TRACER GAS TECHNIQUE IN COMPARISON WITH OTHER TECHNIQUES FOR VENTILATION RATE MEASUREMENTS THROUGH NATURALLY VENTILATED BARNS

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ABSTRACT: Naturally ventilated barns have the advantages of providing energy saving and low noise environment for animals. Hence this type of building has gained wide acceptance worldwide. However, there is concern about the ammonia emissions and other airborne pollutants that cause direct damages to ecosystems. Therefore the researchers need to estimate the ventilation rate through out the barn at first to calculate the ammonia stream emitted from it. The calculations of the ventilation rate through such kind of stables are uncertain, because the inside climate in an open stable is directly influenced by atmospheric conditions. Tracer gas technique using radioactive gas (Krypton^{85}) was used to estimate the ventilation rates through two naturally ventilated dairy stables. A good relationship was found between the ventilation rate calculated from the tracer gas measurements and the one measured using velocity sensors at the inlet openings. The possibilities of this technique are described in this paper and the obtained results are compared with other methods. Finally some recommendations have been concluded to improve the experimental procedure and evaluation methodology.

Keywords: naturally ventilated barns, tracer gas technique and ventilation rate

INTRODUCTION: The livestock building structure and the type of the ventilation system have substantial influence on the climatic and environmental variables within the stable which in turn affects the animal welfare and airborne gas emission rate. The ventilation is required for removing harmful gases in order to ensure an acceptable indoor air quality. The microclimate variables such as the concentration of gases, temperature, velocity, dust and humidity have an influence on welfare of animals, workers and the buildings themselves. Naturally ventilated barns are so called due to natural driving forces (wind effect and thermal buoyancy). These systems should be flexible to provide a comfortable environment for animals throughout the year. These requirements are different according to the dominating season. The minimum ventilation rate per cow to keep CO_2 concentrations below recommended harmful limits (3000 ppm according to CIGR, 1984) is 100 m^3h^{-1}. For typical dairy building with 100 m^3 space per cow, the minimum exchange rate of air is about once per hour to fulfil this requirement of refreshment. Air movement in the velocity range between 1 to 2 (m/s) across the cows is needed (Turner et. al., 1997). The knowledge of ventilation rates throughout such kind of building is essential for determining indoor air quality and for estimating the emission stream of harmful gases and particles. The ventilation rate and the gas concentration in the exhaust air must be known to quantify the emission stream. Whereas the determination of the emissions stream from buildings with forced ventilation is a standard procedure, it is still considered to be a challenge to record this stream from naturally ventilated buildings, which are widespread in cattle farming. Such buildings have wide air openings with large contact surfaces with the outside environment, which complicates to measure ventilation rate through the structure. Hence the emission rates are directly influenced by a lot of factors including the outside atmospheric conditions with permanently changing conditions (Brehme, 2000).

The ventilation rate throughout the naturally ventilated barn is dependent on both the thermal buoyancy forces and the wind pressure on the openings of the building. In order to determine the ventilation rate in such cases, many approaches can be found in the literature i.e. tracer gas technique. The tracer gas may be carbon dioxide CO_2 (Kittas et al., 1996), nitrous oxide N_2O or sulphur hexafluoride SF_6 (Seipelt et al., 1999; Snell et al., 2003).

Tracer gases are used for wide variety of diagnostic techniques including leak detection and atmospheric tracing (Sherman, 1988). In addition the tracer gas techniques are the only way of making many types of quantitative measurements of ventilation. These include infiltration, air exchange measurements, fume hood efficiencies and spreading of pollutants. In other cases tracer gas analysis methods are chosen in preference to other analysis methods because they are more convenient and more accurate (Peter et al). A very important aspect of tracer gas technique is the possibility to test occupied building. This is not only more convenient but also much more accurate since it takes into account the large effect occupancy on the ventilation rate. For instance the effect of opening and closing doors and windows, this can present the normal working conditions that are important in most cases. Generally there are four known tracer gas methods as following: 1- Constant tracer gas injection. 2- Variable tracer gas injection. 3- Fan duct constant flow. 4- Concentration decay. With this technique the tracer gas would be injected in the tested barn. The knowledge about how the tracer gas varies with time and in space gives information about total and local ventilation rates, ventilation effectiveness and the distribution of gas in the barn. This technique is based on the assumption of completely mixing of tracer gas with air in the barn. However in practice, completely mixed air spaces are rarely found in naturally ventilated buildings and it is difficult to achieve uniform distribution of the tracer gas within the space (Barber & Ogilvie, 1982). The most convenient method for using $Krypton^{85}$ in livestock building is the concentration decay. The reasons are many e.g. risk of radioactive gas, huge building size, environment requirements, costs and also the decay method doesn’t need a lot amount of tracer gas. A lot of information about the spatial and temporary distribution of the inside air can be estimated by using eighteen sensors which enable measurement of $Krypton^{85}$ concentration at different points with high resolutions in time (one record per second).

OBJECTIVE: There is still no applicable method for an accurate, reliable and online ventilation rate measurement throughout the naturally ventilated barns. Therefore the purpose of this study was to compare between the obtained ventilation rates values according to widely used tracer gas technique and air velocity through the opening. This comparison can be useful to understand dynamic behaviour of the ventilation rate which was measured by velocity sensors in relation to the global ventilation rate measured by tracer gas technique over a very short period (1 min.).

MATERIALS AND METHODS: The service trips were performed covering both the mild and the cold periods of the year. Measurements of ventilation rate were carried out in two dairy cattle building situated in eastern Germany. There were about 220 milking cows. The first goal of these service trips was to determine the ventilation rate throughout these barns by using tracer gas technique ($Krypton^{85}$).

1. Experimental barns Both of experimental barns were naturally ventilated by adjustable opening using plastic curtains at the side walls. The both barns were nearly similar in dimensions and constructions. The area of each barn was 1575 m², with a volume of 5670 m³, length 75 m, width: 21 m and height: 3.6 m. The keeping system was for both barns loose housing with laying boxes and the milking centre was in a nearby building of both barns. The first barn A had 230 laying boxes with litter technique and five fans inside the barn over the manure alley to great air movement in longitudinal axis. The barn had solid concrete floors with four rows of laying boxes, two feeding passages and three manure alleys. Figure [1] shows horizontal section of the barn and sensors locations.

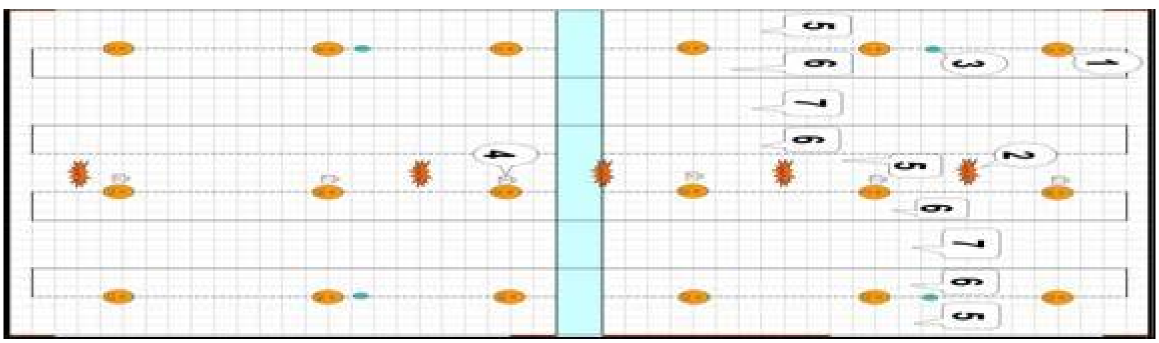


Figure 1. Horizontal section of dairy barn A. 1. Sensor of radioactive gas $Krypton^{85}$. 2. Fan. 3. Thermometer. 4. Data logger. 5. Manure alley. 6. Laying boxes. 7. Feeding passage.

Also it was equipped with eight additional mixing fans at one side wall in the dominant wind direction (cross ventilation system). The purpose of these side fans is to increase the ventilation rate and the air movement in the animal zone. As well as it avoids the heat stress in the hot condition in the summer.

Additionally twenty four impeller anemometers were fixed along same side wall in the dominant wind direction to measure the horizontal air velocity through the opening as shown in figure [2].

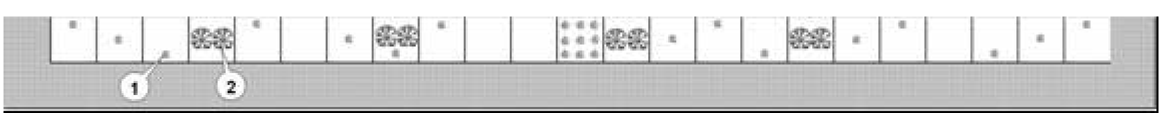


Figure 2. side view of dairy barn A. 1. Impeller anemometer. 2. Huge side fans.

The dung was removed every day by tractors to the manure yard outside of the barn.

The second barn B had 240 laying boxes with rubber mattress (Figure 3). Closed to the barn there were two round silo storages were situated in the southern area.

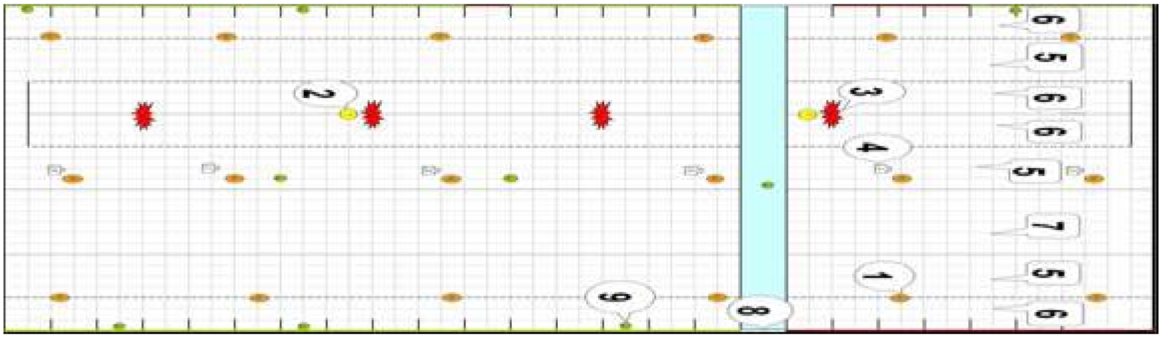


Figure 3. Horizontal section of dairy barn B. 1. Sensor of radioactive gas Krypton^{85}. 2. Thermometer. 3. Fan. 4. Data logger. 5. Manure alley 6. Laying boxes. 7. Feeding passage. 8. Passage to milking centre. 9. Ammonia sensor.

The building had solid concrete floors with four rows of laying boxes where two rows of laying boxes were placed at both side walls and the others two rows were closed to each other in the southern half of the barn between two manure alleys. Only one feed passage between two manure alleys were in the northern half of the barn. Four huge fans were constructed over the middle rows of laying boxes to enhance the air movement in longitudinal axis. The dung was removed by a delta manure scraper. The manure was stored in an underground concrete tank covered by iron sheets. Twenty impeller anemometers were fixed along same side wall of dominant wind direction as shown in figure [4] as well as three more impeller anemometers were fixed at front wall of the barn.

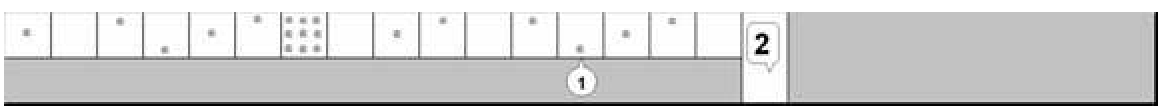


Figure 4. Side view of dairy barn B. 1. Impeller anemometer. 2. Gate to milking centre.

2. Tracer gas technique The sensors to measure Krypton^{85} concentrations were symmetriccally distributed inside the barn at a height of two meter above the floor. As known Krypton^{85} is a radioactive gas and it radiates electrons as Beta rays. The tracer gas Krypton^{85} was injected as fast as possible in the stable, while the sensors were measuring the resulting beta rays. The impulses can represent the concentration of radioactive gas with the time. The concentration of tracer gas was found to decay exponentially with time. By plotting the natural logarithm of tracer gas concentrations against time a straight line should be obtained and the gradient of the line is the air exchange rate in the stable. The ventilation rate can be calculated by multiplying the air exchange rate with the barn volume. Equation [1] explains the calculation of air exchange rate:

$$N = \frac{\ln C(0) - \ln C(t_1)}{t_1} \quad \text{Eq (1)}$$

Where N is the air exchange rate (h^{-1}), C(0) is the concentration of tracer gas at time 0 (m^3/m^3), $C(t_1)$ is the gas concentration at time t_1 (m^3/m^3), t_1 is the total measurement period (h). The calculation of air change rate is based on a steady ventilation rate throughout the measurements. However, due to higly fluctuating airflow in the stable, this linear decrease was not always evident during the experiments.

3. Ventilation rate according to the air velocity through the opening The measurements of air velocity were done by using impeller anemometers, which were installed along side wall of dominant wind direction to measure the horizontal velocity of entering air. These impeller anemometers were fixed in three different heights (high level=0.3m, middle level= 1.0m and low level=1.7m under the roof) Figure [2] and [4]. This arrangement of impellers ensures a sufficient measuring accuracy at different openings and heights in the side wall at different adjustment of side plastic curtains. Each impeller delivers values of air velocity with sampling rate of one record per minute. The ventilation rates were calculated according to the equation [2].

$$VR = 3600 \times \sum_{i=1}^{i=n} V_{ave,n.} \times S_n \qquad \text{Eq(2)}$$

Where VR is the ventilation rate (m^3/h), n is the number of window, $V_{ave.}$ is the average air velocity through the window (m/s), S is the opened vertical area of the window (m^2).

RESULTS AND DISCUSSION Firstly, the ventilation rate values throughout the dairy barns were estimated according to the tracer gas trials. Each measuring point can deliver a probable value for ventilation rate, if there was a clear regression in the obtained impulse curve for this point. Even if this regression took place over short time like thirty seconds, the estimated value was taken into account. Analysis of collected data showed strong variations of the decay functions at different measuring points. High air velocities cause a faster dilution of the tracer gas concentration within the barn than low air velocities. Also the decay behaviour in an open stable becomes highly variable at each measuring point due to the airflow pattern distribution (Van Buggenhout et al., 2009). Additionally, the dosing method has a big influence on decay method behaviour. Thus the estimated value from each sensor does not represent the situation of whole barn and it may be so far from the truth.

According to equation [1], C(0) is considered as a concentration of tracer gas at time 0 or at the beginning of experiment when the tracer gas was completely injected and well mixed with the stable air. That means the end of tracer gas injection and mixing process. In practice C(0) was taken as the beginning of selected clear regression in impulses curve. Figure [5] shows the obtained impulses curve for one sensor.

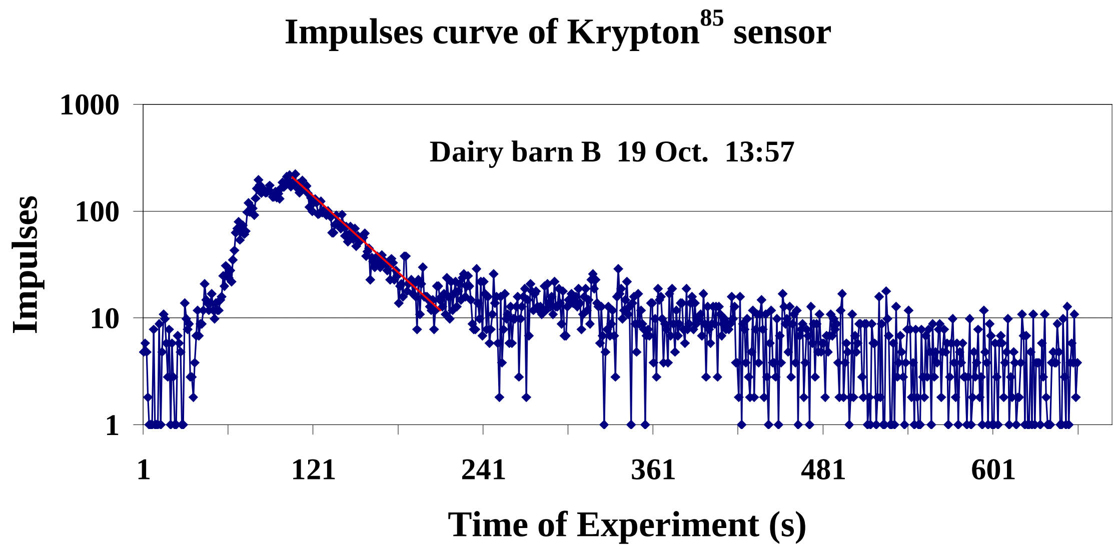


Figure 5. Impulses curve of one sensor for radioactive gas Krypton[85].

A few sensors had clear regressions in the obtained impulses curve and only those sensors could deliver probable values of ventilation rate at different times during the experiment period. The rest of data which showed a lot of fluctuations in impulses curve stayed outside the analysis. Therefore the sum of impulses for all sensors was taken and evaluated. According to this evaluation procedure the whole pure data were used and better regressions in impulses curves were found for all experiments. Therefore, the sum of impulses for all sensors together can represent the whole conditions in the barn (Figure 6).

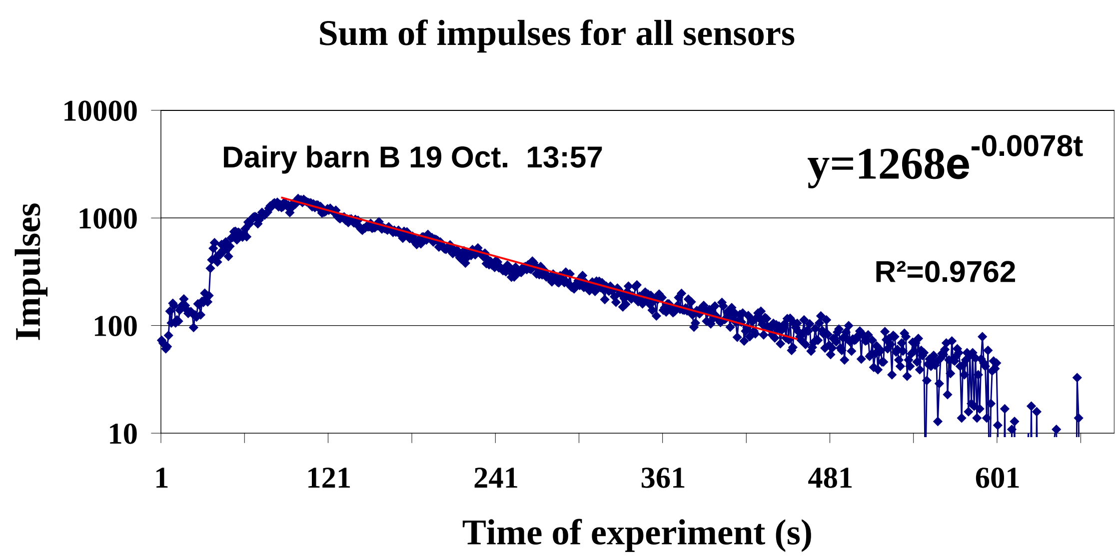


Figure 6. Sum of impulses for all sensors of Krypton[85].

During the experiment the tracer gas was completely injected in the first minute, but the sensors took more time to record the maximum value of all impulses. It was found that the sum of impulses showed more stability and fewer fluctuations than the single sensors, at least it could deliver probable values for ventilation rate for all experiments.

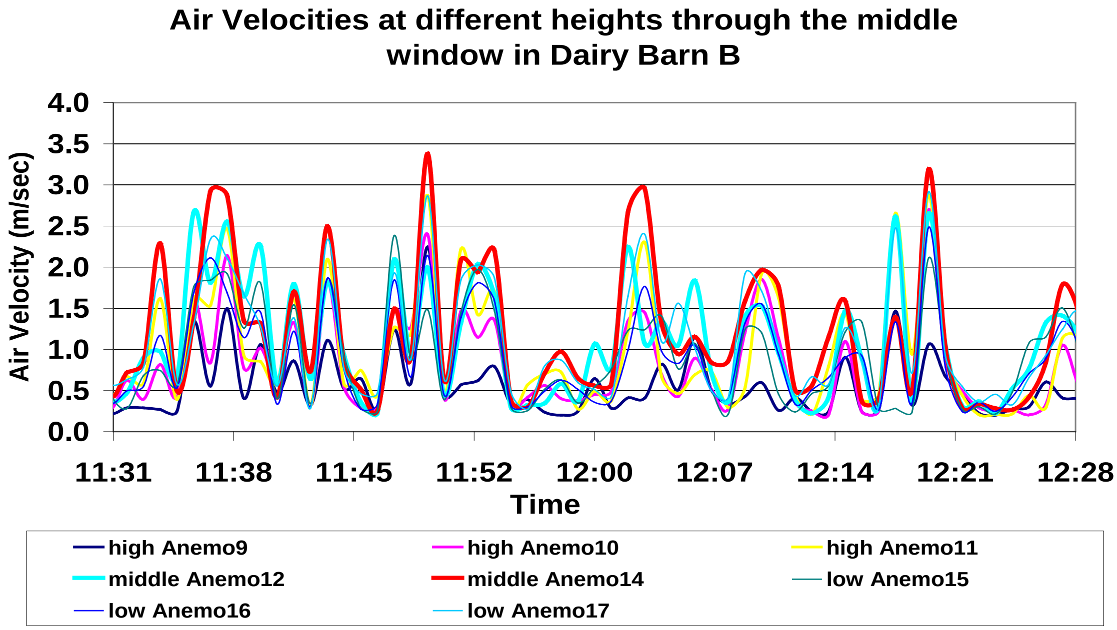


Figure 7. Air velocities at different points in three horizontal levels in one window.

Air velocities through ventilation inlets are different according to the measuring points. Figure [7] shows the differences in air velocities at different locations in one window.

The air velocities in the middle measuring level were greater than upper and lower levels.

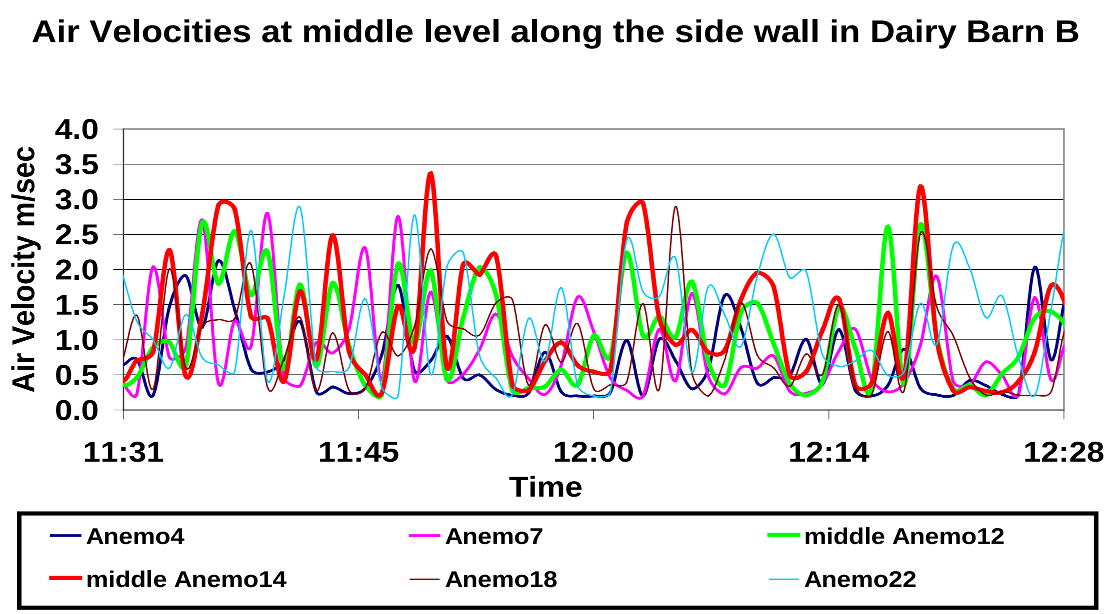


Figure 8. Air velocities at different points in the same horizontal level in different windows along the side wall.

Figure [8] showed no relationship between the air velocities at different locations along the side wall in same horizontal level. Thus the height of measuring point above the curtain ridge was more considered than the location of the window in the calculations of ventilation rates.

Figure [9] shows the calculated ventilation rates (VR) according to the tracer gas technique and velocity measurements.

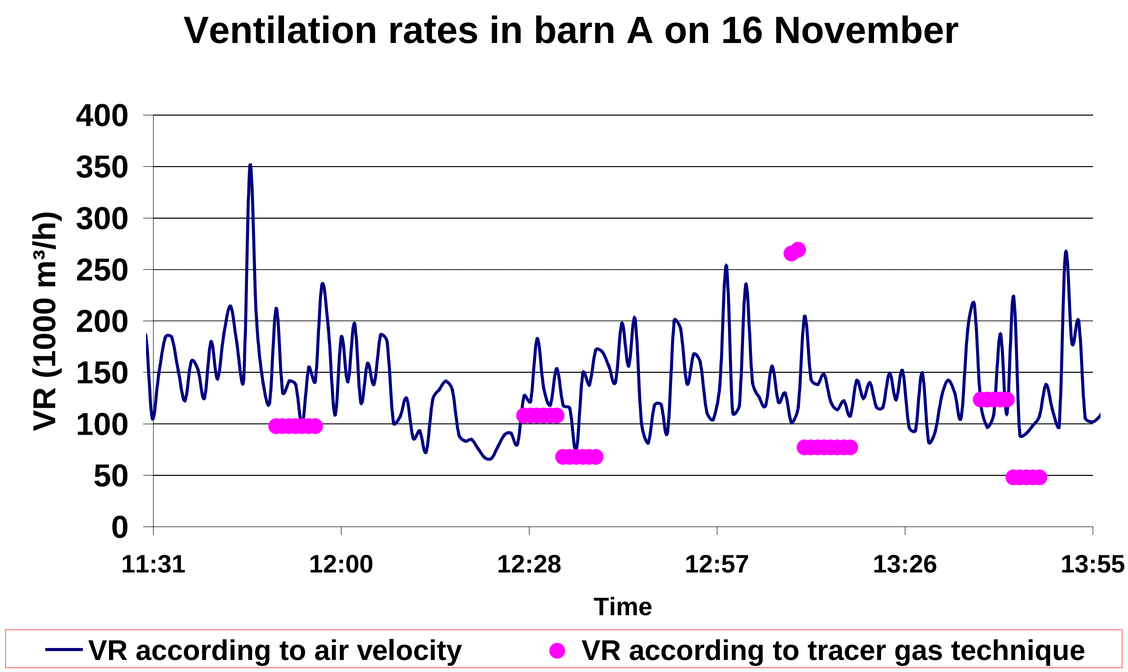
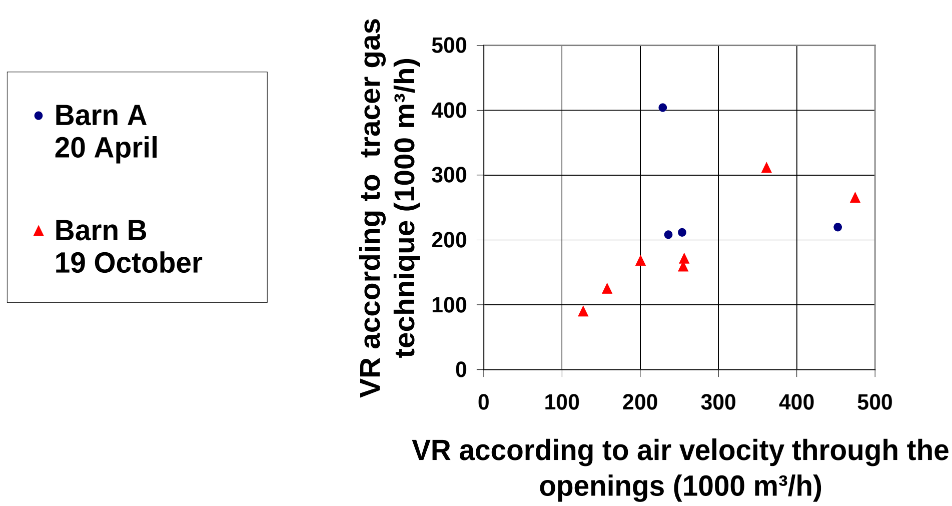


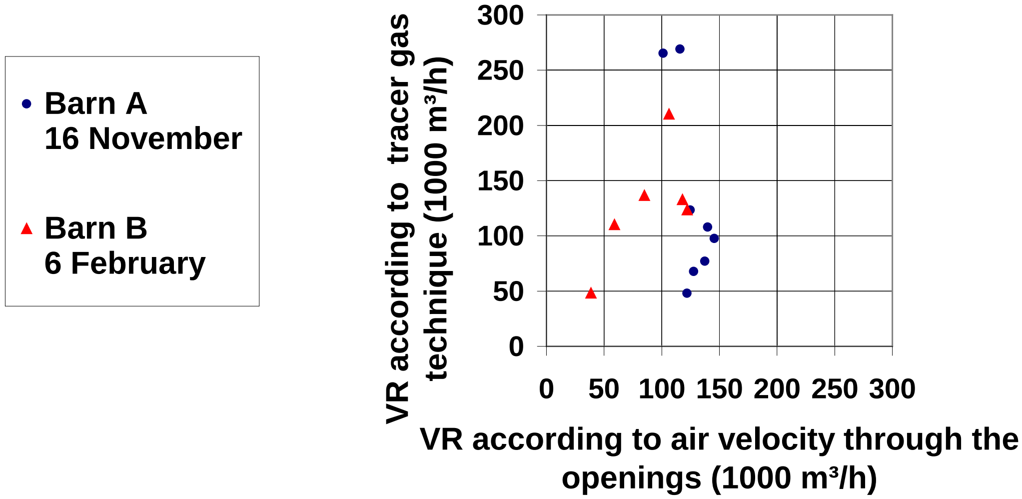
Figure 9. Ventilation rates according to the tracer gas technique and air velocity measurement through the windows.

Figure 10. Comparison of ventilation rates between both barns with completely opened windows



It was evident that the situation in the dairy barn was not in a steady state. But at least the minimum estimated ventilation rate was several times greater than the minimum required value to keep CO_2 concentrations below the recommended harmful limits (100 m^3h^{-1} per cow according to CIGR, 1984). Figure [10] and [11] present the comparison of ventilation rates between both barns according to two methods in two different weather conditions. If the calculations of ventilation rate according to air velocities through the opening have been taken as a reference method, the tracer gas technique has a little bit underestimated the ventilation rate in the barn in B under mild weather in autumn and spring, where the windows were completely opened as shown in figure [10], while the relationship wasn't clear in the barn A. Vice versa it was overestimated it in barn B and underestimated it in barn A in cold conditions in winter, where the windows were partly opened as shown in figure [11].

Figure 11. Comparison of ventilation rates between both barns with partly opened windows



Thus it is evident as written before in the literature that the estimation of ventilation rate throughout naturally ventilated building is still a challenge for the researchers and the recent available techniques still need to be developed.

CONCLUSION The tracer gas method is an appropriate technique for estimating the ventilation rates throughout naturally ventilated barns. For further development of this method, a better mixing between the tracer gas and the air should be achieved by improving the injection process. Also the distribution of sensors inside the stable must be better investigated in advance. The development of ventilation rate estimation according to air velocity measurement through the opening must begin with good selection for measuring points, which ensure a sufficient accuracy in all expected cases of curtains opening. Natural ventilation system provided under the investigated conditions in all experiments enough ventilation rates much more than the minimum recommended ventilation rate. But in the summer time some additional fans are may be required to avoid heat stress conditions.

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