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Assessing airflow rates of a naturally ventilated test facility using a fast and simple algorithm supported by local air velocity measurements

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A B S T R A C T

The high spatial and temporal variations of airflow patterns in ventilation openings of naturally ventilated animal houses make it difficult to accurately measure the airflow rate. This paper focusses on the development of a fast assessment technique for the airflow rate of a naturally ventilated test facility through the combination of a linear algorithm and local air velocity measurements. This assessment technique was validated against detailed measurement results obtained by the measuring method of Van Overbeke et al. (2015) as a reference.

The total air velocity $|\overline{U}|$, the normal $|\overline{Y}|$ and tangential velocity component $|\overline{X}|$ and the velocity vector $\overline{U}$ measured at the meteomast were chosen as input variables for the linear algorithms. The airflow rates were split in a group where only uni-directional flows occurred at vent level (no opposite directions of $|\overline{Y}|$ present in the airflow pattern of the opening), and a group where bi-directional flows occurred (the air goes simultaneously in and out of the opening). For airflow rates with uni-directional flows the input variables $\overline{U}$ and $|\overline{Y}|$ yielded the most accurate results. For this reason, it was suggested to use the $|\overline{Y}|$ instead of $|\overline{U}|$ in ASHRAE's formula of $Q = E \times A \times |\overline{U}|$.

For bi-directional flows a multiple linear model was suggested where input variable $\overline{U}$ gave the best results to assess the airflow rate.

Contents

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Nomenclature

A	surface area (m^2)
Ap	partial surface area (m^2)
ANN	Artificial Neural Networks
β_0	regression coefficient Bland Altman plot
β_1	intercept Bland Altman plot (m^3/h)
C_D	still-air discharge component (dimensionless)
E	opening effectiveness (dimensionless)
MR	model results
NE	north east
NW	north west
ΔP	pressure difference across the opening (Pa)
Q_{bi}	airflow rate with bi-directional flow in the side vents (m^3/h)
Q_{uni}	airflow rate with uni-directional flow in the side vents (m^3/h)
RR	reference results
SE	south east
SD	standard deviation
SW	south west
$\overline{U}$	velocity vector (m/s)
$\lvert\overline{U}\rvert$	total air velocity (m/s)
V	reference velocity (m/s)
$\lvert\overline{X}\rvert$	tangiental air velocity component (m/s)
$\lvert\overline{Y}\rvert$	perpendicular air velocity component (m/s)
ρ	air density (kg/m^3)

1. Introduction

An accurate assessment of ventilation rates of animal houses is important with regard to, among others, the quantification of the related emissions. The importance of accurate measurements of ammonia emissions from naturally ventilated animal houses has risen since the increasing awareness of its major impact on the environment [2] and its consequences as e.g. eutrophication by deposition on the soil or in the water.

However, measuring ventilation rates in commercial animal houses is difficult in practice, due to significant uncertainties in measurements [3].

Emissions from mechanically ventilated animal houses, as commonly used for pig and poultry production in Western Europe, can be measured and calculated by multiplying the differences in ammonia concentrations at the inlet and the outlet with the corresponding ventilation rates [4]. A similar straightforward emission measurement procedure is less evident in naturally ventilated stables and in particular for dairy stables with large openings, because of the strong dependency of the emissions on weather conditions and building geometry. Therefore, significant spatial and temporal variations of the air velocity and of NH_3 concentrations occur in the ventilation openings of the stables. Errors in emissions measurements are often due to the complexity of the airflow rate measurements [5–8]. Currently there is no standardized reference method available for measuring the ventilation rate in naturally ventilated animal housing [7,9,10].

Van Overbeke et al. Ref. [1] developed and validated an accurate measuring method for the airflow rate of a naturally ventilated test facility with continuous direct velocity measurements using moving sensors (more details are given in §2.3.2). However, simplification is still necessary to achieve a more practical, time-reduced, low-cost and yet sufficiently accurate method. Combining modelling techniques with local air velocity measurements could be of interest to develop such a method [7,9,11]. This with the aim to simplify and speed up the assessment of the ventilation rate and to result in real time determination of the ventilation rate. With this respect, the method of Van Overbeke et al. Ref. [1] can serve as an excellent starting point since it provides detailed information on the velocity profiles in the vents.

The conventional envelope model that describes how the air enters and leaves a building, is the Bernouilli equation as a simplification of the Navier-Stokes equations. This so-called ‘orifice equation’ [1] is the most general relation describing the airflow rate through large intentional openings [12–15].

$$\mathbf{Q} = \mathbf{C_D} \times \mathbf{A} \times \sqrt{\frac{2\mathbf{x}|\Delta \mathbf{P}|}{\boldsymbol{\rho}}} \tag{1}$$

Where

Q = Airflow rate (m^3/s)
C_D = Still-air discharge component (dimensionless)
A = Surface area of the opening (m^2)
ΔP = Pressure difference across the opening (Pa)
ρ Air density (kg/m^3)

This equation applies a still-air discharge coefficient for a typical opening but it fails for large openings as the main assumptions are not fulfilled (e.g. pressure and velocity distributions are not constant in the opening [16]) and changes in weather conditions can cause unsteadiness for measuring or estimating the parameters in the formula [17,18]. On top of these difficulties, very large openings (as typically found in dairy cow houses) would make it even more challenging to sample air volumes using the orifice equation due to