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MEASUREMENT METHOD OF VENTILATION RATE WITH TRACER GAS METHOD IN OPEN TYPE LIVESTOCK HOUSES

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ABSTRACT The relationship between locations of tracer gas measuring points and those of the emitted point in the constant emission method was examined to investigate a measurement method of ventilation rate in Japanese open type dairy houses. Wind tunnel model experiments were performed. The constant emission method which is applied easier on site was compared to the concentration decay method. An air exchange rate obtained from the constant emission method was 5 times as large as that from the concentration decay method when the tracer gas measuring points were distributed in the house. The air exchange rate was estimated 40 % as small as that from concentration decay method when the measuring point was located near the tracer gas emitted point.

Keywords: livestock house, natural ventilation, tracer gas method

INTRODUCTION Usually it is difficult to measure ventilation rate in open type livestock houses rather than green houses in Japan because open area and building size in livestock houses is larger than those in greenhouses. The more accurate measurement method of ventilation rate is requested.

There are several methods to measure natural ventilation rate, for example, a heat balance method, a moisture balance method and a tracer gas method. The concept of these methods is to obtain ventilation rate by measuring balance of mass or heat which are moving with airflow (e.g., Fernandez and Bailey, 1992; Munoz et. al., 1999 and 2001). According to the marker of airflow, it is referred to as either a heat balance method or a tracer gas method. It is inconvenient to use the heat or moisture balance method because the response of changing to ventilation rate is slow and the generation rate of heat or moisture should be known or assumed. Therefore tracer gas method is better than other methods. There are three kinds of tracer gas method, which are 1) constant concentration, 2) constant emission and 3) concentration decay. Many previous researches adapted the concentration decay method among tracer gas methods and nitrous oxide as a tracer gas. Baptista et al. (1999) compared the concentration decay method to the constant emission method in a greenhouse. The results obtained from both methods showed good agreement for wind speeds greater than 1 m s^{-1}. However, it is impossible to apply concentration decay method to practical open type livestock house in Japan because the open area can not be closed as to be so large. In commercial farms the most practical and convenient method seems to be constant concentration method because tracer gas is only generated constantly. However, this method only expresses local ventilation rate. Ikeguchi et al. (2005) investigated constant concentration method in a greenhouse. They reported responded sensitively and was not affected by the tracer gas dosing area size.

Therefore the objective of this study was to exam location of measuring points in the constant emission method with wind tunnel tests in order to eliminate external causes. As to be a true ventilation rate obtained from decay method, comparison with proposed method to decay method was performed. A relationship between location and measuring points was examined.

TRACER GAS METHOD Above three tracer gas methods are based on the balance equation of a marker gas and are simplified by assumptions. The basic balance equation was expressed as follows:

$$V\frac{dM}{dt} = P(t) + \nu(t)M_O - \nu(t)M(t) \qquad (1)$$

where: V is a volume of ventilation space, m^3; M is a concentration, mg m^{-3}; t is a time, s; ν is a ventilation rate, m^3 s^{-1}; P is generation rate of tracer gas, mg s^{-1}; subscript O means outside. The left hand term expresses the change of gas quantity in the objective ventilation space and first term in the right hand shows generation inside the space, the second term in the right hand shows incoming gas quantity and the third one shows outgoing gas quantity.

The concentration decay method is required complete diffusion and discrete ventilation rate is obtained for short period. The tracer gas at a certain concentration is filled with in the space and the gas concentration difference between certain times is measured. When the open area of the building can be closed, complete diffusion of tracer gas can be reached. Likewise, from equation (1) the ventilation rate is expressed as follows;

$$\nu = V\frac{log(C_0) - log(C_1)}{t_1} \qquad (2)$$

where; subscript 0 is time at 0 and subscript 1 is time at 1. C is constant gas concentration, , mg m^{-3}

The constant emission method is required complete diffusion of gas in the objective ventilation space. It has assumption that the ventilation rate is constant and the gas concentration is constant. The constant concentration gas is generated constantly. The ventilation is calculated from the equation (1) under required condition;

$$\nu = \frac{P}{C} \qquad (3)$$

The constant emission method and the concentration decay method have the same assumption of complete diffusion. But it is difficult for an actual naturally ventilated livestock houses to accept this assumption because the tracer gas is realistically not able to diffuse well in the constant emission method.

In this study constant emission was adapted as a method of generated tracer gas because it is ease to do on site. The remaining issue is space distribution of ventilation rate. It is seemed that there are tracer gas emission point and measuring point at each divided space in the livestock house. However, it is not practical on site when there are many divided spaces. So tracer gas generated points were lessened and the location of measuring points were examined by compared with concentration decay method. In this study ventilation rate was calculated from the following equation which was derived from a discrete balance equation (1);

$$v = \frac{P}{C_t} - V\frac{(C_{t+1} - C_{t-1})}{2\,\Delta t\,C_t} \qquad (4)$$

This equation was used central difference with respect to time. An air exchange rate (*AER*) was used as an index of ventilation;

$$AER = \frac{v}{V} \times 60 \qquad (5)$$

where: *AER* is air exchange rate, h^{-1}.

WIND TUNNEL EXPERIMENT To eliminate external causes wind tunnel tests were performed. The wind tunnel used was located at the National Institute for Rural Engineering, Japan. The length was 68 m including the 20 m testing section. The cross-section in the testing section was 4 m by 3 m. The plane and cross-section in the testing section view are shown in figure. 1. Spires, blocks and artificial grass carpet placed in the testing section were used to develop an adequate wind speed and turbulence intensity profile. The windward scale model building was put on a turntable that was located 12.6 m downward from the front of the testing section.

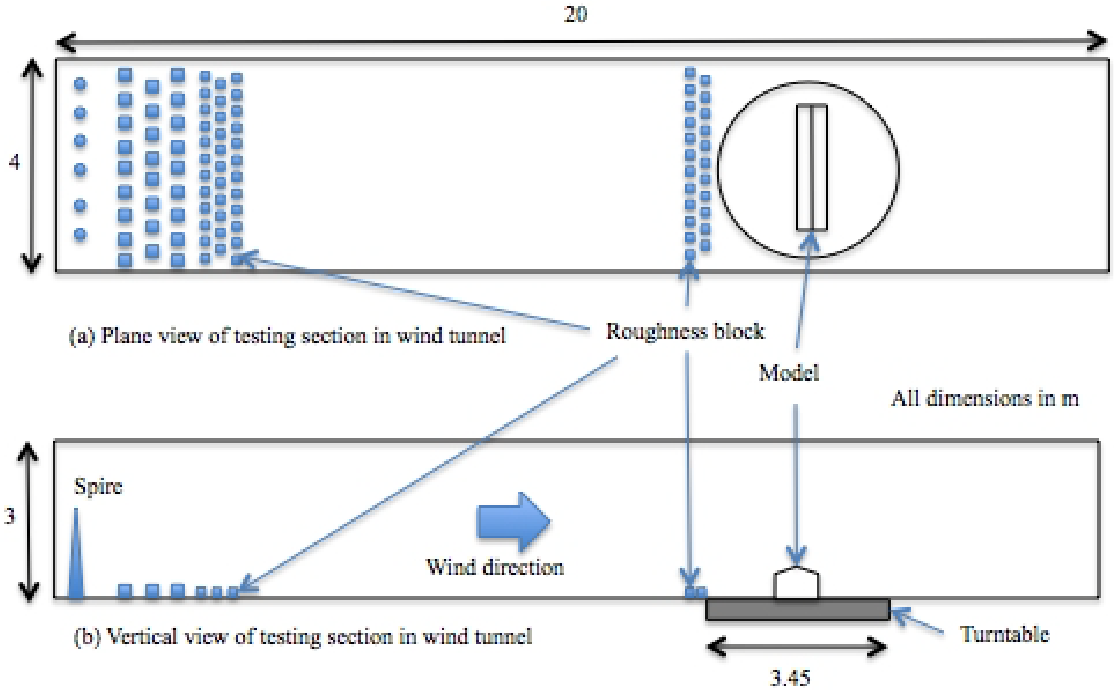

Figure 1. Wind tunnel.

It was assumed that airflow was steady state and non-isothermal. Though 1/10 scale model of actual dairy burn was used, similarity was not applied. The ventilation rate of the model itself was used as a ventilation rate. The representative mean air velocity at ridge height was 0.88 m s^{-1}.

Target livestock house An actual dairy burn was imitated and the scale was one tenth. The model was made of acrylic board with 2 mm thickness and 5 mm aluminum square pipe. The length was 1.8 m, the width was 1.2 m, eaves height was 0.386 m and the ridge height was 0.567 m. The dimension and the measuring points of gas are shown in figure 2.

Measurement Sulfur hexafluoride (SF_6) was used as a tracer gas. The measurement system of gas concentration was composed of a Photoacoustic Multi-gas Monitor (Innova AirTech Instruments A/S, Denmark: model 1412) and a multipoint sampler (Innova AirTech Instruments A/S, Denmark: model 1309) with an accuracy of ± 0.1 ppm. The sampling interval was about 20 sec.

In the concentration decay method the measuring protocol was the following;

1. The model was covered with a sheet and the tracer gas was filled within the model.
2. When inside concentration reached more than 100 ppm, the tracer gas was stopped emitting.
3. The sheet was removed as fast as possible.
4. Decreasing concentration was measured.

At 12 points inside the model (figure 2) the concentration of decay was measured one by one following above protocol. These average value was used for calculating a standard ventilation rate. Furthermore, ventilation rate was calculated with the measuring points at open area.

For the constant emission, ventilation space was divided into two volume and there was generation point in the center of the volume each zone. The number of measuring points was 6 in each zone and the points were located at the center of each face (figure 2). SF_6 was emitted continuously at 3.3×10^{-6} m^3 s^{-1} with a digital mass flow controller (Yamatake Co. model CMQ0020B). After reaching steady state inside gas concentration, measurement of gas concentration was started. The sampling period was 3 hours and the average value was used. Furthermore, ventilation rate at open area was calculated. And as an ordinary way, ventilation rate was also calculated using the location near the tracer gas generation point. The measuring point was located at 3 cm below the generation point.

Experiment design The experiment cases are shown in table 1. Case 1 was standard ventilation rate and case 2 was concentration decay method and the measuring points were located at opening. Case 3, 4 and 5 were constant emission (CE) method . The location of measuring point in case 3, 4 and 5 were inside, near tracer gas generation point and opening, respectively.

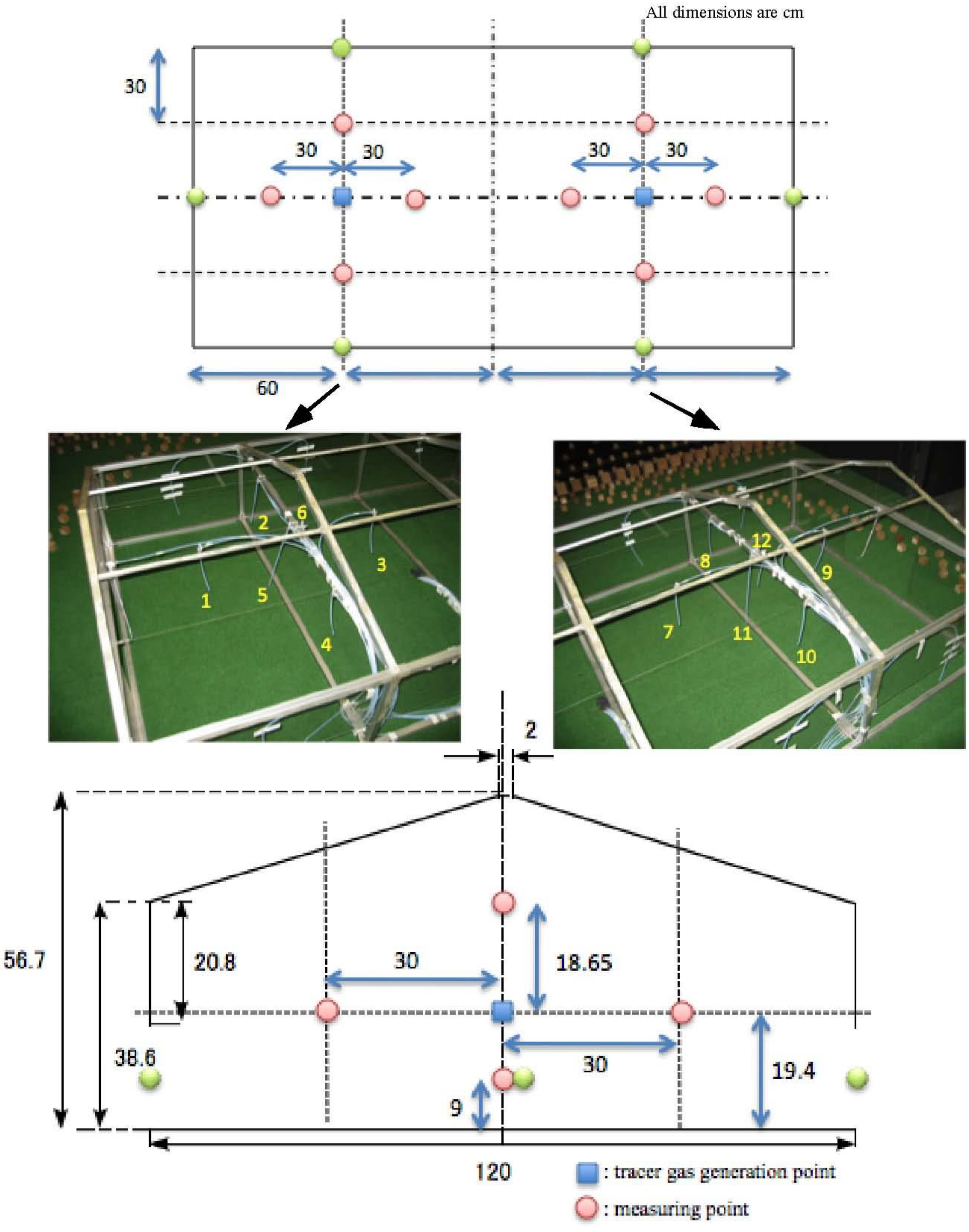

Figure 2. The dimension of model and the locations of gas measuring point

Table 1. Experiment cases.

Experiment case	Tracer gas method	Location of measuring point
1	concentration decay	inside: standard
2	concentration decay	opening
3	constant emission	inside
4	constant emission	near gas generation point
5	constant emission	opening

RESULTS AND DISCUSSION A space average air exchange rate (*AER*) calculated in concentration decay method was 90.7 ± 8.4 h^{-1}. The coefficient of variation was 0.092. This average *AER* was used as a standard *AER*. In the experiment case 2 the *AER* was 86.0 h^{-1} and the value was close to the standard *AER*. *AER*s in the experiment cases are shown in figure 3.

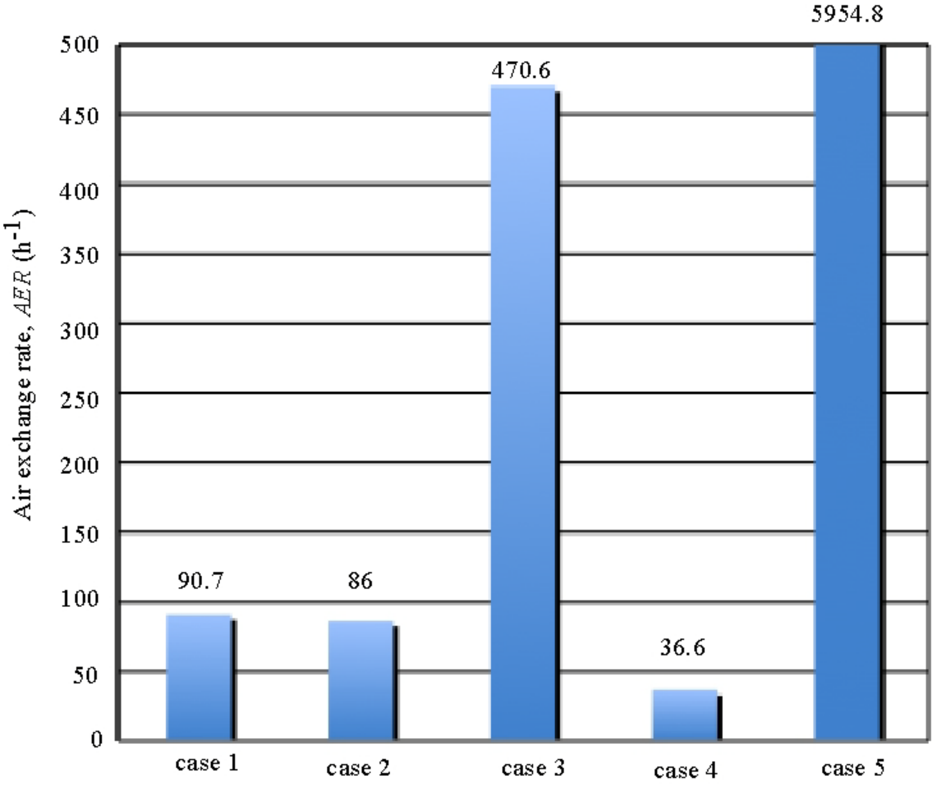

Figure 3. Air exchange rate (*AER*) in all experiment cases.

Air exchange rate (*AER*) in constant emission method The inside space average of *AER* in the concentration emission method was 470.6 ± 190.0 h^{-1} and the average value was about 5 times as large as the standard *AER*. *AERs* at all measuring points in the constant emission method were larger than the standard value. This indicates that emitted tracer gas was not diffused well and the measuring points could not catch the tracer gas flow. Many measuring points in the house did not always show the correct value. On site it is tedious to install many measuring points actually.

The coefficient of variation in the experiment case 3 was 0.4. The variation was large according to the measuring location. The *AERs* are shown in table 2. There was significant difference among the location of measuring points (F=12.3, (11,24), P=0.0000). The larger *AERs* were shown at measuring points number 3 and 7 (figure 2). These locations were the center in the house and incoming wind flowed this area. The largest value was seen at measuring point number 11.

Table 2. Experiment cases.

Measuring points	*AER* (h^{-1})	Measuring points	*AER* (h^{-1})
1	361.8	7	567.1
2	309.6	8	411.4
3	620.3	9	429.7
4	438.0	10	411.8
5	435.5	11	966.3
6	373.9	12	321.5

In the experiment case 4 *AER* was 36.6 ± 3.0 h^{-1} and the coefficient of variation was 0.081. The measuring point was close to the gas emission point. In this case the *AER* was estimated about 40 % as small as the standard *AER*. The tracer gas did not diffuse well at this location.

When the measuring points were located at the openings in the experiment case 5, the average *AER* was 5954 ± 398 h^{-1} and this value was about 66 times as large as the standard *AER*. This showed that it was impossible to measure correct *AER* at the air entrance.

In the constant emission method it is important the relationship between the location of measuring points and that of tracer gas emitted point. A wrong *AER* is calculated according to locations of measuring point and tracer gas emitted point. In this study, though appropriate relationship could not be find in constant emission method, it was shown how different between standard *AER* obtained from the concentration decay method and that from constant emission method.

CONCLUSION Wind tunnel model experiments were performed to investigate measurement method of ventilation rate for Japanese open type dairy houses. The relationship between location of tracer gas measuring points and emitted points was examined in the constant emission method which is applied easer on site rather than the concentration decay method. An air exchange rate (*AER*) calculated from the concentration decay method was used as a standard *AER* and was compared to the constant emission method. An *AER* obtained from constant emission method was 5 times as large as the standard *AER* when the tracer gas measuring points were distributed in the middle between the location of tracer gas emitted point and house boundary. When the measuring point was closed to the emitted point, the *AER* was about 40 % as small as the standard *AER*. It is necessary to prove appropriate positional relationship in the constant emission method as a future work.

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