

Use of CO₂ balances to determine ventilation rates in a fattening rabbit house

F. Estelles*, N. Fernandez, A. G. Torres and S. Calvet

*Institute of Animal Science and Technology. Universitat Politècnica de València.
Camino de Vera, 14. 46022 Valencia. Spain*

Abstract

Determining accurately the ventilation rates from rabbits houses, using non-expensive and non-invasive methods, is needed. The main aim of this work was to test the carbon dioxide balance as a method to determine the ventilation rate in fattening rabbit farms. In addition, the CO₂ release rate from rabbit manure was measured, and the effect of CO₂ concentration gradient between the inlet and outlet air of the building, on the method accuracy was characterized. To these aims, a fattening rabbit farm was evaluated during two periods and CO₂ concentrations were simultaneously monitored in the inlet and outlet air by using a photoacoustic monitor. Ventilation rates were also directly determined by calibration of the exhaust fans and monitoring their operation times. CO₂ emissions from manure were measured during two whole fattening periods, using a flux chamber and a photoacoustic monitor. The effect of CO₂ concentrations gradient between the inlet and outlet of the farm on the accuracy of the balance was studied through statistical regressions. The CO₂ emission from manure resulted in 13% of total CO₂ emissions (considering both manure and animals). No statistically significant differences were found between measured and calculated ventilation rates. The effect of the CO₂ gradient on the balance accuracy was statistically significant only in one of the trials. According to these results, the CO₂ balance can be recommended for the determination of ventilation rates in fattening rabbit buildings.

Additional key words: accuracy; animal welfare; climatization; emissions.

Resumen

Aplicación de balances de CO₂ para determinar la tasa de ventilación en una granja de conejos de engorde

El desarrollo de técnicas de bajo coste y poco invasivas es necesario para la determinación de la tasa de ventilación en granjas de conejos. El objetivo principal de este trabajo fue evaluar el balance de CO₂ como método para determinar la tasa de ventilación en granjas de conejos de cebo. Además, se midió la tasa de producción de CO₂ procedente del estiércol, y se estudió el efecto del gradiente de concentraciones de dicho gas, entre el interior y exterior de la instalación, sobre la precisión del método. Para ello, se evaluó una granja de conejos de cebo durante dos periodos y utilizando un medidor fotoacústico se midieron simultáneamente las concentraciones de CO₂ en el interior y exterior de la nave. La tasa de ventilación se determinó tras calibrar los ventiladores de la nave y monitorizar su tiempo de funcionamiento. Las emisiones de CO₂ del estiércol se midieron durante dos ciclos de cebo, utilizando un medidor fotoacústico y una cámara dinámica. El efecto del gradiente de las concentraciones de CO₂ sobre la precisión del método se evaluó mediante análisis de regresión. La producción de CO₂ del estiércol fue el equivalente al 13% de la producción total en la nave. No se encontraron diferencias estadísticamente significativas entre los flujos de ventilación medidos y calculados. El efecto del gradiente de CO₂ sobre la precisión del método fue significativo sólo en uno de los periodos. Así pues, se puede recomendar el uso de balances de CO₂ para determinar las tasas de ventilación en granjas de conejos de cebo.

Palabras clave adicionales: bienestar animal; climatización; emisiones; precisión.

Introduction

The intensive rearing of rabbits for meat production is a specialised farming activity in certain countries,

most of them located in the Mediterranean area. Several studies have been carried out in order to study rabbit management, nutrition and genetics but the environmental pollution impact of this activity is not

* Corresponding author: feresbar@upv.es
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Abbreviations used: CIGR (Commission Internationale du Genie Rural); PMMA (polymethyl methacrylate).

well known. In this sense, few publications can be found related to airborne emissions from rabbit farms (Michl and Hoy, 1996; Hol *et al.*, 2004; Calvet *et al.*, 2011).

Airborne emissions from livestock facilities are usually estimated using mass balances. In these balances the difference between incoming and outgoing matter fluxes for the building measured is defined as the emission rate.

To determine these incoming and outgoing matter fluxes, two factors are needed: mass concentrations and airflow rates. The measurement of gas, dust and odour concentrations can be achieved, with adequate accuracy, by using a wide variety of techniques (Chen *et al.*, 1999; Ni and Heber, 2008). On the contrary, measuring the airflow rate in an animal house is one of the main challenges when estimating these emissions. Airflow rates can be determined using several methods. According to Phillips *et al.* (2001) they can be classified in two main groups regarding to their nature: indirect and direct measurement methods. The first ones consist of using a tracer, which allows determining the ventilation flux both in mechanically and naturally ventilated houses. Direct measurement methods are based on determining the airflow rates through all openings in a building. This second group of techniques is generally more accurate, but they can be used only in mechanically-ventilated houses and when all openings of the farm can be assessed.

When measuring airborne emissions from commercial livestock buildings, direct airflow measurements are difficult to apply in practice. As explained before, these methods can not be applied in naturally-ventilated buildings. Measuring ventilation in mechanically-ventilated buildings may be a challenging task due to the technical difficulties associated (*e.g.* calibrating the fans may disturb their normal operation procedure). In addition, this task is time-consuming (Pedersen *et al.*, 1998).

Indirect methods arise then as a useful alternative, which allow us to determine airflow rates in most situations. The principle of the method is to monitor the inlet and outlet concentrations of a tracer gas with a known release rate. The airflow can then be calculated by applying a mass balance. The ideal characteristics of a tracer include low and stable background level, no hazard, acceptability, ease of measurement, stability and low cost (Phillips *et al.*, 2001). Carbon dioxide, which is emitted naturally on the farm, fulfils most of these characteristics except for low background levels (around 500-600 mg m⁻³ in clean atmosphere). However, the difference between CO₂ concentrations inside

and outside the livestock buildings is normally high and can be accurately determined with the proper equipment, which is an additional requirement for tracers (Van Ouwkerk and Pedersen, 1994). Consequently, carbon dioxide balances have been commonly used in Europe to determine the ventilation rates in livestock buildings (Pedersen *et al.*, 1998).

The accuracy of carbon dioxide balance methods when determining ventilation rates has been demonstrated for most farm species, such as poultry (Li *et al.*, 2005; Xin *et al.*, 2009) and pigs (Blanes and Pedersen, 2005), but not for rabbits.

The aim of this work was to test the accuracy of carbon dioxide balances to estimate ventilation rates in fattening rabbit houses, by comparing measured ventilation rates with those calculated through the CO₂ balance in two fattening rabbit houses at different measuring integration times. In addition, the CO₂ emission rate from manure was determined, and the effect of CO₂ concentrations difference between the inlet and outlet of the farm on the accuracy of the balances was studied.

Material and methods

Theoretical background

Carbon dioxide balances

Considering mass conservation under steady state conditions in the building, the general equation for the carbon dioxide balance can be expressed as follows (Eq. [1]):

$$V_{CO_2} = \frac{CO_{2rel}}{(CO_{2outlet} - CO_{2inlet})} \quad [1]$$

where V_{CO_2} is the ventilation rate estimated using the CO₂ balance (m³ h⁻¹ animal⁻¹), CO_{2rel} is the CO₂ release rate (mg h⁻¹ animal⁻¹), $CO_{2outlet}$ and CO_{2inlet} are the CO₂ concentrations (mg m⁻³) in the outlet and inlet of the building, respectively.

Therefore, to develop these CO₂ balances it is necessary to know the amount of carbon dioxide that is being released in the building (CO_{2rel}) as well as CO₂ concentrations.

Carbon dioxide production

There are two main sources of CO₂ in an animal house: animals and manure. Most of the CO₂ released

in the building is originated by the animals during respiration processes, while the rest is originated from the decomposition of manure (Van Ouwerkerk and Pedersen, 1994). After a comprehensive literature review (CIGR, 2002), carbon dioxide emission rates have been provided for most animal species and categories, such as poultry, cattle and pigs. For rabbits, some general values are provided in the same CIGR document. Other authors also provide experimental results in which CO₂ emissions were measured (e.g. Kiwull-Schöne *et al.*, 2001; 2005; Estellés *et al.*, 2009).

It is known that the metabolism of animals is not constant during the day, thus the production of CO₂ cannot be considered constant during the day for most animal species (CIGR, 2002). A relationship between the amount of CO₂ released by the animals and their daily activity pattern has been described in the literature (Pedersen *et al.*, 1998; Blanes and Pedersen, 2005). The CIGR (2002) proposes sinusoidal curves to model this daily variation on animal activity and CO₂ production for most livestock species but for rabbits. Estellés *et al.* (2010) proposed a cosine model to predict daily variations in CO₂ production from fattening rabbits.

Regarding to the amount of carbon dioxide that is emitted by the manure in the building, van Ouwerkerk and Pedersen (1994) proposed a relationship of 4% over the CO₂ production from animals. Other authors used a constant emission rate independently of the emissions from animals (Xin *et al.*, 2009), or even neglect this factor (Li *et al.*, 2005).

Therefore, if considering the effect of manure on carbon dioxide emission, as well as both factors affecting carbon dioxide release rates from the animals, Eq. [1] can be expanded to Eq. [2]:

$$V_{CO_2} = \frac{CO_{2rel_anim} D + CO_{2rel_manure}}{(CO_{2outlet} - CO_{2inlet})} \quad [2]$$

where CO_{2rel_anim} is the CO₂ produced by the animals (mg h⁻¹ animal⁻¹), D is the correction factor for daily variation of animal activity (dimensionless) and CO_{2rel_manure} is the CO₂ produced by the manure (mg h⁻¹ animal⁻¹)

Experimental layout

An experiment was developed in order to test the reliability of CO₂ balances to determine ventilation rates in fattening rabbit buildings. An experimental fattening rabbit farm with 1,560 places located in the Universitat Politècnica de València (Valencia, Spain)

was monitored for CO₂ emissions, by simultaneous measurements of ventilation rates and CO₂ concentrations.

Fattening rabbits (*Oryctolagus cuniculus*) were used, resulting from the New Zealand × Californian cross (Khalil and Baselga, 2002). The farm had a conventional management for fattening rabbits in the Spanish Mediterranean area. Animals were reared in collective cages (80 × 50 cm and 9 animals per cage on average) above a manure pit.

Two periods were selected for the measurements in order to obtain representative data of different environmental conditions. The first period (Trial 1) was performed at the beginning of summer while the second one (Trial 2) took place at the end of autumn. The first trial took 14 consecutive days in which the average weight of animals was 1.33 kg. During the second trial 19 complete measurement days were taken in two batches. The first one lasted for 10 days and the second one took place one week later. In this case, the average weight of the animals in the building was 1.63 kg.

Ventilation rate measurement

The house was equipped with constant flow wall fans. Ventilation rates were calculated considering the operation time of each fan and the corresponding fan performance at the nominal pressure drop in the farm. The percentage of time each fan was operational was registered by means of an electrical circuit connected to the auxiliary contacts of the fan relays (Calvet *et al.*, 2010). Fan status was recorded every minute by means of a voltage data logger (Hobo H8-004-02, Onset Computer Corp., USA). Each fan was calibrated for airflow before and after each experiment, multiplying the free flow area by the average air speed in the fan. Air velocity was measured at 24 points of the cross section of the fan by means of a hot wire anemometer (Testo 425; with measurement range 0 to 20 m s⁻¹) following the general recommended procedure (ASHRAE, 2001). Ventilation rates were then integrated and determined for period of two hours.

Gas concentrations and environmental conditions measurement

CO₂ concentrations were measured using a photoacoustic gas monitor (Innova-1412, Air Tech Instruments, Denmark). Air samples were conducted through

Teflon tubes to a multiplexing system which allowed consecutive measurements at eight points every two hours. Six sampling points were placed inside building, which were located at the air exhaust to determine $CO_{2outlet}$. Two sampling points were used to determine background concentrations (CO_{2inlet}) by placing them outside the building. Temperature sensors (Hobo H8-004-02, Onset Computer Corp., USA) were also located outside the building.

Carbon dioxide release rate

Carbon dioxide production from fattening rabbits can be determined according to their live weight following the regression equation (Eq. [3]) described by Estellés *et al.* (2010):

$$CO_{2rel_animal} = 2,660 LW^{0.85} \quad [3]$$

where LW is the live weight of the animal (kg).

Regarding the daily variation, the circadian rhythm for CO_2 production described by Estellés *et al.* (2010) can be expressed by Eq. [4] related to the hour of the day (0-24 h):

$$D = 1 - 0.16 \cos(h \cdot 2 \pi \cdot 24^{-1} - 14.87 \cdot 2 \pi \cdot 24^{-1}) \quad [4]$$

where h is the hour of the day.

Carbon dioxide released from manure was determined by direct measurement of emissions from representative manure samples in a dynamic chamber (Estellés *et al.*, 2009), during two complete fattening cycles (five weeks each).

During each cycle, manure samples were taken by placing three 20×13 polymethyl methacrylate (PMMA) boxes in the manure pit below the cages (one box per cage). Cages were installed five days before the measurement and the manure produced by the rabbits in these days was accumulated.

A PMMA chamber was used to determine the emissions. The chamber had a 29×49 cm base and 29 cm height, with 4 mm thick walls. One extraction pump (Silent-pump AC-9902, Resun, China) was used to vent the chamber with a ventilation flow of 3 L min^{-1} , which was tested before and after each measurement using a flow meter (Yokogawa RAGH, Yokogawa Electric Corporation, Japan). A small fan was used to homogenise the air inside the chamber. CO_2 concentrations were measured every two minutes using a photo acoustic gas monitor (Innova-1412, Air Tech Instruments, Denmark). According to Estellés *et al.* (2009) and considering chamber dimensions and the ventilation flow, it

was estimated that the equilibrium of gas concentrations was reached after approximately 45 min. The gas emission rate was estimated during 20 min after equilibrium was reached.

Data analysis

The absolute value of relative difference (*Diff*) between estimated and measured ventilation rate was used as an indicator of the accuracy of carbon dioxide balances. This relative difference was calculated in absolute terms for each bihourly period following Eq. [5]:

$$Diff = \text{Abs} \left(\frac{V - V_{CO_2}}{V} \right) \quad [5]$$

where V is the directly measured ventilation rate ($\text{m}^3 \text{ h}^{-1} \text{ animal}^{-1}$)

In order to assess the effect of carbon dioxide concentrations difference between the inlet and the outlet, on the accuracy of the method, regression analysis was performed. PROC REG of SAS (SAS, 2002) was used to this aim. The following model equation was used (Eq. [6]):

$$Diff = \alpha + \beta \times \ln(\Delta CO_2) + \varepsilon \quad [6]$$

where ΔCO_2 is the difference of CO_2 concentrations (in mg m^{-3}) between the inlet and outlet of the building

Results

CO_2 emission from manure

The average (\pm SE) results on CO_2 emissions from manure from weeks 1 to 5 of both cycles were 42 ± 14 , 124 ± 66 , 590 ± 88 , 563 ± 140 and $1,125 \pm 187 \text{ mg h}^{-1} \text{ animal}^{-1}$ respectively (considering an average surface occupied by each animal of 0.044 m^2). The average CO_2 emission rate during the whole cycle was $489 \pm 87 \text{ mg h}^{-1} \text{ animal}^{-1}$, following an upward trend as animals grew up. Considering that the average CO_2 emission rate from animals during the whole fattening cycle is $3,221 \pm 1,171 \text{ mg h}^{-1} \text{ animal}^{-1}$ (Estellés *et al.*, 2010), emissions from manure represent 13.18% of total CO_2 emissions in fattening rabbits farms.

Carbon dioxide concentrations

CO_2 concentrations measured in both farms are shown in Figure 1. Average CO_2 concentrations in the outside

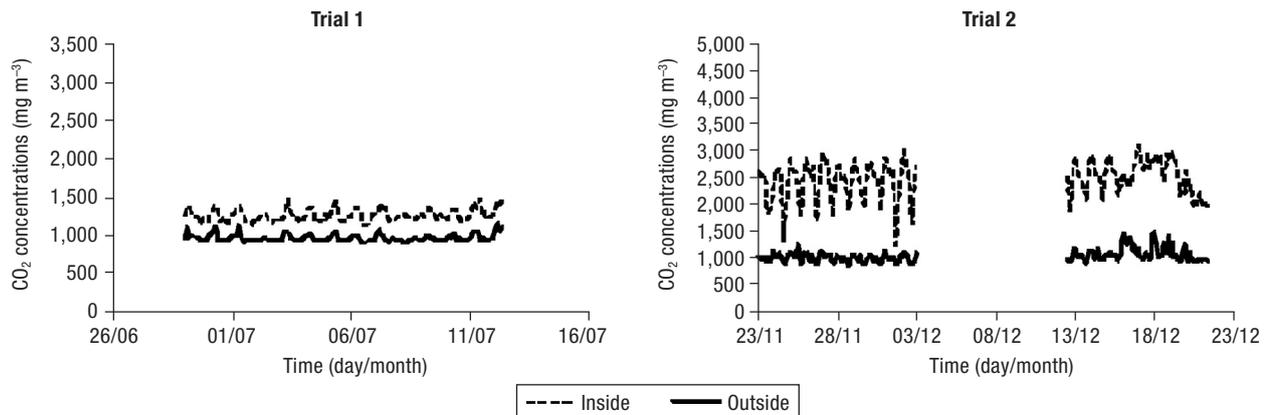


Figure 1. CO₂ concentrations registered in both trials.

were similar in both experiments ($954 \pm 46 \text{ mg m}^{-3}$ for Trial 1 and $1,024 \pm 114 \text{ mg m}^{-3}$ for Trial 2). CO₂ concentrations inside the building were on average $1,253 \pm 77 \text{ mg m}^{-3}$ for Trial 1 and $2,464 \pm 347 \text{ mg m}^{-3}$ for Trial 2.

Regarding the daily variation of concentrations, Figure 2 provides the average concentrations for each hour registered in both experiments. Little effect of time of the day is observed on outside concentrations while this is higher for inside concentrations. Also this effect is higher in autumn measurements in which a higher variability is observed.

Concentrations differences between the inlet and outlet air ranged from 194 to 536 mg m⁻³ in Trial 1 and from 357 to 2,013 mg m⁻³ in Trial 2.

Comparison between measured and calculated ventilation flows

Results of measured and calculated ventilation rates for both experiments, as well as outside temperatures are presented in Figure 3.

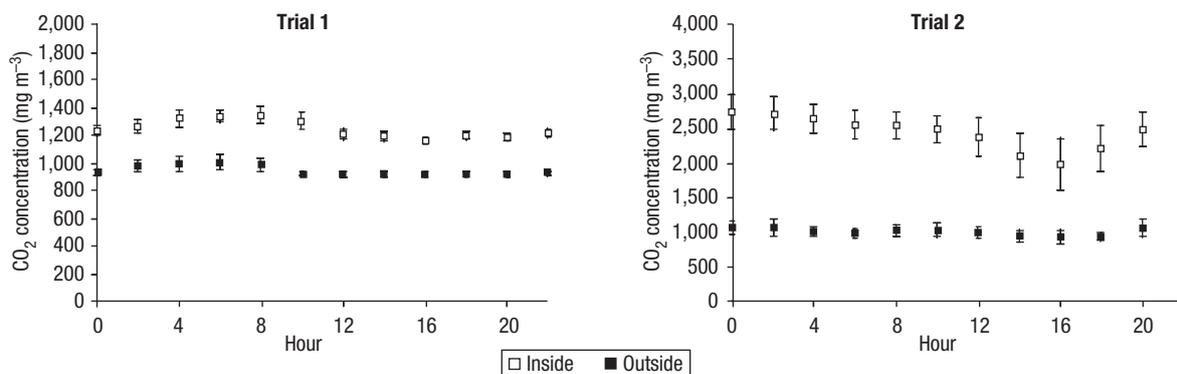


Figure 2. Average (\pm SD) hourly CO₂ concentrations observed in both trials.

Regarding the direct measurements, as expected, higher ventilation rates were observed for summer conditions (constant at $12.99 \text{ m}^3 \text{ h}^{-1} \text{ animal}^{-1}$), than for autumn ($3.24 \pm 0.92 \text{ m}^3 \text{ h}^{-1} \text{ animal}^{-1}$).

Although during Trial 1 no daily variation for ventilation rates is observed, in Trial 2 a clear daily pattern on ventilation rates can be noticed. The average ventilation rate determined using the CO₂ balances was $13.3 \pm 2.2 \text{ m}^3 \text{ h}^{-1} \text{ animal}^{-1}$ in summer and $3.3 \pm 0.6 \text{ m}^3 \text{ h}^{-1} \text{ animal}^{-1}$ in autumn conditions. Attending to these results of the t-test, differences were not significant for Trial 1 ($p > 0.07$, $n = 158$), neither for Trial 2 ($p > 0.92$, $n = 218$).

Effect of CO₂ concentrations difference on balance accuracy

There was no effect of CO₂ concentrations difference on the accuracy in Trial 1 since the slope (β) of the regression was not significant ($p > 0.5$). This may be caused by the low variability of CO₂ concentrations

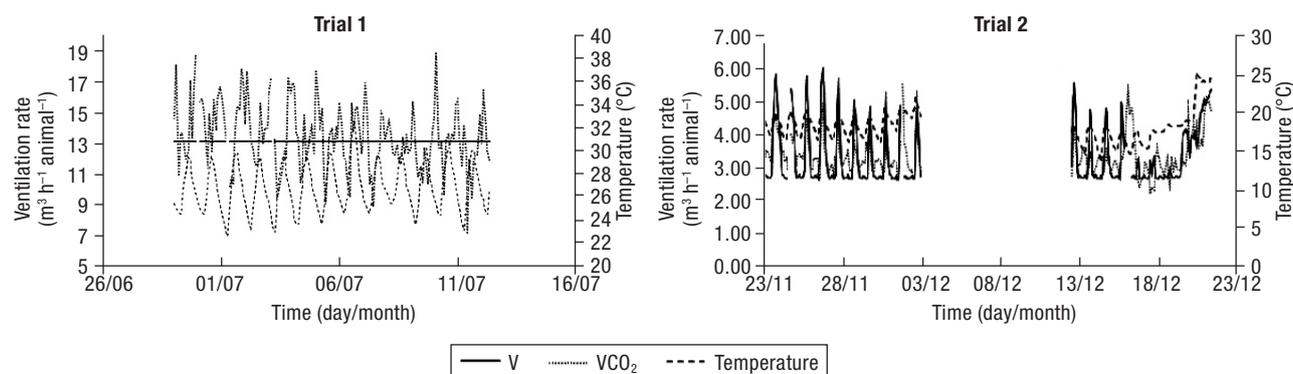


Figure 3. Measured and calculated ventilation rates and outside temperatures for both experiments.

differences, the small values of these differences, as a result of the constant, high ventilation rates in this trial.

On the contrary, for Trial 2 the calculated slope ($\beta = -0.27 \pm 0.04$) resulted highly significant ($p < 0.001$). Attending to the result of this regression, considering $\alpha = 2.14 \pm 0.32$ ($p < 0.001$, $R^2 = 0.14$), the absolute error of the balance method achieves values below 10% when CO_2 differences become higher than $2,000 \text{ mg m}^{-3}$, and below 5% for differences higher than $2,325 \text{ mg m}^{-3}$.

Discussion

CO_2 emission from manure

The value obtained in this work for the CO_2 emissions from manure, in relation to the total CO_2 emissions in the farm, is over the range reported by van Ouwerkerk and Pedersen (1994), that varied between 0 to 8.5%, and is also higher than the values used by Pedersen *et al.* (1998) in previous studies (4%). These higher rates may be caused by the management system of rabbits' manure in the studied farm, which is accumulated in deep pits during at least a whole cycle (5 weeks).

Carbon dioxide concentrations

Average CO_2 concentrations outside the buildings were higher than expected for fresh air (which is around 550 mg m^{-3}). A daily pattern was also found for these background concentrations. These facts may be caused by the presence of other rabbit buildings in the surroundings. Inside CO_2 concentrations followed similar patterns to these previously described by Estellés *et al.* (2010). As expected, inside CO_2 concentrations

were higher in autumn due to the lower ventilation rates registered ($12.99 \text{ m}^3 \text{ h}^{-1} \text{ animal}^{-1}$ in summer and $3.3 \text{ m}^3 \text{ h}^{-1} \text{ animal}^{-1}$ in winter).

Regarding the concentrations gradient, according to van Ouwerkerk and Pedersen (1994), when carbon dioxide is being continuously recorded, the difference between inlet and outlet concentrations should be at least 240 mg m^{-3} . In this case, most of the data (94.5%) accomplished this requirement. However, part of the random variability expected could be caused by this reduced difference in CO_2 concentrations. The rest of this variability should arise from imperfect mixing processes and other error sources such as the measuring devices and not representative sampling (Van Buggenhout *et al.*, 2009).

Ventilation rates

The fact that ventilation rates were much higher in summer than in autumn is explained by the high temperature difference registered ($26.53 \pm 2.12^\circ\text{C}$ in summer and $17.88 \pm 2.16^\circ\text{C}$ in autumn), since the ventilation system in the farm was controlled by temperature sensors.

Regarding to the variation patterns, it can be observed during Trial 1 a constant ventilation rate during the whole period. This fact may be caused by the poor environmental control in the studied farm which was not able to achieve target temperatures inside the building.

The pattern observed in Trial 2 is directly related to temperature daily variations. It can be also observed a lower limit for the ventilation rate in the building (about $2.6 \text{ m}^3 \text{ h}^{-1} \text{ animal}^{-1}$). This limit is controlled by the ventilation control system of the farm, which is programmed to keep a minimum ventilation rate independently of the temperature.

Effect of CO₂ concentrations difference on balance accuracy

According to the prediction equation obtained in this work, for the minimum recommended difference on CO₂ concentrations of 240 mg m⁻³ (van Ouwerkerk and Pedersen, 1994), the expected error is 66% when determining the airflow rate for 2-hours periods. Despite the interesting information obtained, those results must be considered carefully, due to the low *R*² obtained. Further research is needed in this topic in order to obtain accurate prediction equations which may help to decide whether the CO₂ balance is an appropriate method to determine ventilation rates, according to the CO₂ gradient.

Conclusions

The CO₂ emission factor for fattening rabbits manure was established at 489 ± 87 mg h⁻¹ animal⁻¹ during a whole fattening cycle. These emissions represent around 13% of global CO₂ emissions in fattening rabbit buildings. The CO₂ balance demonstrated to be an accurate tool for the determination of ventilation rates in fattening rabbit houses, since no statistical differences were found among the airflow rates calculated using this method and the directly measured values. The difference on CO₂ concentrations between the inlet and outlet of the building had an effect on the accuracy of the method for one of the experimental periods. According to these results, CO₂ concentrations differences below 2,000 mg m⁻³ lead to errors higher than 10% when using this methodology to determine ventilation rates.

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