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A review on different approaches for evaluating ventilation rate in laying hen facilities

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Abstract**—**Air pollution has become one of the most remarkable environmental concerns associated with sustainable agriculture development. To accurately determine air pollutant emission rates from livestock buildings, determination of ventilation rate and pollutant concentrations are both imperative, because the air pollutant emission rate is the product of ventilation rate and pollutant concentration. On the other hand, ventilation rate evaluation is necessary to develop technologies to mitigate emissions and to predict pollutants transportation and dispersion patterns from livestock buildings. Different experimental and numerical approaches have been adopted so far to determine the ventilation rates of poultry layer houses which are reviewed and discussed in this study. A classification of experimental measurement techniques is given and previous studies on layer houses which employed those techniques are mentioned. Beside experimental ventilation rate measurement approach, numerical simulation is another tool to estimate ventilation. In recent years, computational fluid dynamics (CFD) has become increasingly important in the study of airflow and ventilation patterns in layers houses. Steps involved in numerical simulation of layer houses are discussed and previous simulation studies adopted in layer houses are discussed. This article aims to facilitate researchers in their search for ventilation evaluation approaches in layer houses by providing a review of the available approaches and techniques.

Keywords—ventilation, layer house, in-situ measurement, CFD

I. Introduction

The welfare and egg productivity of laying hens are closely intertwined with their immediate environment. As a result, indoor microclimate assessment is crucial in providing birds with their ultimate comfort conditions. A well-functioning ventilation system should maintain a continuous airflow, providing sufficient oxygen, appropriate air velocity, temperature, and humidity, while effectively removing dust and gaseous pollutants.

Layer houses are typically large structures with multiple inlets and outlets. Typically, a very complex airflow phenomenon exists in layer houses. Estimating the ventilation rate in a layer barn is challenging because of the effects of various factors such as time and season, harsh environment, dynamic and irregular wind effects, housing system type, and some uncontrollable variations in exhaust fans such as large numbers of fans, having several sizes and types, and asymmetric installation of fans inside the barn.

Different experimental and numerical approaches have been employed for the evaluation of ventilation in layer houses which the present study aims to review and categorize. First, experimental approaches are classified, and the measuring instruments are discussed along with studies which implemented each of the devices in layer houses. Second, the numerical simulation approach for ventilation estimation is explored. The crucial steps involved in simulation of indoor microclimate of layer houses and ventilation assessment are explained and studies which have applied the simulation approach are mentioned.

II. Experimental approach for ventilation evaluation

Two primary techniques exist for in-situ measurement of the ventilation rate of a laying hen house: direct and indirect methods. In Fig. 1, a classification of different methods for ventilation measurement is illustrated.

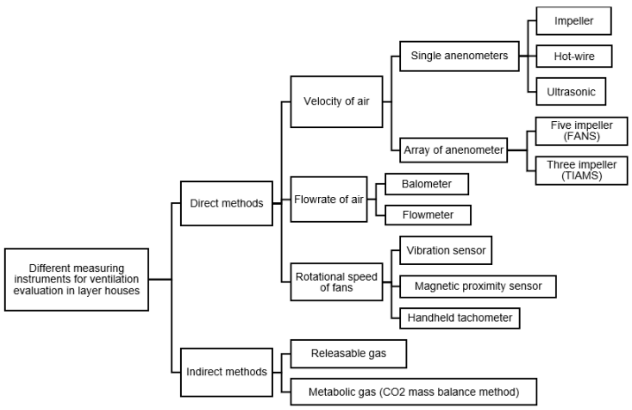

Figure 1. Classification of different measuring instruments for ventilation evaluation.

A. *Direct measuring methods*

Direct measurement involves in-situ determination of the airflow rate of exhaust fans in operation in the barn. In direct methods, devices either measure 1) air velocity from the fans or 2) flowrate of the air, or 3) the rotational speed of the fans.

1) *Velocity of air measurement*

The velocity of air is measured by using anemometers. Anemometers measure the amount of wind pressure acting against a surface and can gather quite accurate readings. Anemometers are used either as single or in an array.

a) *Single anemometers*

The use of anemometers is useful in applications where portability and size are important to the data collection process. The working principle of anemometers varies depending on blade shape, orientation, method of detection, etc. The seven different types of anemometers are cup, propeller, hot-wire, vane, ultrasonic, pressure, and tube.

Impeller anemometers consist of blades that spin perpendicular to their connected shaft. Air pushes the blades around which generates a current proportional to wind speed. These devices can measure speed in one direction and were used in a study by [1].

Hot-wire anemometers consist of a wire that is heated to a certain temperature, which is then cooled by the airflow it is exposed to. The wind velocity is then able to be calculated through the heat transfer from the wire during cooling. These devices have been extensively used in previous studies [2-6].

Ultrasonic anemometers utilize sound waves to measure velocity. It measures how much sound waves travelling between a pair of transducers are sped up or slowed down by airflow. By measuring frequency, and having no moving parts, the device can give measurements with high resolution. They have been used in a study by [7].

b) *Array of anemometers*

The use of an array of anemometers is useful in measuring the velocity of large-diameter fans. However, it is only suitable for periodic testing and monitoring.

Fan Assessment Numeration System (FANS) incorporates multiple impeller/propeller anemometers in a horizontal array to perform real-time traverse of airflow entering the ventilation fans [8]. The anemometers move vertically, over the cross-sectional area of the fan. A DC voltage is generated, which is linearly proportional to the air velocity. This measurement can then be multiplied by the cross-sectional area to calculate volumetric flow rate. This method is suitable for fans of up to 137 cm in diameter and is only for perioding fan testing and monitoring. This method has been widely used in many layer barn studies [9-16].

The Three-impeller anemometer airflow monitoring system (TIAMS) is an alternative to FANS, proposed for when it is too large for the fans to be measured. In this system, the three impeller anemometers are secured at a fixed height to measure the varying air speed across the diameter of the fan. TIAMS is suitable for variable-speed fans of up to 61 cm in diameter and is only for periodic testing and monitoring. This method was used in a study by Lim [17].

2) *Flow rate of air measurement*

Some devices are able to directly measure air flow rate directly. The two different types of airflow rate measurement instruments are balometers and flowmeters.

a) *Balometer*

Balometers are capture hood devices that measure velocity and pressure to take direct air volume readings, even of very low volumetric flows. This device contains a grid with many holes called a flow grid and a micro-manometer to measure flow and pressure through the grid. Comparing the pressure to the atmospheric pressure gives a volumetric flow rate. Balometers use an S-Type Pitot tube matrix to determine the pressure drop between the Balometer grid and atmospheric pressure. Balometer was used in layer house studies by Dixon [18].

b) *Flowmeter*

A flowmeter is an instrument that indicates the fluid moving through a space by measuring mass or volumetric flow rates. There are different principles that flowmeters can operate on. These include mechanical, pressure drop bases, vortex, optical, thermal, ultrasonic, electromagnetic, and mass flowmeters. A thermal-mass flow which is based on the physical effect of heat convection was used in a layer house study by Chepete [19].

3) *Rotational speed of fans measurement*

One other method of ventilation rate determination is by measuring fan rotational speed (FRS). FRS can be measured by either 1) vibration sensors, 2) magnetic proximity sensors, and 3) handheld tachometers. The fan airflow is nonlinearly related to the differential pressure and linearly proportional to FRS. The pressure difference across the walls where ventilation fans are installed in the barn can be obtained using pressure transducers [20].

a) *Vibration sensors*

Vibration sensors monitor fan operation status, making this device suitable for single speed (on/off) fans. Within the sensor is a vibration transducer, which converts mechanical movement into an electric signal. It also contains an electronic unit which processes the signal and can output data in digital form. These sensors are suitable for large scale applications and provide only on/off status of fans. They are also low cost and have easy installation. This type of device was used in a study by Chai [21].

b) *Magnetic proximity sensor*

Magnetic proximity sensors are used for non-contact object detection and can measure variation in distance to the object by an electromagnetic field. These devices are suitable for measuring the fan rotational speed of variable-speed fans and can be used for continuous fan testing and monitoring. Chai used such device to measure both rotational speed and differential pressure in his study [21].

c) *Handheld tachometer*

Electronic handheld non-contact tachometers measure rotational speed by lasers, infrared or LED light. This light reflects off the blade or a piece of tape attached to the rotation point, allowing the device to take measurements [21].

B. *Indirect measuring methods*

Instead of using a device to directly measure wind or fan rotational speed, an alternative reliable method can be using gas tracers. These tracers consist of different gases, which are measured over time, and then analyzed. The method of using gases to indirectly measure ventilation rate applies to naturally and mechanically ventilated buildings.

1) *Releasable gas*

In this approach, a known amount of tracer gas is released and then monitored at downward points to measure the decay rate. This allows for the calculation of the air exchange rate. The commonly used gases for this technique include carbon monoxide, helium, and sulfur hexafluoride (SF6) [22].

2) *Metabolic gas (CO2 mass balance method)*

Metabolic tracers are analyzed similarly to releasable tracers. The gas that is commonly monitored in this method is CO2. In the CO2 balance method, carbon dioxide concentrations are measured by either air sampling and gas chromatography or in-situ instruments. This basis for the estimation of ventilation flow uses a series of equations for the relation between concentrations and flow rates and has been adopted by various studies to measure and validate ventilation rates in different layer house studies [23-27].

III. NUMERICAL APPROACH FOR VENTILATION EVALUATION

As an alternative to field measurements, numerical simulation by CFD is a powerful and cost-effective tool for the prediction of indoor microclimate of laying hen houses. CFD can facilitate the exploration and testing of different ventilation scenarios in a virtual environment and provide detailed insights into traditional and alternative ventilation patterns. Moreover, CFD has the ability to be combined with machine learning (ML), which opens many possibilities for improving simulations of technical and natural systems [28].

CFD analysis consists of three main steps: pre-processing, processing, and post-processing. The steps and details of CFD approach are illustrated in Fig. 2.

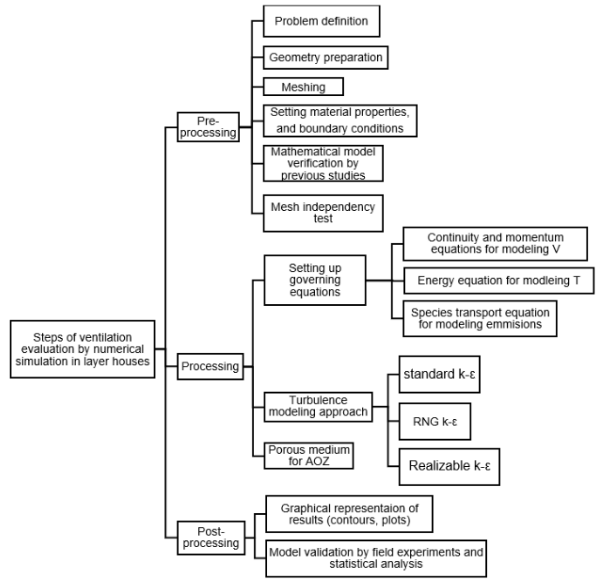

Figure 2. Steps involved in ventilation evaluation by numerical simulation in layer houses.

A. *Pre-processing*

The first step is pre-processing, which involves defining the problem; creating the geometry of the layer house; subdividing the geometry into smaller, discrete control volumes or cells, a procedure called “meshing”; setting the physical properties of materials; defining the boundary conditions for walls (sidewalls, floor, ceiling, cages), inlets (baffles and eaves), and outlets (exhaust fans).

Usually, the model is verified by simulating previous similar studies. A mesh independency test is also performed to ascertain that the obtained results are independent of the number of grids.

B. *Processing*

Processing involves setting up governing equations (continuity, and momentum) for fluid flow. These mathematical equations are applied to each control volume (mesh) and solved to obtain velocity and temperature distributions in the computational domain (i.e., the barn). If transport of pollutants generated in the layer house are to be simulated, the species transport equation should also be considered. Some previous CFD studies have simulated the dispersion patterns of NH_3 [29-31], bio-aerosols [32], and pathogens [33].

Chickens inside the cages is called animal-occupied zone (AOZ). Some previous studies have simplified the AOZ as heated solid [29,30,34]. However, this assumption of treating AOZ as solid blocks prevents further understanding of the airflow and heat exchange mechanism between AOZ and its surrounding space. Therefore, recent studies have tried to apply the porous medium approach to the AOZ [31-33,35-37]. In this case, flow resistance coefficients are taken into account [38].

Since the airflow inside the barn has complex patterns, a turbulence model should be considered to capture flow fluctuations. The most commonly used turbulence models in layer houses were the standard k-ε [29,39,40,37], renormalization group (RNG) k-ε [30,31,33,34,36] and realizable k-ε [32,35] models .

C. Post-processing

The final step in CFD is post-processing. Once the solution is converged, the results are graphically presented by vector plots, contour plots, data curves, and streamlines. Visualization helps to grasp the distribution of airflow and evaluate the microclimate environment within the layer house. In this step, the model is usually validated by taking with field measurements and comparing the experimentally obtained data with the numerical simulation results.

IV. Conclusions

Ventilation is critical to maintain a favourable indoor microclimate for laying hens. When the layer house environment is enhanced; egg production will increase, animal welfare will improve, and carbon footprints will reduce. This study aimed to comprehensively review the available ventilation estimation approaches that have been utilized in laying hen houses. Ventilation can be evaluated by either experimental in-situ measurements or by simulation using CFD. Both approaches are discussed, and previous studies that implemented those approaches in layer houses are reviewed. CFD analysis is regarded as a cost-efficient and time-saving alternative to traditional field measurements with the ability to be combined with machine learning techniques to improve and optimize layer house microclimate conditions. A combination of measuring and modeling techniques can provide a reliable estimation of ventilation in these buildings.

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