Assessing natural ventilation rates using a combined measuring and modelling approach

G. De Vogeleer\textsuperscript{1,2}, P. Van Overbeke\textsuperscript{1,2}, J.G. Pieters\textsuperscript{2}, P. Demeyer\textsuperscript{1}

\textsuperscript{1}Technology & Food Unit, Institute for Fisheries and Agricultural Research (ILVO), B. Van Gansberghelaan 115, 9820 Merelbeke, Belgium, Peter.Demeyer@ilvo.vlaanderen.be, tel: 003292722764

\textsuperscript{2}Department of Biosystems Engineering, Ghent University, Coupure links 653, 9000 Ghent, Belgium

Abstract

Natural ventilation of animal houses clearly has advantages as for instance its low power consumption. However its application is often limited due to the lack of a reliable measuring and control system of the ventilation rate and so of emissions, as required for legislation. Although a lot of models exist to determine natural ventilation rates in buildings, it is still a challenge to know the ventilation rate accurately with few measurements. The objective of this work was to develop a model for the prediction of the natural ventilation rate in a pig house with as few measuring points as possible. Neural networks were used to investigate the reliability and accuracy of using as limited input as possible, taken from data collected from measurements with sonic anemometers in a real scale test building under outside weather conditions.

Keywords: natural ventilation, sonic anemometers, modelling, neural networks

Introduction

A proper indoor climate is of great importance in animal housing for different aspects, such as disease prevention, emission control, heating and ventilation control. Advantages of natural ventilation are not only a possible decrease in stress for animals (less noise of fans) and limited investment costs, but because there are no fans present, there exists a considerable lower consumption of energy (absence of fans) potentially resulting in a more economical housing. Disadvantages are the unpredictable pattern in the wind leading to more or less uncontrollable conditions in the stable. A good ventilation system requires adequate control, which implies a reliable measurement method and a control system that can interact with different weather conditions. This measurement method is also necessary when emissions have to be measured for legislation, health or other purposes. But due to the lack of a reliable control and measuring technique, the application of natural ventilation is still limited (Van Buggenhout et al., 2009). Naghman (2008) stated that a direct measurement or model for the ventilation rate is difficult to obtain. Many measurement techniques are in use but have no known or acceptable uncertainty on the ventilation rate.
A reliable natural ventilation measurement method should be able to handle different conditions. For every building, internal and external features are different, such that a statistic model cannot be valid for all situations. Wind profiles in an opening change as wind conditions differ. This can influence the place of measurement greatly or the interpretation of the measured value. Measuring conditions differ due to changing wind velocity and incidence angle (De Paepe et al., 2013). Also the envelope and framework of the ventilation opening have an influence on the measurement (De Paepe et al., 2012).

Despite the demand for a reliable ventilation technique, Calvet et al. (2013) state that there is no reference method available for measuring the ventilation rate in naturally ventilated buildings. So a new technique for ventilation measurements is needed.

To develop a measuring technique for natural ventilation with good accuracy and a broad applicability, experiments should be handled at real scale and with a reference airflow. The challenge for the measurement method is the large variability of the wind and the lack of a good reference when measuring under natural conditions.

The presented reference method for the measurement of the ventilation rate focuses at rectangular ventilation openings using ultrasonic anemometers supported by an automated moveable sensor frame. Wind tunnel experiments were performed for validation of the technique before performing field tests in a real life section of a pig house. The objective of this work was to develop a model for the prediction of the natural ventilation rate in a pig house with as few measuring points as possible.

The last decades, artificial neural networks (ANN) have been used more frequently to analyse or predict weather data (Marwa, 2011; Sreelakshmi, 2008; Ayata, 2007). A great advantage of ANN is that these models use data from real experiments instead of simulation data (e.g. CFD) to predict parameters (Kalogirou, 2003). Therefore, artificial neural networks were chosen to investigate the reliability and accuracy for predicting the airflow rate, with possibly as limited measurements as possible.

**Materials and methods**

**1.1 Wind tunnel experiments**

To develop a reference method for the ventilation rate in a naturally ventilated pig house, first measurements were carried out in a wind tunnel under steady conditions (mechanical ventilation). A wind tunnel was constructed consisting of: a rectangular airflow duct of 1mx0.5m (WxH) (small scale) and 3mx0.5m (more representative scale). The reference airflow was assessed by a pressure reading over an orifice plate placed in a cylindrical duct upstream of the fan according to the standard VDI 2041 (1991).

![Figure 1: Wind tunnel installation for the development and calibration of the manual and automatic sensor frame (ASF)](image-url)
An automatic sensor frame (ASF) was developed to measure and calibrate the reference method under different conditions of mechanical ventilation. The ASF existed of a 2D linear guidance system placed at the end of the duct as it could not be combined with measurements in the duct. Software controlled electro motors were installed for movement of the sensors on the ASF. Implementation of a self-programmed pattern made it possible to move the sensors completely automated. Details of the calibration are described in Van Overbeke et al. (2013).

Because of its robustness, high accuracy for both wind speed and direction, short response time and fast measuring time, 3D ultrasonic anemometers were used for the experiments. As such a sensor takes a certain volume, a specific calculation method was elaborated for the airflow rate (Van Overbeke et al., 2014b). The cross section of the duct was divided in a number of rectangular sub-volumes. These sub-volumes were sampled by the 3D-sensor. The respective average velocities through each volume were multiplied by its perpendicular surface and summed to obtain the airflow rate. The ventilation opening of the 1m-duct was divided in 16 volumes, the 3m-duct in 48 volumes. Only the measured vector components normal to the traverse plane were taken into account for the calculations.

The experiments were carried out under steady ventilation rates, while different velocity patterns were created by using obstructions to obtain disturbed profiles. Previous research showed a mean relative measurement error of 5.4±1.7% (1m width) and 1.3±2.6% (3m width) for the ASF method showed (Van Overbeke et al., 2014).

1.2 Test installation in the field

To conduct real-scale experiments under outside weather conditions, a test installation, which represents a section of a pig house, was built at ILVO in Merelbeke (70 km inland from the North Sea), Belgium (De Vogeleer et al. 2013).
This location was chosen because of the open space in the prevailing wind direction (SW) giving undisturbed wind profiles. The building (12 m (L) x 5 m (W) x 4 m (H)) has two side openings of 4,5 m (W) x 0,5 m (H) and one ridge opening of 4,5 m (W) x 0,3 m (L). The ridge was equipped with 8 2D-ultrasonic sensors. The width of the ventilation openings can vary between 1m, 3m and 4,5m to perform different ventilation tests. 2 ASF’s were installed in the test installation. A smaller test room was built in the test installation. One ASF was placed at the outer (SW) wall of the installation while the other one was placed at the other side of the small room.

A telescopic mast at 10m height equipped with a 2D ultrasonic sensor to characterize the outside wind conditions, was installed 20m next to the test installation.

1.3 Data collection

The testing period lasted from August to October 2013. All data was taken during the experiments in the small room in the test installation. The X, Y, and Z components of the velocity of the 3D-sensors in the test construction and the X, and Y components of the velocity on the telescopic mast were logged continuously and simultaneously with a frequency of 1Hz during 10s. Temperatures at different heights were measured using PT100’s.

1.4 Measuring approach
The developed method for the wind tunnel experiments was used to calculate the airflow rate for the ventilation openings.

This method existed of consecutive measurements of 16 areas (measuring locations) in the ventilation opening. This resulted for each measuring location in **discontinuous information from a continuous wind signal**. This inherently leads to a loss of information because the velocity profile in the ventilation opening changes faster than new measurements take place for a given measurement location. Van Overbeke et al. (2014) showed that a periodic repetition of the measurement over the ventilation opening gives a better estimate per measuring location. In this case, repeating the measurements 10 times and averaging the data over 10x10s for each measuring location gave satisfactory results ( >85% of the measurements had a maximum deviation of 20%).

![Figure 5: Example of a graphical presentation of the averaged vectors in the ventilation openings](image)

### 1.5 Model approach

The airflow data obtained by the reference method was used and compared with airflow data obtained from a neural network. Several multi-layered perceptron networks (MLPN) were trained using the feed-forward back propagation (FFBP) algorithm. Each training, the learning rate, the amount of neurons and the momentum rate were altered with predefined values leading to different neural networks. Initially weights and biases were chosen randomly and afterwards adjusted during training to produce the desired output (airflow rate of vent 1).

As input for the network, (a selection of) the measurements of the different components of the wind velocities measured at the vents and telescopic mast were used. The obtained airflows from the reference method were taken as targets for the model. The data used to validate the different networks, was new information to the ANN in order to test its prediction ability for unknown data. The evaluation of the network results were based on R-values. This parameter is an indication of the relationship between the output and the target (correlation coefficient).

### Results and Discussion

During the measuring period, the prevailing wind came from the south, south-west direction as expected (figure 6).
During the measuring period, 1040 airflow rates were calculated using the 10x10s measuring method. Figure 7 gives a graphical overview of all results plotting the airflow rates through vent 1 for different wind directions. When the wind was perpendicular to the test installation, the airflow rate reached the highest values. When the wind turned more sideward, the maximum airflow rate decreased proportionally with the Y component of the telescopic mast.

These measurements (X,Y,Z components in the vents and on the telescopic mast) and the calculated airflow were used to feed different ANN’s. The measurements were used as input, the airflow as target. These data were used to train different ANN’s. The networks using X, Y and Z velocity components of the ventilation opening 1, gave correlations of >99%.

When using velocity components of only 1 measuring location (of 16), the correlations were still > 89%. Better correlations were obtained for measuring locations in the middle of the vent, as compared to locations near the side of the vent.

Using only the X and Y velocity components of the telescopic mast readings, the R-value was still very high (96 – 99%).

Overall, the correlation coefficient decreased significantly when only an X or an Y velocity component was used as ANN input.

Wind direction was the most important parameter for the prediction (80-84%), but also the wind speed (8-34%) was necessary to obtain correlations of >96%.

<table>
<thead>
<tr>
<th>Input ANN</th>
<th>Target ANN</th>
<th>Correlation</th>
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<tbody>
<tr>
<td>XYZ velocity components of the outlet volume of vent opening 1</td>
<td>Airflow rate vent opening 1</td>
<td>&gt;99%</td>
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Wind direction and speed telescopic mast & Airflow rate vent opening 1 & 96-99% \\
Wind speed telescopic mast & Airflow rate vent opening 1 & 8-34% \\
Wind direction telescopic mast & Airflow rate vent opening 1 & 80-84% \\
XYZ velocity components of 1 volume & Airflow rate vent opening 1 & 89-95% \\
| volume 1 | Airflow rate vent opening 1 & 97-99% \\
| volume 6 | Airflow rate vent opening 1 & 97-98% \\
| volume 8 | Airflow rate vent opening 1 & 91-96% \\
volume 16 | Airflow rate vent opening 1 & 44-60% \\
Y velocity component of 1 volume & Airflow rate vent opening 1 & 87-92% \\
| volume 1 | Airflow rate vent opening 1 & 44-60% \\
| volume 8 | Airflow rate vent opening 1 & 87-92% \\

Conclusions

The airflow rates were calculated with the method as proposed by Van Overbeke et al. (2014b). It was possible to predict the airflow of the small test room in the 12mx5m test installation (2 vents) with ANN. Correlations of more than 99% were found between the output and the target of the network. Using limited measurement data still gave satisfactory correlations. Data of only 1 measuring location in the vent resulted in >89% correlation for side locations, middle locations gave even higher R-values.

The prediction capacities with data from the telescopic mast were very high (96-99%). prediction between the independent velocity measurements of the telescopic mast and the calculated airflow rates show a high correlation between the calculated airflow rate in vent 1. For both the mast and the vent measuring locations it was important to use the X and Y velocity components as both wind direction and wind speed data were needed to give satisfactory predictions.

Further research will focus on performing tests in the whole test installation and the use of wider (more representative) ventilation openings. Also the ridge opening will be included to use data from all three ventilation openings.

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