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CHARACTERISATION OF THE INDOOR ENVIRONMENT AND GAS EMISSIONS IN RABBIT FARMS

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Abstract: There is a need to characterise gas concentrations and emissions from rabbit production. A study was conducted in order to determine ammonia, nitrous oxide and carbon dioxide concentrations and emissions on 3 rabbit farms in the Spanish Mediterranean area. Gas emissions were measured for 187 d in 2 different production stages (reproductive does and fattening rabbits). Gas concentrations were measured every 2 h. Indoor temperature, relative humidity and ventilation flow were measured hourly. As a result, indoor temperature and relative humidity varied throughout the year, following a sinusoidal daily variation pattern. Maximum gas concentrations (14.3, 7041 and 5.10 mg/m^3 of NH_3, CO_2 and N_2O, respectively) did not exceed the maximum recommended thresholds considering human health and animal welfare. Ammonia emissions were on average 55.9 and 10.2 mg/h per reproductive doe and fattening rabbit, respectively, and were affected by temperature and relative humidity. The average carbon dioxide emission was 12588 mg/h per animal for does and 3341 mg/h for fattening rabbits. Nitrous oxide emission from does was 10.3 mg/h per animal, whereas for fattening rabbits the emission was negligible. Daily variation patterns of all measured parameters were observed and characterised in this study.

Key Words: rabbits, ammonia, carbon dioxide, nitrous oxide, emissions.

INTRODUCTION

Animal production is a potential source of pollutants in the atmosphere. It is considered the most important source of ammonia (NH_3) and a significant source of greenhouse gases, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), according to different emission inventories (e.g. European Environment Agency 2009a and 2009b; EPA, 2010). These gases may impair the global environment and affect animal and human health, so they have been quantified in most livestock productions. However, information about these emissions from rabbit farming is scarce. Rabbit rearing is different to other animal productions in terms of animal biology and management, and this may influence gas emissions, in comparison with other animal species.

Ammonia emissions from animal production arise from the relative inefficiency in the use of nitrogen by the animals. In the production of fattening rabbits, approximately 60% of the nitrogen intake is excreted as urine and faeces (Calvet *et al*., 2008), and a part of the excreted nitrogen is lost as ammonia, with 3 main consequences. Firstly, ammonia is a pollutant contributing to acidification and eutrophication in

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the environment (Krupa, 2003). Secondly, nitrogen losses reduce the fertiliser value of manure (Burton and Turner, 2003). Lastly, ammonia accumulation over 25 parts per million (ppm) may affect human and animal health (Roney *et al*., 2004).

Carbon dioxide is produced in animal facilities by respiration of the animals and by the aerobic decomposition of their manure. This gas is not considered a net pollution source, since the emission is part of a short-term closed cycle (International Panel on Climate Change, 2006). However, carbon dioxide emissions have been widely used to estimate ventilation flows in livestock buildings (CIGR, 2002). Finally, methane and nitrous oxide are greenhouse gases with high global warming potential, which is 21 and 310 times the greenhouse effect of CO_2, respectively (Solomon *et al*., 2007). Methane is produced by fermentation of organic matter, whereas nitrous oxide is closely related to the agricultural nitrogen cycle and is produced in the nitrification-denitrification process in the management of manure and after its application to agricultural soils.

The environmental implications of rabbit production are not well understood, and there are few scientific publications related to nutrient balances and gas emissions in rabbit production (e.g. Maertens *et al*. 2005, Hol *et al*., 2004). Some research has also dealt with emissions from rabbits as laboratory animals (Kaliste *et al*., 2002; Ooms *et al*., 2008), but these values are not applicable to commercial production because of differences in animal cycles, nutrition and management.

The particular aspects of rabbit production (physiology of the animals, housing systems and manure management) may influence the emission of atmospheric pollutants. For this reason, emission values cannot be extrapolated from other species, and therefore scientific research is still necessary. The main objectives of this study were: firstly, to characterise the indoor environment in 3 rabbit farms under conventional management in the Spanish Mediterranean area; secondly, to quantify the emission of gases (NH_3, N_2O and CO_2) from buildings for fattening rabbits and for reproductive does; and finally, to describe the daily variation patterns of gas production and determine the influence of environmental parameters on these emissions.

MATERIALS AND METHODS

Housing and animals

Gas emissions were measured in 3 rabbit farms in Eastern Spain during 2006 and 2007. In the studied farms, reproductive does of approximately 4 kg live weight were continuously housed in individual cages. Fattening rabbits were housed in collective cages (7 to 9 animals) for a 5 wk growing period, with approximately 9 batches per year and an average live weight of 1.2 kg.

Ten observation periods were established to measure gaseous concentrations and emissions of 2 production phases (breeding and fattening), in different parts of the year, as detailed in Table 1. The emissions produced in manure removal operations were not evaluated, since they were relatively infrequent in the studied farms (from 1 to 4 mo), and therefore they were considered a particular situation beyond the scope of this study. The studied farms are represented in Figure 1. Farms 1 and 2 were commercial facilities having separate buildings for breeding (1a and 2a) and fattening (1b and 2b), and equipped with constant flow wall fans. In contrast, Farm 3 was an experimental unit with commercial management with three buildings for reproductive does (3a, 3b and 3c), each one equipped with one variable speed ceiling fan.

Animals were fed *ad libitum* using a commercial pelleted rabbit feed. The feed for reproductive does and for fattening rabbits had a crude protein content of 17.0 % and 15.5%, respectively, and a dry matter content of 90%.

Table 1: Experimental setup with the temporal distribution of measurements.

	Observation period	Number of animals	Season	Duration (d)
Reproductive does[1]				
1a	1	446	summer	14
2a	2	400	winter	12
2a	3	400	spring-summer	48
3a	4	80	autumn	16
3b	5	80	autumn	16
3c	6	43	autumn	16
Fattening rabbits[1]				
1b	7	1500	summer	14
2b	8	3600	winter	6
2b	9	3600	summer	17
1b	10	1500	autumn	28

[1] Buildings as in Figure 1.

Environmental parameters and emissions

Indoor temperature and relative humidity were measured every 10 min, at the locations shown in Figure 1. Temperature and relative humidity data loggers (HOBO H8-004-002, Onset Computer Corp., USA) were used for these measurements.

Gas emission rates (E, mg/h per animal) were measured by determining ventilation rates (V, m^3/h per animal) and gas concentrations in the building outlet and inlet air (C_{outlet} and C_{inlet}, mg/m^3), according to Equation 1. Therefore, the calculated emissions included those from animals and from their manure together.

$$E = (C_{outlet} - C_{inlet}) \times V \qquad (1)$$

Gas concentrations (NH_3, N_2O, CO_2 and CH_4) were measured with a photoacoustic multi-gas analyser (Innova-1412, Air Tech Instruments, Denmark). However, laboratory tests demonstrated that methane measurements lower than 10 ppm were not reliable due to cross correlation with water vapour. Considering that most CH_4 readings were within this range, methane emissions could not be included in this study. Air samples were conducted through Teflon tubes to a multi point sampling system which allowed consecutive measurements at 8 points every 2 h. At least 2 internal sampling points were registered in each building, which were located at the air exhaust. In all cases, 2 external sampling points were used to determine background concentrations (Figure 1).

Considering that Farms 1 and 2 were equipped with constant flow 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 determined by means of an electrical circuit connected to the auxiliary contacts of the fan relays, similar to the system described by Calvet *et al*. (2010), and was recorded every minute by means of a voltage data logger (HOBO H08-004-02, Onset Computer Corp., USA). The flow of each fan was measured before and after each observation period, 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, Germany, measurement range 0 to 20 m/s).

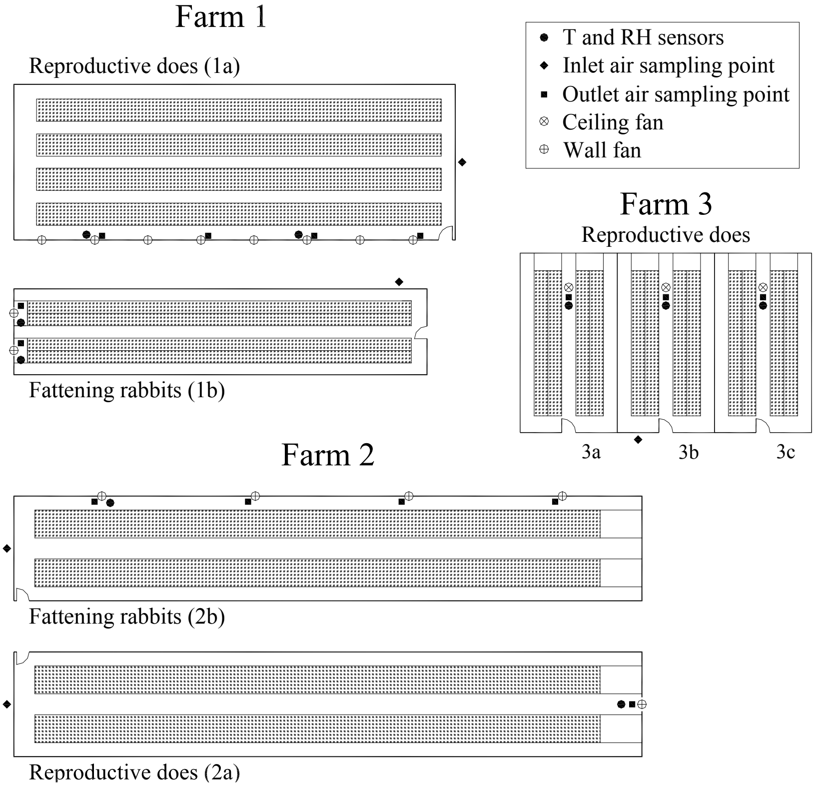


Figure 1: Schema of the buildings of the 3 farms studied and location of the measuring points for temperature (T), relative humidity (RH) and gas concentration.

Since Farm 3 was equipped with variable speed fans, ventilation flow was calculated considering the direct relationship between ventilation flow and electric consumption. To calibrate each fan, ventilation flow and electric intensity were simultaneously measured at 6 different airflow levels at the beginning of the experiment. During the calibration, ventilation flow was measured using the methodology previously described, whereas electric intensity was determined by means of an AC intensity sensor (CTV-A 0-20 A, Onset Computer Corp., USA). During the gas emission measurements, electric intensity was measured every minute by means of the same AC intensity sensor and registered in a data logger (HOBO H08-004-02, Onset Computer Corp., USA).

Data analysis

Average temperature, relative humidity, ventilation flow, gas concentration and gas emission were obtained for each observation period. The analysis of variance (Proc GLM) of the statistical program SAS (2001) was used to determine significant differences in emissions of NH_3, N_2O and CO_2, between different types of animals (reproductive does and fattening rabbits), and also among observation periods.

To determine the daily variation rhythm of the measured parameters, a Fourier transformed series was modelled. Considering the daily basis of the data, the length of the period was established in 24 h. Data from all measurements were used to model the daily variation of temperature, relative humidity, ventilation flow and NH_3, N_2O and CO_2 concentrations and emissions. The following regression (Equation 2) was modelled using the NLIN procedure of SAS (2001), separately for does and fattening rabbits.

$$X_i = \mu + A\cos\left(\frac{2\pi}{24}t_i - \frac{2\pi}{24}t_{max}\right) + \varepsilon_i \qquad (2)$$

where X_i is the modelled parameter, μ is the average value, A is the modelled amplitude, t_i is the hour of the day (h), t_{max} is the time at which the maximum value is achieved (h), and ε_i is the model error.

The influence of the temperature and relative humidity on gas emissions was studied according to the following model (Equation 3), using the REG procedure of SAS (2001).

$$E_{ijk} = \beta_1 T_i + \beta_2 RH_j + OP_k + \varepsilon_{ijk} \qquad (3)$$

where E_{ijk} is the gas emission (mg/h per animal), T_i is the temperature (ºC) and RH_j is the relative humidity (%). The qualitative term OP_k describes the effect of the different observation periods and was introduced as dummy variables; β_1 and β_2 are the model coefficients and ε_{ijk} is the model error. The term OP_k was used to account for different average emission levels in different observation periods. Therefore, the parameters β_1 and β_2 of this model represent the effect on gas emissions of temperature and relative humidity, respectively, regardless of the emission value.

RESULTS

Environmental conditions

The average indoor temperature, relative humidity and ventilation flows are shown in Table 2. As a consequence of the non-intensive environmental control in rabbit farms, differences in indoor temperature and relative humidity were found among observation periods, both for reproductive does and fattening rabbits. Daily average indoor temperatures varied from 16.1 to 26.5 ºC in buildings for reproductive does, whereas for fattening rabbits the temperature varied from 17.6 to 26.5ºC. Average relative humidity tended to be higher for reproductive does than for fattening rabbits. Ventilation flow was higher for reproductive

Table 2: Indoor temperature, relative humidity and ventilation flows for each observation period in buildings for reproductive does and fattening rabbits. The number of measurements (No.) is also indicated.

	Observation period	No.	Temperature (ºC)	Relative humidity (%)	Ventilation flow (m^3/h per place)
Reproductive does[1]					
1a	1	161	26.5 ± 0.2	65.8 ± 1.2	27.5 ± 0.5
2a	2	144	16.1 ± 0.2	58.6 ± 1.3	13.1 ± 0.6
2a	3	559	22.0 ± 0.1	53.4 ± 1.6	18.7 ± 0.3
3a	4	125	19.0 ± 0.2	76.5 ± 1.3	53.8 ± 0.5
3b	5	125	19.3 ± 0.2	75.9 ± 1.3	50.5 ± 0.5
3c	6	125	19.3 ± 0.2	71.1 ± 1.3	127.1 ± 0.5
Fattening rabbits[1]					
1b	7	161	26.5 ± 0.2	62.4 ± 1.0	13.0 ± 0.1
2b	8	60	17.6 ± 0.3	45.0 ± 1.7	4.3 ± 0.2
2b	9	209	23.1 ± 0.2	42.6 ± 0.9	5.2 ± 0.1
1b	10	341	18.4 ± 0.2	55.1 ± 0.7	3.1 ± 0.1

[1] Buildings as in Figure 1.

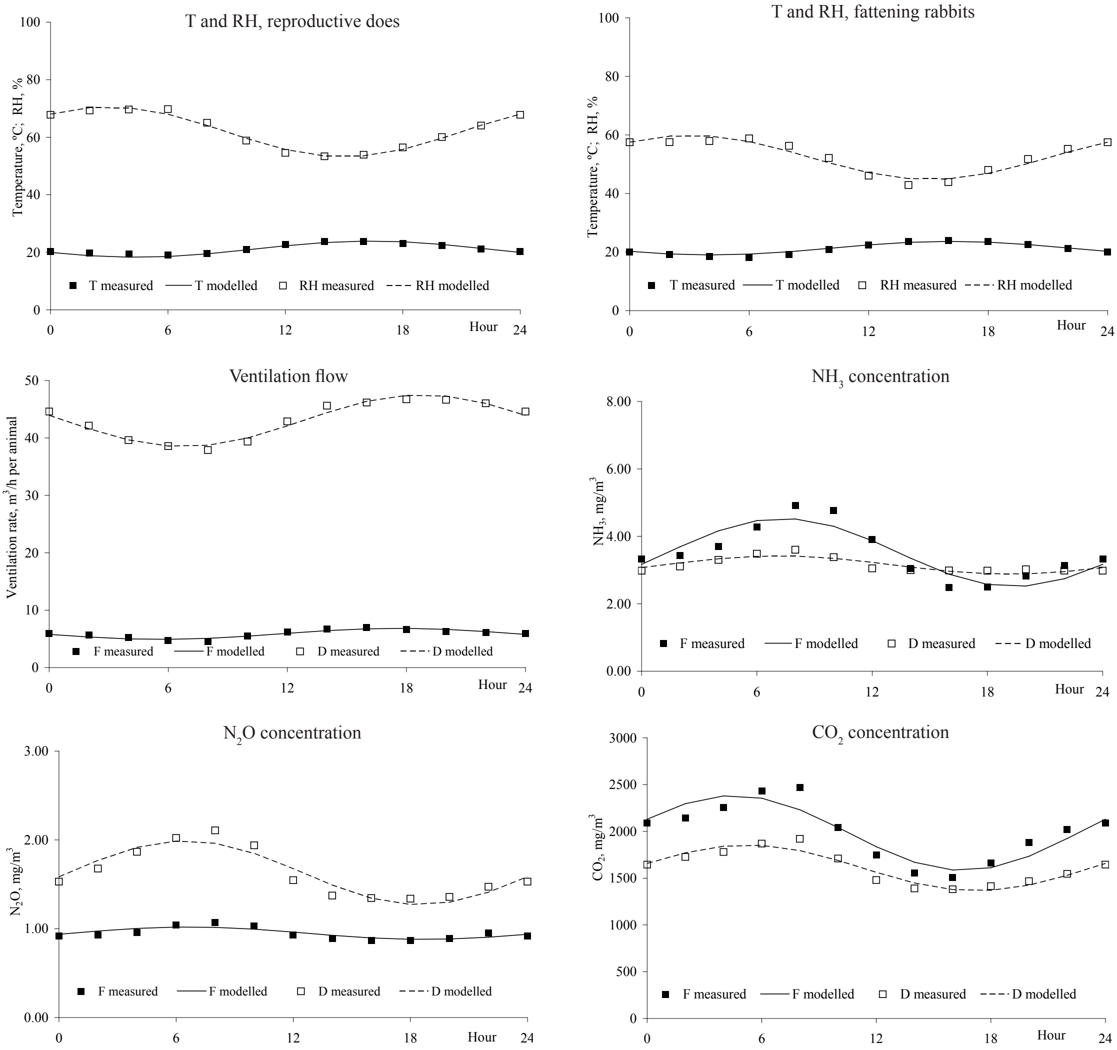


Figure 2: Daily variation of measured average values and modelled indoor temperature (T), relative humidity (RH), ventilation flow and concentrations of ammonia, nitrous oxide and carbon dioxide for fattening rabbits (F) and reproductive does (D).

does than for fattening rabbits. In farm 3c, ventilation flow per animal was higher than in the rest. The reason for this is that this farm housed approximately one third of the usual number of animals, without a reduction in the target ventilation flow, so higher ventilation flows per living animal were obtained.

The daily variation pattern of temperature, relative humidity and ventilation flow could be approximated to sinusoidal models ($P<0.01$), as shown in Figure 2. Maximum temperature, relative humidity and ventilation rates were found approximately at 16, 3 and 4 h, respectively.

Table 3: Ammonia, nitrous oxide and carbon dioxide concentrations (mg/m^3) in rabbit buildings (average± standard error). The number of days of measurements (No.) is also indicated.

	Observation period	No.	NH_3	CO_2	N_2O
Reproductive does[1]					
1a	1	161	2.50 ± 0.08	1316 ± 35	1.27 ± 0.08
2a	2	144	6.10 ± 0.08	2492 ± 37	0.76 ± 0.09
2a	3	559	4.71 ± 0.04	2258 ± 19	2.83 ± 0.04
3a	4	125	1.05 ± 0.07	935 ± 31	0.86 ± 0.08
3b	5	125	1.66 ± 0.07	918 ± 31	0.90 ± 0.08
3c	6	125	0.78 ± 0.07	779 ± 31	0.70 ± 0.02
Fattening rabbits[1]					
1b	7	161	1.33 ± 0.12	1253 ± 55	1.22 ± 0.02
2b	8	60	1.87 ± 0.21	1709 ± 91	0.97 ± 0.04
2b	9	209	3.80 ± 0.11	1825 ± 49	1.63 ± 0.02
1b	10	341	4.71 ± 0.09	2487 ± 38	0.39 ± 0.02

[1] Buildings as in Figure 1.

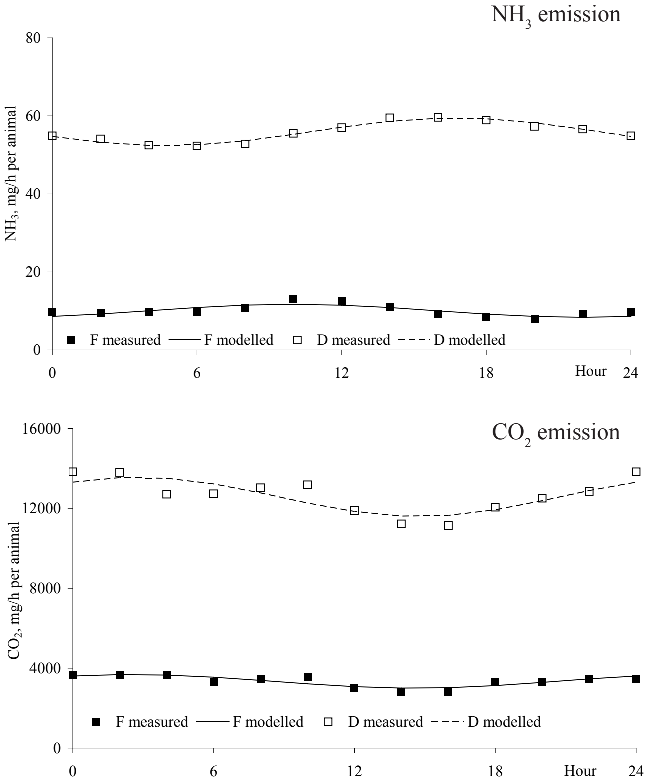
Gas concentrations

Ammonia concentrations (Table 3) were higher for reproductive does than for fattening rabbit buildings, except in Farm 3, because of the higher ventilation flow used this facility. Maximum records (10.9 and 14.3 mg/m^3 for reproductive does and fattening rabbits, respectively) were found in winter.

Table 4: Ammonia, nitrous oxide and carbon dioxide emission (mg/h per animal) in rabbit buildings (average±standard error). The number of days of measurements (No.) is also indicated.

	Observation period	No.	NH_3	CO_2	N_2O
Reproductive does[1]					
1a	1	161	55.0 ± 1.6	9956 ± 448	5.7 ± 1.0
2a	2	144	65.6 ± 1.7	16320 ± 474	0.0 ± 1.0
2a	3	559	56.8 ± 0.9	17820 ± 240	20.8 ± 0.5
3a	4	125	38.7 ± 1.4	10158 ± 403	8.1 ± 0.9
3b	5	125	63.6 ± 1.4	8333 ± 403	9.3 ± 0.9
3c	6	125	56.5 ± 1.4	4004 ± 403	0.0 ± 0.9
Average			55.9 ± 0.5	12588 ± 164	10.3 ± 0.3
Fattening rabbits[1]					
1b	7	161	10.6 ± 0.4	3880 ± 128	2.0 ± 0.2
2b	8	60	3.5 ± 0.7	1180 ± 210	0.0 ± 0.3
2b	9	209	8.9 ± 0.4	1893 ± 112	0.0 ± 0.1
1b	10	341	12.1 ± 0.3	4354 ± 88	0.0 ± 0.1
Average			10.2 ± 0.6	3341 ± 226	0.0 ± 0.5

[1] Buildings as in Figure 1.



Reproductive does ($P<0.01$):

$$E_{NH_3} = 55.92 + 3.54 \times \cos\left(\frac{2\pi}{24} \times (t - 16.7)\right)$$

Fattening rabbits ($P<0.01$)

$$E_{NH_3} = 10.10 + 1.67 \times \cos\left(\frac{2\pi}{24} \times (t - 9.97)\right)$$

Reproductive does ($P<0.01$):

$$E_{CO_2} = 12580 + 200 \times \cos\left(\frac{2\pi}{24} \times (t - 2.76)\right)$$

Fattening rabbits ($P<0.01$)

$$E_{CO_2} = 3340 + 70 \times \cos\left(\frac{2\pi}{24} \times (t - 2.56)\right)$$

Figure 3: Daily average values of ammonia and carbon dioxide and emission pattern for fattening rabbits (F) and reproductive does (D). The regression curves are also indicated. No emission pattern could be identified for nitrous oxide.

Carbon dioxide average concentrations ranged between 779 and 2492 mg/m^3 (Table 3). Maximum punctual concentrations were also registered in winter (4488 and 7041 mg/m^3 in reproductive does and fattening rabbits, respectively). Finally, nitrous oxide concentrations ranged between 0.39 and 2.83 mg/m^3 (Table 3).

As shown in Figure 2, daily variation patterns of gas concentrations were also approximated to sinusoidal models ($P<0.01$). Maximum concentrations were found approximately at 5 h for CO_2 and at 7 h for NH_3 and N_2O.

Gaseous emissions

Gas emissions from each observation period are presented in Table 4. Average ammonia emission from does was 1.34 g/d per animal, whereas for fattening rabbits, the average emission was 0.25 g/d per animal. As shown in Figure 3, ammonia emissions followed a sinusoidal pattern both for does (maximum at 17 h) and fattening rabbits (maximum at 10 h).

Carbon dioxide emission was on average 302 and 80 g/d per animal for reproductive does and fattening rabbits, respectively. A wide range was found for this emission (from 96 to 428 mg/d per doe and from 28 to 104 mg/d per fattening rabbit). A sinusoidal daily emission pattern was identified, with a maximum carbon dioxide generation approximately at 3 h (Figure 3). Finally, nitrous oxide emissions averaged

Table 5: Effect of temperature and relative humidity on gas emissions within the studied range (temperature from 12 to 32 ºC and relative humidity from 15 to 98%). The effect is the change in gas emission (mg/h per animal) when temperature increases 1ºC or when relative humidity increases 1%.

	NH_3	CO_2	N_2O
Temperature	1.96 ± 0.15 ($P<0.01$)	126 ± 44 ($P<0.01$)	NS[1] ($P>0.05$)
Relative humidity	0.34 ± 0.03 ($P<0.01$)	60 ± 8 ($P<0.01$)	0.19 ± 0.02 ($P<0.01$)
R^2	0.69	0.65	0.49

[1] NS: stands for non significant differences

0.25 g/d per doe, whereas the emission from fattening rabbits was negligible. In reproductive does, only 2 of the 6 observation periods led to significant N_2O emissions ($P<0.01$), but a maximum emission of 0.50 g/d per animal was found for the observation period 3. No daily pattern in nitrous oxide emission could be identified ($P>0.05$).

The effect of temperature and relative humidity on gas emissions obtained from Equation 3 is presented in Table 5. A significant effect of temperature and relative humidity was obtained for ammonia and carbon dioxide emission ($P<0.01$), whereas nitrous oxide was only affected by the relative humidity. These results were obtained for the studied ranges of temperature (12 to 32ºC) and relative humidity (15 to 98%).

DISCUSSION

Environmental conditions

Indoor temperature distribution was similar for reproductive does and for fattening rabbits, and was within the thermoneutral zone (between 15 and 25ºC) described by Cervera and Fernández Carmona (1998) for 75% of the time. However, indoor temperatures above 25ºC were registered during 50% of the summer time and temperatures above 30º C were registered during 3% of the summer time.

Since ventilation flows in commercial farms are commonly designed as a function of the temperature, higher ventilation flows tend to be recorded during warm periods.

Gas concentrations

Maximum ammonia concentrations did not exceed the recommended thresholds for farms of 25 ppm (approximately 17.4 mg/m^3) recommended by Wathes and Charles (1994). Measured ammonia concentrations were found to be in the same range as previous results reported in the literature. However, different housing and manure management systems were used and therefore comparing gas concentrations is not useful in practice. Hol *et al.* (2004) measured average ammonia concentrations between 8.5 and 10 mg/m^3 for reproductive does in summer, whereas these concentrations were slightly higher in winter (11.7-13.4 mg/m^3). For fattening rabbits, they found lower concentrations (4.2-4.7 mg/m^3 in summer and 4.3-5.2 mg/m^3 in spring). Michl and Hoy (1996) also measured low ammonia concentrations in a building for fattening rabbits in winter (1.4-3.9 mg/m^3). Ammonia concentrations have also been measured for laboratory rabbits. However, management and cleaning practices differ from those in commercial rabbit production, and lower values (less than 2 mg/m^3) have been reported (Kaliste *et al.*, 2002; Ooms *et al.*, 2008).

Carbon dioxide concentrations did not exceed the maximum recommended threshold of 5000 ppm (approximately 9000 mg/m^3) proposed by Wathes and Charles (1994), although they were higher than the values reported by Michl and Hoy (1996) for fattening rabbits (945-1420 mg/m^3 CO_2). Carbon dioxide accumulation does not have any health implication except for exposure to concentrations about 5% (50000 ppm) for 15-30 min, and acute responses have been only reported at concentrations as high as 35% (Kaye *et al*., 2004).

As in the case of carbon dioxide, the observed range of nitrous oxide was also higher than the values obtained by Michl and Hoy (1996) for fattening rabbits (0.37-0.83 mg/m^3). The measured values are much lower than the long-term exposure limit of 183 mg/m^3 established in the English and German official recommendations (HSE, 2007; German Institute for Occupational Safety, 2009).

As a consequence of the relationship between temperature, relative humidity, ventilation flow, and concentrations of gases, the average values of all concentrations followed an expected daily variation pattern, defined by sinusoidal curves (Figure 2). Maximum daily temperatures were registered at approximately 16 h. At this time, maximum relative humidity and ventilation flow and minimum gas concentrations were registered, both for fattening rabbits and reproductive does. The inverse situation was found between approximately 6 h and 8 h.

Gaseous emissions

Significant differences in gas emissions were obtained among different observation periods both for does and fattening rabbits. This indicates that, in addition to the seasonal effect, different housing systems used in this study may affect the emission value. In other species, differences in ventilation flows, manure management and other practices on the farm significantly influenced gaseous emissions (Groot Koerkamp *et al*., 1998). For example, the higher ventilation flows per animal place in Farm 3 could be related with the different emission rates measured in it.

Ammonia emission values obtained here are lower than those obtained by Hol *et al*. (2004) for reproductive does (90.2-97.0 mg/h per animal in summer, and 77.6-89.0 mg/h per animal in autumn) and for fattening rabbits (17.5-22.8 mg/h per animal in summer and 10.7-14.8 mg/h per animal in autumn). However, Michl and Hoy (1996) estimated a lower emission rate for fattening rabbits in Germany (1.9 mg/h per animal). Differences between these results and those in our study may be explained by the different manure management system used in this study (deep pit) compared with the manure belt used in Hol *et al*. (2004) and the slat used in Michl and Hoy (1996). Ooms *et al*. (2008) found an average ammonia emission rate of 43.1 mg/h per animal for adult laboratory rabbits with an average weight of 3.8 kg. This value is slightly lower in comparison with the emission obtained in this study for reproductive does (55.9 mg/h per animal), which are similar animals in terms of weight. This can be interpreted considering the less intensive management of laboratory animals and the absence of lactating rabbits. Therefore, a comparison between laboratory and commercial rabbit production is difficult because of the different management of animals and manure.

As obtained in this study, and also as reported by several authors for other species (e.g. Oldenburg, 1989, Kavolelis, 2006), increasing the temperature may enhance the emission of ammonia. However, Lacey *et al*. (2003) found no significant influence of temperature and relative humidity on ammonia emission from broilers, and Groot Koerkamp *et al*. (1998) could find a clear relationship between ammonia emission and outside temperature only in very few cases. The daily variation pattern of ammonia emission and temperature found in this study for rabbits was similar to the pattern reported by Oldenburg (1989) for swine and poultry, which may indicate that the ammonia emission mechanisms are not different among species.

Ammonia emissions are also commonly reported in terms of mass per livestock unit (LU), which is 500 kg live weight. Using these units, emissions from different animal species can be compared. Ammonia emissions from does (7.0 g/h per LU) are still higher than for fattening rabbits (4.3 g/h per LU). This may

Table 6: Ammonia emissions corrected for animal weight in rabbit production, compared with previous studies in other species.

	Emission (g NH_3/LU per h)
Oldenburg (1989)	
Cattle	2.1-3.0
Pigs	2.0-4.5
Poultry	1.5-9.1
Groot Koerkamp *et al*. (1998)	
Cattle	0.26-1.79
Pigs	0.65-3.75
Poultry	1.6-10.9
This study	
Rabbits, does	7.0
Rabbits, fatteners	4.3

be caused by the increased metabolic activity of does during pregnancy and lactation, and also by the presence of the young rabbits in the mother's cage until weaning.

Table 6 compares rabbit ammonia emissions obtained in this study with those corresponding to other studies on a weight basis. Overall, ammonia emissions are higher for rabbits than for cattle and pigs, whereas they lie in the same range as poultry emissions. These high emissions may be derived from the high urinary alkalinity of rabbit urine (pH>8), caused by high concentrations of calcium carbonate, which causes characteristic precipitations (Kiwull-Schöne *et al*., 2005). This may affect the ammonium-ammonia equilibrium in the manure, in which the ammonia is readily available for volatilisation at high pH values.

Carbon dioxide emissions are commonly reported in the literature on a weight basis. The CIGR (2002) estimated an average carbon dioxide production in rabbits of 1.55 g/h per kilogram of live weight. For fattening rabbits, Kiwull-Schöne *et al*. (2005) estimated an overall emission of 1.16 g/h per kilogram of live weight, whereas Estellés *et al*. (2010) found an average emission rate of 2.55 g/h per kilogram of live weight. Those studies were conducted in flux chambers, and carbon dioxide production by manure was therefore not considered. In the study presented here, carbon dioxide emission from does and fattening rabbits was 3.14 and 2.80 g/h per kilogram of live weight, respectively. Carbon dioxide production from manure could be the reason for the higher carbon dioxide emission rate obtained in this study. Comparing emissions relative to animal weight basis, does produced more carbon dioxide per kilogram of live weight than fattening rabbits, which may be related to the increased metabolic weight and also to the presence of the lactating rabbits in the same building.

Carbon dioxide emitted by the animals has previously been used as a tracer gas to determine ventilation flows in animal buildings (Pedersen *et al*., 1998). To apply this balance in rabbit farms, not only the average emission value, but also the daily pattern must be known. The daily pattern in carbon dioxide emission identified in this study (Figure 3) is very similar to the pattern identified by Estellés *et al*. (2010). According to these authors, the lowest carbon dioxide production occurs approximately at 3 h, and is associated with the daily minimum in animal activity. This is in accordance with the fact that rabbits are nocturnal animals (Jilge, 1991), therefore being more active and producing more carbon dioxide during the night.

Finally, the difference in nitrous oxide emissions from does and fattening rabbits could be related to differences in microbiology of the excreta between the 2 animal categories. A lower frequency in the removal of manure from reproductive does could also be related to more intensive nitrification and denitrification processes, contributing to an increased nitrous oxide production. However, further research is needed to understand the origin of this difference.

CONCLUSIONS

Temperature, relative humidity, gas concentrations and gas emissions (NH_3, N_2O and CO_2) were characterised in 3 rabbit buildings in the Spanish Mediterranean area. The 2 main phases of rabbit production (reproductive does and fattening rabbits) were studied. Indoor temperature, relative humidity and ventilation flows were also studied.

Average indoor temperature, relative humidity, ventilation flow and gas concentrations varied considerably among experiments throughout the year. Relative humidity and ventilation flow were higher for reproductive does than for fattening rabbits, but indoor temperature was similar. All these parameters could be described by sinusoidal daily variation patterns. Ammonia, nitrous oxide and carbon dioxide concentrations were in general higher for reproductive does than for fattening rabbits, but they did not exceed the maximum thresholds established according to human health and animal welfare criteria, and in most cases the values were far below these thresholds.

Average emissions from does were higher than those from fattening rabbits. Ammonia and carbon dioxide emissions were affected by temperature and relative humidity, whereas nitrous oxide was independent from temperature. Carbon dioxide and ammonia emission followed a sinusoidal daily emission pattern. However, no emission pattern was found for nitrous oxide. Maximum carbon dioxide emissions occurred during the night according to the activity pattern of rabbits. However, ammonia emissions were mainly produced during the day time.

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