq. (1)].

$$E = Q \cdot (C_2 - C_1) \tag{1}$$

where E is aerial pollutant emission rate, mass time^{-1}; Q is ventilation rate, volume time^{-1}; C_1 and C_2 are aerial pollutant concentrations at the inlet and outlet of the building, respectively, mass volume^{-1}.

However, the determination of accurate ventilation rates in animal buildings remains technically challenging since the early days of animal environmental research (Anderson, Cherms, & Hanson, 1964). As a consequence, the greatest uncertainty in estimating emission rates is the calculation of ventilation rate (Wathes et al., 1998).

Measurement of fan ventilation rate can be either indirect or direct. Indirect methods require post-measurement data calculation. For mechanically-ventilated buildings, these methods are usually based on several measurement variables plus the ventilation fan characteristic models to obtain the required ventilation rate. These variables can include fan operation status, fan rotational speed, building static pressure, tracer gas concentration, etc. Fan characteristic models describe the fan airflow rates under different pressures, power supplies, etc. Indirect methods are often used in research projects when there are technical or budgetary restrictions that prevent the use of direct measurement methods. In terms of measurement accuracy, indirect methods are usually not comparable with direct methods.

Direct measurement provides outputs from the measurement device that are in volume time^{-1}. Direct and continuous measurement using ventilation sensors (Berckmans, Vandenbroeck, & Goedseels, 1991) has been realised for some research projects in Europe (e.g., Cabaraux et al., 2009; Costa & Guarino, 2009; Demmers et al., 1999). However, these sensors are designed as ducts that must be connected to the fan inlets. They are usually installed at ceiling fans and are impractical to use at pit fans unless substantial structural changes in pit fan ventilation design are made such as in the project described by Heber, Ni, Haymore, Duggirala, and Keener (2001).

To quantify pit ventilation rates, Lim, Ni, Heber, and Jin (2010) developed and evaluated a device using three impeller anemometers and the traverse principle (AMCA, 2007). The device provided reliable data based on calibrations at the Bioenvironmental and Structural Systems (BESS) laboratory of the University of Illinois at Urbana–Champaign, USA, but it was only used for sporadic fan tests and post-test data processing was still needed to obtain fan airflow rates. Improvement of the method was needed to realise direct and continuous pit ventilation measurement.

A state-of-the-art swine environmental research building (SERB) for controlled scientific studies was built at Purdue University, IN, USA in 2004. The building was equipped with 24 pit fans for 12 rooms. The pit ventilation monitoring methodology in the building has been under development since 2004. Multiple techniques have been tested. An innovative ventilation measurement system was designed and installed in 2011 to improve research quality. The objective of this paper is to present (1) the design of the pit ventilation measurement system, and (2) the system's characteristics in laboratory studies and its performance at field conditions.

2. Materials and methods

2.1. *The building*

2.1.1. *Building indoor climate control*

The SERB is located at the Animal Science Research and Education Center, Purdue University, about 15 km from the