Field test facility for the development of a reference method for ventilation rate and emission measurements in naturally ventilated pig houses

Feld Testanlage für die Entwicklung einer Referenzmethode für Luftwechselrate und Emissionsmessungen in natürlich belüfteten Schweineställen

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Summary
A test facility for field measurements of natural ventilation in livestock buildings was developed. Choice of used materials and methods were taken into account: ultrasonic wind anemometers, linear guiding systems for sensor movement and data loggers were carefully chosen. The true scale test facility makes it possible to measure and study air flows and related characteristics for long periods, under real conditions of natural ventilation.

Zusammenfassung
Eine Testanlage für Feldmessungen der natürlichen Lüftung in Stallgebäuden entwickelt wurde. Wahl der verwendeten Materialien und Methoden wurden berücksichtigt: Ultraschall-Anemometer Wind, lineare Führungssysteme für Sensor Bewegung und Datenlogger wurden sorgfältig ausgewählt. Das wahre Ausmaß Testanlage ermöglicht es, zu messen und zu studieren Luftströmungen und Kenngrößen für längere Zeit, unter realen Bedingungen der natürlichen Lüftung.

Introduction
Natural ventilation is potentially the most sustainable way to accomplish a proper indoor climate for production. Economic advantages are mainly the lower primary investment costs (no expensive fans) and less energy costs. The advantages for animals and farmers include less stress situations (reduced noise levels).

However, the application of natural ventilation is still limited due to the lack of a reliable measuring and control technique for the ventilation rate. Van Buggenhout et al. (2009) stated that an accurate and reliable measuring technique for naturally ventilated systems does not exist. Other researchers state that it is difficult to directly measure or model the ventilation rate of a naturally ventilated livestock building (Naghman K. 2008). Inherently, also the related emissions (ammonia, greenhouse gases, dust, odour,…) cannot be measured accurately. Therefore, it is still not possible to reliably assess the emission behaviour of naturally ventilated animal houses. This also inhibits the development and certification of such low emission animal houses in Flanders and other EU member states.

The overall goal of this research was to develop an accurate and reliable measuring technique for the natural ventilation rate, consisting of calibrated sensor frames and validated algorithms. To this end, extensive field experiments under real life conditions of natural ventilation are required. Therefore, a unique test facility was built in the field, equipped with previously developed automatic reference sensor frames mounted in the ventilation openings using 2D and 3D sonic anemometers.

Materials and Methods

Test construction in the field

A real scale section of a pig house was built at the experimental farm of the Institute for Agricultural and Fisheries Research (Merelbeke, Belgium) to conduct experiments under real conditions of natural ventilation. The location of the test facility was selected considering undisturbed wind profiles coming from the main wind direction (SW). The front side of the pig stable is oriented SW (the prevailing wind direction) in order to use the maximum potential of the natural ventilation process. The section (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) (see figure 1). In order to make the different ventilation tests flexible, the width of the ventilation openings can vary between 1 m, 3 m and 4,5 m (initial tests will take place with a side opening width of 1m instead of the full 4,5m).

Figure 1: test facility with fully closed side ventilation opening

Automatic sensor frames

Two automatic sensor frames (ASF) were placed in the side openings (see figure 2). These ASF exist of 2D linear guiding systems and include software controlled electro motors for vertical and horizontal movement (Siemens Step7). This makes it possible to implement a self-programmed pattern for automatic sensor movement. The reach of the air velocity sensors on the frame (4,5m x-direction; 0,7m z-direction) covers the complete side ventilation opening area (see figure 2). The ASF have the possibility to hold more than one sensor.

Figure 2: automatic sensor frame

The pre-set pattern for the sensor movement provides a complete scan of the ventilation opening areas. The sensor head can move along the opening area both in vertical and horizontal steps of 0.125 m and 0.250 m, respectively. This step size was selected in view of the dimensions of the sensor head. For example, when measuring a 1 m-opening, the sensor-head will measure 16 locations distributed over 4 horizontal rows and 4 vertical columns (see figure 3). Initially, each location was measured during 60s at a frequency of 1Hz. These settings can be adapted for the different experiments.

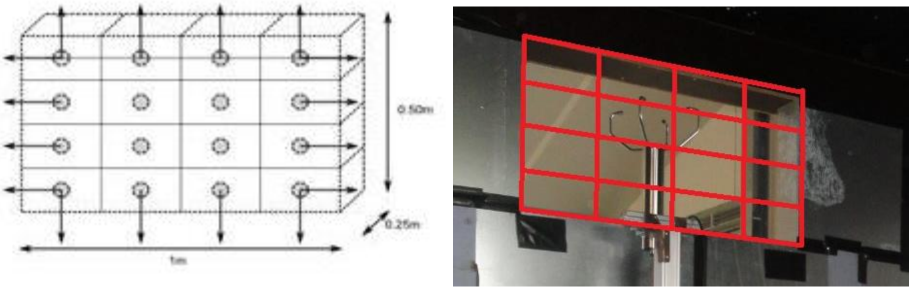

Figure 3: measurement locations for a 1m opening

Sensors

After an evaluation of different velocity sensors based on literature and some preliminary tests, 2D and 3D ultrasonic anemometers were selected. Advantages of this type of sensor are e.g. their mechanical robustness and low maintenance, low external influence on performances, high accuracy for both air speed and direction, short response time and fast measuring rate.

The ASF in the side openings are equipped with 3D sensors. In the ridge opening 2D-ultrasonic sensors are used. The ridge opening area is covered by 8 fixed 2D anemometers, equally spread over the width of the opening and each alternatively placed on opposing sides.

With these sensor configurations, a quasi-continuous and dense measurement of the in- and outgoing airflows in the test facility is possible.

Temperature is measured at different locations and at evenly distributed heights in the pig house, using PT100's attached to steel wires.

In the field next to the experimental unit, a telescopic mast of 10m height equipped with a 2D ultrasonic anemometer and a PT100, is installed to characterise the outside weather conditions.

All sensor signals are simultaneously logged at a frequency of 1Hz (frequency can be adjusted for different tests) and transferred into one data file .

Air flow calculation method

Existing standards for measuring ventilation rates only apply on mechanical ventilation and measurements in ducts. Another system, FANS (Gates et al.,2004), can perform accurate measurements of airflow rates close to fans, which suggest that this method could also be applicable to other flow disturbances. However, our measurements concern naturally ventilated buildings as the FANS system is assumed to be used for buildings that are mechanically ventilated (Gay, 2004).

Van Overbeke et al. (2013) developed a reference method to measure and calculate the airflow when placing the sensor just in front of the opening. A 'new' outflow calculation surface is introduced, and is determined by the volume of the sensor placed before the total surface of the ventilation opening. The airflow is calculated through a summation of the multiplication of all areas and their vectors perpendicular to the surface. The airflow through the opening is calculated with the following formula:

$$Q\ (m^3/s) = \sum \perp v\ (m/s) \cdot A\ (m^2)$$

When calculating the airflow through a rectangular section, the areas of the outflow are multiplied by the normal vector components of the velocities and summed. Because of the dimensions of the ultrasonic sensor head (diameter 0,25 m; height 0,125 m) and the placement of sensors just in front of the opening, the vector perpendicular to the opening (Y-component, see figure 4) may not reflect all outgoing air. The resulting vector is divided in its three components, the Y-component (normal vector), Z-component (vertical direction) and X-component (horizontal direction). To reflect an accurate reference of the outgoing air, the three velocity components have to be taken into account together with the dimension of the sensor head (diameter 0,25 m; height 0,125 m) that determines the related area. For example, in this situation the X-component of the velocity vector (for one measurement) on the side of the opening will be multiplied with an area of 0,125 m (H) x 0,25 m (W).

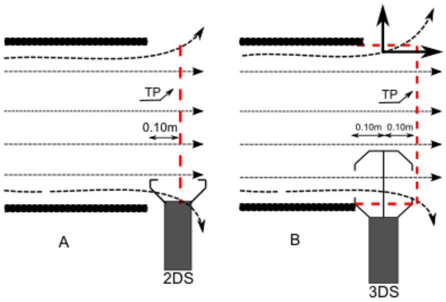

Figure 4: air volume for calculating the mean velocity with perpendicular vectors
Figure 5: new outflow surface around volume of the sensors

Mean values of the measured airflows through the opening can be visualised (see figure 6).

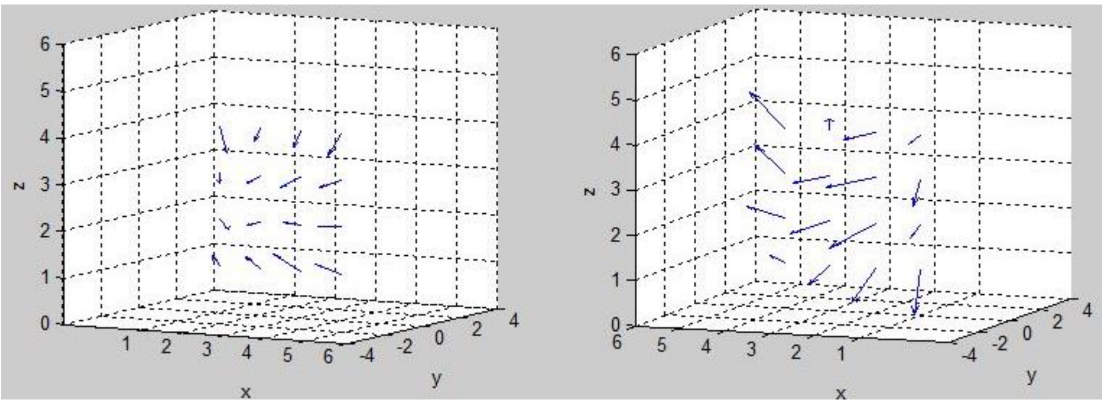

Figure 6: visualisation of the airflow through the side openings (1m)

<u>Future data processing for reference method development</u>

One of the potential and promising ways to process the field data is to use artificial neural networks.
An artificial neural network is used for predictive modelling and will be trained with the dataset of the field test facility. Like biological neural networks, artificial neural networks consist of a network of neurons. This network can be adapted by different means: a choice of algorithms altering of the weights of the connections to produce the targeted airflow rate, enlarging of the dataset, changing the number of layers in the network,.... The dataset of the test facility will be used to feed the network with input data. The data to feed the target data for the network will be generated with the developed reference method (Van Overbeke et al., 2013).

Results & Discussion

A test facility for field measurements was developed and built with full measuring equipment as previously discussed.

The developed real scale test construction will allow to measure and study the air flows and related characteristics over relatively long periods, under real conditions of natural ventilation. Therefore, the results of the measurements will automatically include a variety of different weather conditions and should give a good representation of measurements of airflows in situations over a year .
Measurement results over a complete year should allow to collect datasets to feed artificial neural networks for data processing and eventually to develop an adapted (reduced), accurate and reliable measuring method for predicting the airflow under real life conditions of natural ventilation.

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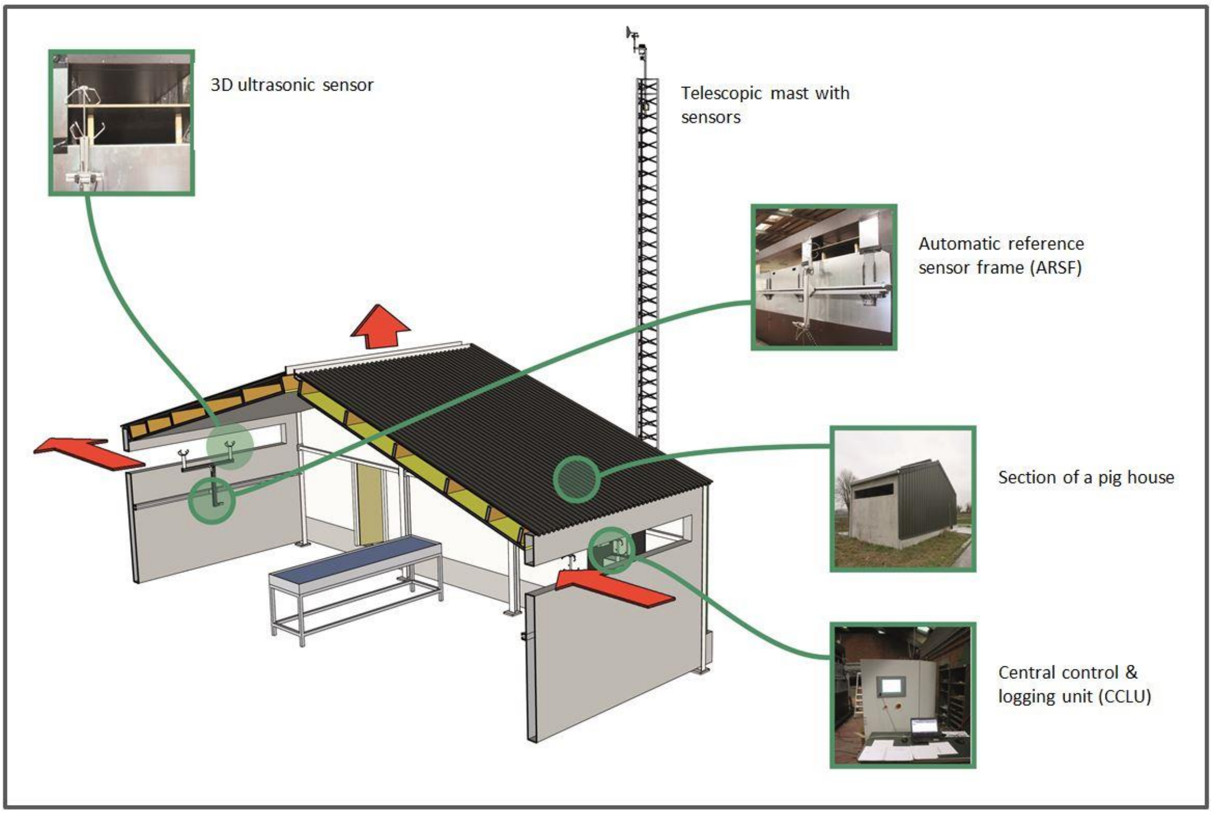

Figure: section of the test construction

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