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Investigation on ventilation characteristics in a full-scale model pig house with partial pit ventilation system

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Abstract:

Mechanic ventilation system is the most common way being used to improve the indoor air quality and thermal conditions in pig housing. The efficiency of removing airborne contaminants and heat depend on the design and control of a mechanical ventilation system. High concentrated gaseous contaminants can accumulate in the regions with poor air circulations. The performance of the ventilation system therefore needs to be clarified, especially in the animal occupied zone (AOZ). In this study, a full-scale sub-section of a commercial Danish pig production unit with partial pit ventilation system was used to characterizing the air distribution and evaluating the ventilation effectiveness. Air velocities, airflow patterns, contaminant concentrations were measured and analyzed. The mean age of air and ventilation effectiveness factor (VEF) are used as two indices for evaluating the ventilation system. A full rotated room flow pattern was found in the experimental chamber. The supplied air mixed with upper moving room air, dropped near the far end wall, and returned in the AOZ. For partial pit ventilation system, generally higher concentrations were observed in the pit headspace than in the room air. Highest concentrations were found at locations near the side wall which installed exhaust units than other measuring locations. The local mean ages of air were generally similar at the six sampling positions in AOZ except point B with a little higher value. In the pit headspace, the lower local mean ages of air were found near both walls, which mean the air near walls easier being replaced. The VEF results were opposite with the concentration results. The VEF results were not suitable for the evaluation as two exhaust units applied in this study.

Keywords: pig housing, partial pit ventilation system, animal occupied zone, ventilation effectiveness

1. Introduction

Nowadays, intensive pig farms are usually confined and have high occupant density. The pigs share a closed and mechanically ventilated room connected to a slurry pit. If the supply air is not correctly distributed, high concentrated airborne pollutants emitted from pit and animals will accumulate and have a negative influence on occupants' health (Barber and Ogilvie, 1982; Zhang *et al.*, 1996; Zhang and Strom, 1999; Morsing *et al.*, 2008). Nevertheless, a conventional ventilation system with only room exhaust units cannot effectively control the air condition in an animal house, especially during winter as the minimum ventilation rates employed (Pohl and Hellickson, 1978). Therefore, applying an extra pit ventilation system in livestock housing has been proposed (Buiter and Hoff, 1998). Systems with partial pit exhaust units have been proved to get remarkable indoor air quality improvement and emission reduction together with pit air cleaning (Ye *et al.*, 2009; Saha *et al.*, 2010; Zong *et al.*, 2014).

Air velocity distribution and airflow pattern inside animal house can significantly affect the dispersion and deposition of airborne contaminants (Wu *et al.*, 2013). The measured air velocity field can be used to predict the possible patterns of contaminant transport. However, for a region with recirculation or other complicated airflow patterns, the airflow velocity vector can be misleading in terms of thermal comfort and pollutant removal (Wang *et al.*, 2008), which always happens in the space near the slatted floor area in pig housing. Ventilation effectiveness is therefore being used for the ventilation evaluation. Among various ways in defining ventilation effectiveness, the local mean age of air has been widely accepted of the residence time of the air (Han, 2012). The ventilation effectiveness factor (VEF) is another practical and very simple tool for evaluating a zonal ventilation in removing airborne pollutants (Zhang *et al.*, 2001).

The objective of this study is to characterize the ventilation field and evaluate the ventilation effectiveness in a pig house with partial pit ventilation system. The local mean age of air and ventilation effectiveness factor (VEF) have been used as the tools for the evaluation.

2. Materials and methods

Experiments were conducted in the Air Physics Lab, Research Center Foulum, Aarhus University, Denmark.

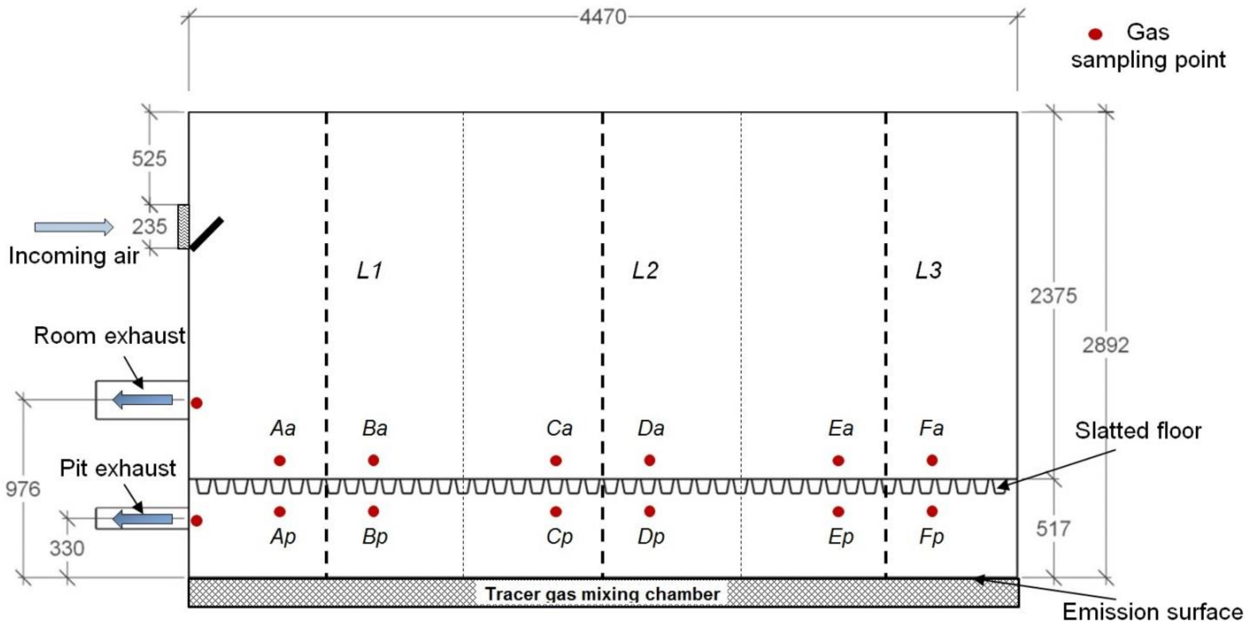

Figure 1: The schematic diagram of experimental chamber and sampling positions, mm.

2.1 Experimental set-up

An experimental chamber with inside dimensions of 4.47 m × 1.17 m × 2.89 m (*L* × *W* × *H*) was built as a sub-section of a fattening pig house which corresponds to a full scale Danish pig unit with half width (Fig.1). The front panel of the chamber was made of transparent glass, and the back and side panels were made of plywood which were painted in dark color for facilitating visualization of airflow patterns with illuminated smoke. There were two air exhaust openings. Room exhaust was a sealed iron pipe outlet with a diameter of 200 mm installed on the left wall (Fig. 1). The pipe was connected *via* a flexible duct to a channel fan (Lindab type VBU 200B, Denmark) discharging the air to outside. Pit air was extracted by another type of fan (Lindab type VBU 100B, Denmark) *via* a 110 mm-diameter pipe outlet installed in the left wall just beneath the slatted floor and a flexible duct. An adjustable flap wall-jet inlet was installed on left side panel beneath the ceiling. The angle of the flap was kept 45 degree to the horizontal plane in this study. The fully slatted floor was used for this study with an opening ratio of 19%. The pit headspace was under the slatted floor, with a height of 0.515 m

2.2 Measurement

Measurements were carried out under isothermal conditions (Fig. 1).

2.2.1 Ventilation rate

The room and pit ventilation rates were set as 720 and 80 m^3 h^{-1}, respectively. Lindab FMU/FMDRU 200-160 and FMU/FMDRU 100-80 flow meters (Denmark) was used to measure the room and pit ventilation airflow rate, respectively. The accuracy of the flow measuring method is 5-10% depending on the distance to the flow disturbance. The ventilation flows in the duct was determined using the equations:

$$VR_r = 29.4\sqrt{\Delta P} \qquad (1)$$

$$VR_p = 7.32\sqrt{\Delta P} \qquad (2)$$

where *VR* is ventilation rate, m^3 h^{-1}; ΔP is pressure difference between upstream and downstream side of the orifice, Pa. The pressure differences were measured using a TSI pressure probe (Model 9596, TSI, USA) with an accuracy of ± 0.7%.

2.2.2 Tracer gas concentrations

N_2O was used as a tracer gas in this study. A constant N_2O flux of 100 ml min^{-1} was supplied uniformly into a mixing chamber below the pit space, and emitted through a wooden plate with150 5-mm diameter holes and two-layer diffusion floor surface into the pit (Fig. 1). Four reference sampling points in the mixing chamber along the length of chamber were used to monitor the uniformity of N_2O concentration in the mixing chamber.

The N_2O concentration was measured by INNOVA multi-gas Monitor (type 1312, Denmark) and a multiplexer (type 1309, Denmark). The sampling locations are points A:F in the animal occupied zone (AOZ) and in the pit headspace (Fig. 1). The sampling period for each N_2O measurement was 40 s, followed by 20 s flushing time to replace the air in the measuring chamber of the Monitor before a new measurement started.

2.2.3 Air velocity and airflow pattern

A two-dimensional Laser Doppler Anemometer (LDA) (DANTEC, Skovlunde, Denmark) was used to measure air velocity at the sampling positions along three sampling lines *L1:L3* (Fig. 1). Each point was measured 10 min.

Airflow patterns were observed using smoke from a smoke machine and a laser sheet.

2.3 Ventilation effectiveness

2.3.1 Local mean age of air

The age of air is the duration of time for the supply air to reach the point. Since air can reach the point through various paths, the mean value of the ages at the point is called the local mean age of the air (Han, 2012). Following equation was used to calculate the local mean age of air t_{lma}.

$$t_{lma} = \int_0^\infty \frac{C_i(t)}{C_i(0)} dt \qquad (3)$$

where $C_i(0)$ is the initial equilibrated N_2O concentration and $C_i(t)$ is the continuing recorded sampling concentration.

2.3.2 Ventilation effectiveness factor

The ventilation effectiveness factor (VEF) has been used to evaluate zonal ventilation for which only a portion of the airspace is the primary concern.

$$VEF_i = \frac{C_{ex} - C_{sup}}{C_i - C_{sup}} \qquad (4)$$

where VEF_i is the ventilation effectiveness factor at position *i*; C_i is the average N_2O concentration, ppm, at *i*th sampling position; C_{ex} and C_{sup} are average concentrations of exhaust air and inlet air, ppm, respectively. Under complete mixing condition, the VEF is one.

3. Results and Discussion

3.1 Air velocity characterization

3.1.1 Air velocity

The two-dimensional velocity vectors were measured on the three lines in the chamber. Fig. 2a shows the horizontal air velocities at different heights on three lines along the length of chamber. Under a total ventilation rate of 800 m^3 h^{-1}, the velocities along the three parallel lines were basically similar with horizontal velocities towards right near the ceiling and return velocities to left near floor region (Fig. 2a). This air velocity feature was typical for a side-wall inlet pig room. The supplied air mixed and warmed with upper room air before it reached the AOZ. Fig. 2b illustrates the vertical velocities at sampling points above and below the slatted floor on the three lines (L1:L3). It can be seen that air entered the pit space from right side, and exited the pit from middle and left part of the floor. This is consistent with previous study regarding side-wall ventilation in pig housing (Ye *et al.*, 2009).

3.1.2 Airflow pattern

Fig. 3 shows the general airflow patterns of the partial pit ventilation with side-wall jet inlet from smoke test. A big return flow was found in this study. The supplied air from wall-jet traveled attaching the ceiling and continued down the far end wall. On reaching the slatted floor near the wall, the airflow generally split into two: a primary airflow returning above the floor and another dropping into the pit headspace below the slatted floor. This phenomenon is consistent with a previous study with only room exhaust unit (Ye *et al.*, 2009).

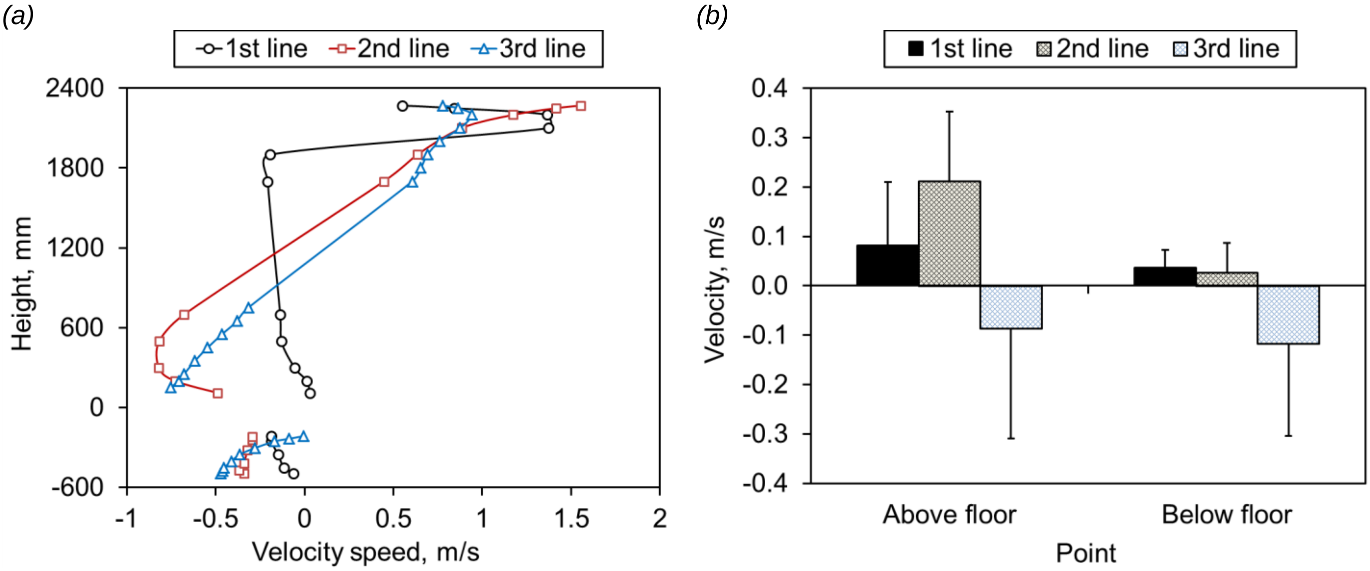

Figure 2: (a) Horizontal air velocities on three lines; (b) Vertical velocities at three sampling points along the lines above (0.2 m to floor surface) and below (0.22 m to floor surface) the slatted floor.

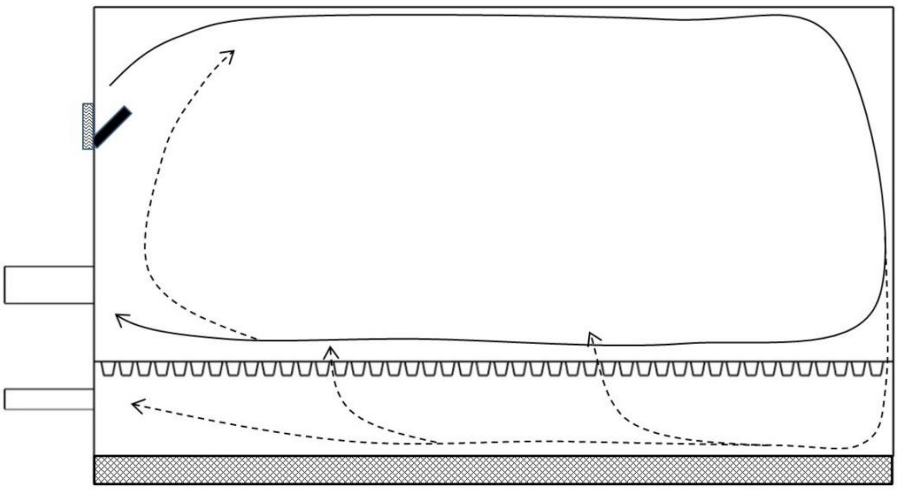

Figure 3: General airflow pattern in the experimental chamber.

3.2 Ventilation evaluation

3.2.1 Contaminant concentrations

The mean concentrations of N_2O for six sampling locations (A:F) above and below the slatted floor were shown in Fig. 4. Generally higher N_2O concentrations were observed in the pit headspace than in room air. The N_2O concentrations were much higher at location A and B near the left side wall installed exhaust units than other measuring locations.

3.2.2 Local mean age of air

The local mean age of air was changed with the locations in the chamber. The mean and standard deviation of the local mean ages of air in the AOZ and in the pit headspace are presented in Fig. 5. The local mean age of air at different locations was related to the corresponding local air distribution. The high velocity could bring more newly supplied air, leading to relatively lower local mean ages of air. In general, larger velocity results in better air exchange, which is correlated to smaller local mean age of air. In this case, the local mean ages of air were generally similar at the six sampling positions in AOZ except point B with a little higher value. In the pit headspace, the lower local mean ages of air were found at point A and F near both walls, which mean the air near walls easier being replaced.

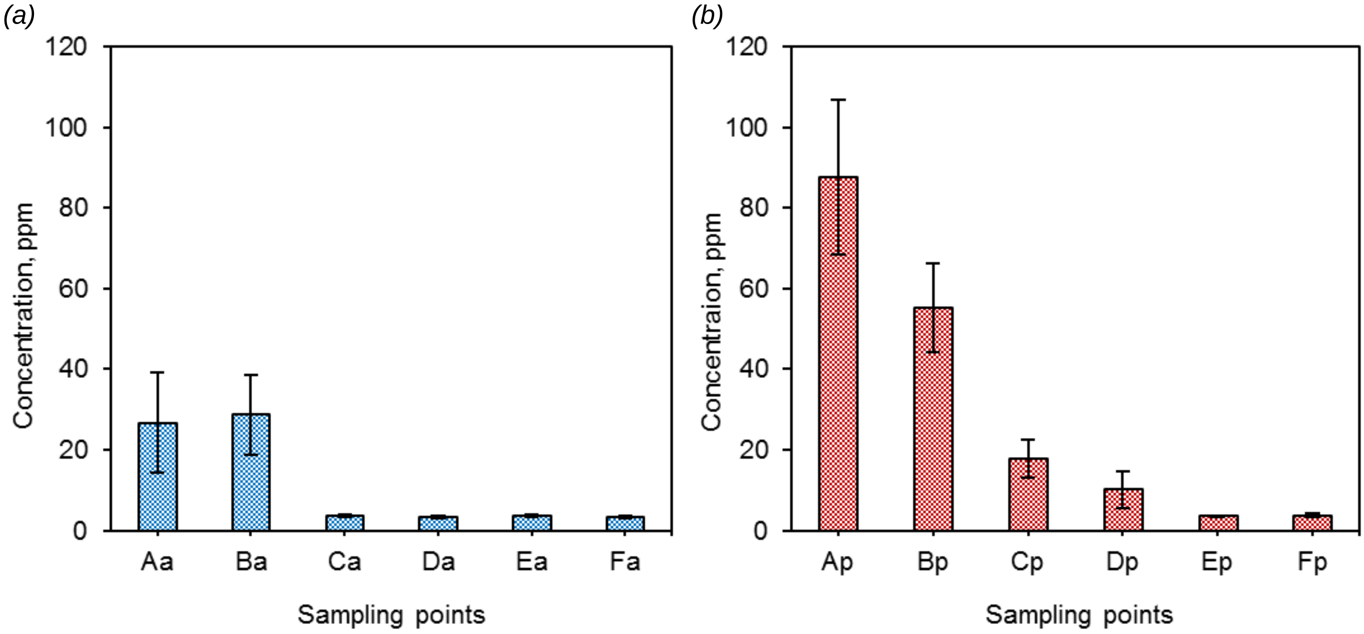

Figure 4: Contaminant concentration at six sampling points in (a) animal occupied zone and (b) the pit headspace.

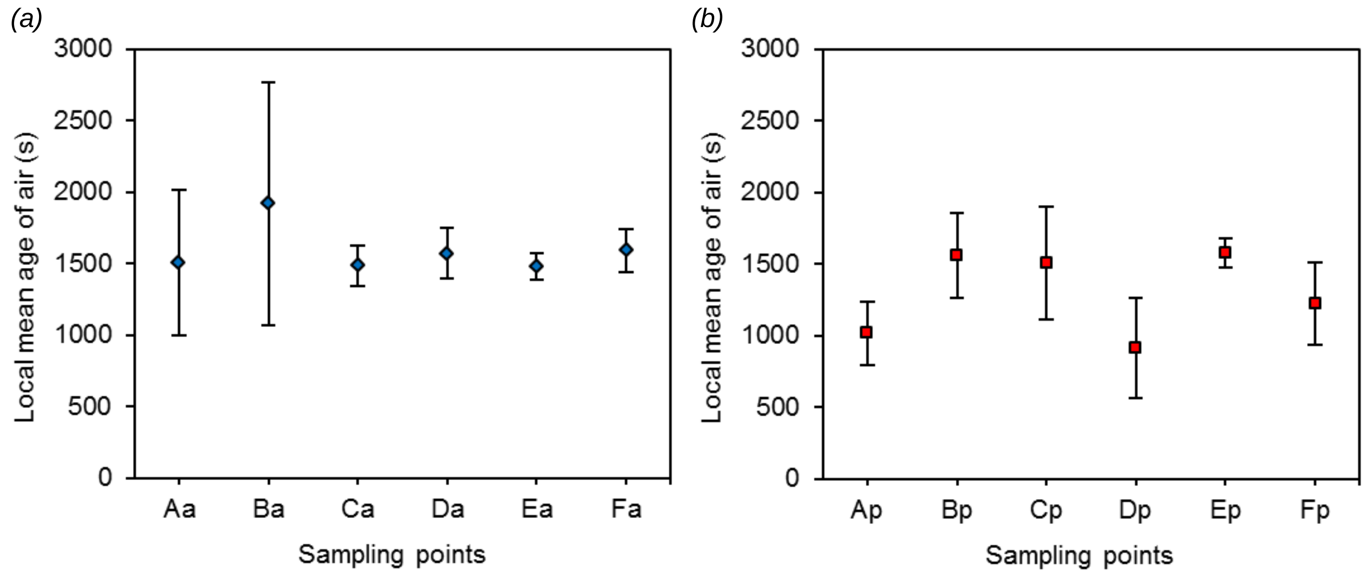

Figure 5: Local mean age of air at sampling positions in (a) animal occupied zone and (b) pit headspace.

3.2.3 Ventilation effectiveness factor

Fig. 6 shows the VEF at different locations along the length of chamber under steady state. It can be seen that the VEF results generally followed an opposite pattern with N_2O concentrations in Fig. 4. according to Zhang *et al.* (2001), the larger the VEF, the more effective in removing contaminants, results from more effective ventilation. However, since there were two exhaust openings in this study, the index of VEF did not precisely reflect ventilation effectiveness on each location.

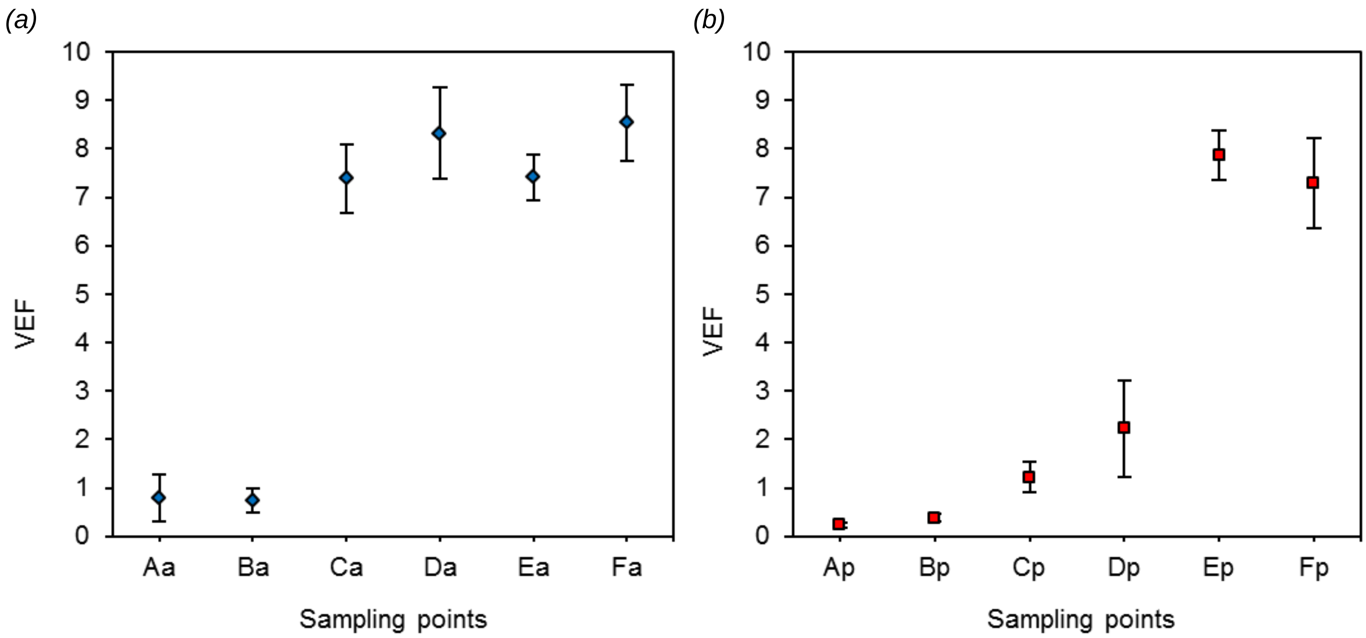

Figure 6: Comparison of ventilation effectiveness factor (VEF) at sampling positions in (a) animal occupied zone and (b) pit headspace.

4. Conclusions

The two-dimensional velocity vectors and airflow patterns show that the horizontal velocities towards right near the ceiling and return to left near floor region. A big return flow was found in the room space. The supplied air first mixed with upper room air, dropped near the far end wall, and returned in the AOZ.

For partial pit ventilation system, generally higher N_2O concentrations were observed in the pit headspace than in the room air. Highest concentrations were found at location near the left side wall installed exhaust units than other measuring locations.

The local mean ages of air were generally similar at the six sampling positions in AOZ except point B with a little higher value. In the pit headspace, lower local mean ages of air were found near both side walls, where air was easier being replaced. The VEF results showed a pattern opposite with the concentration results, which were found not suitable for the evaluation as two exhaust units involved in this study.

5. Acknowledgements

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