On ammonia concentrations in naturally ventilateddairy houses located in Sicily

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Abstract: In this work, the overall objective was to give a contribute to the knowledge of breeding environment conditions as regards issues of great interest which concern the protection of animal welfare, healthiness of the breeding environment, the operators' safety in the workplace and the environmental protection.The main objective of this work was to verify the levels of ammonia concentrations in different functional areas of two naturally ventilated semi-open dairy houses in Sicily (Italy), through the measurement of the concentrations of ammonia at different heights from the floor of the breeding environment, also in relation to the main inside microclimatic variables and outside climate conditions.An experimental protocol for measuring ammonia concentration within the breeding environment at different heights from the floor as well as the main internal microclimate variables and the external climatic ones was proposed.An estimation of ammonia emission values was carried out by comparing different methods.A technique for ammonia emissions reduction was tested, by using a processing residue of the coffee industry.This technique could be regarded as feasible in this field since the experiment showed a reduction of approximately 50% of the emissions and the choice of this dried vegetal material is suitable due to its easy availability in the territory.

Keywords: Emissions, animal welfare, operators' safety, naturally ventilated barns.

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1 Introduction

If it is not properly managed, intensive livestock farming has the potential to cause environmental pollution. Among gaseous emissions there are unpleasant odours, ammonia, methane, nitrous oxide, and dust. Besides the effects of ammonia (NH_3) emissions on the environment, the importance of evaluating the ammonia concentrations in livestock buildings regards the necessity to ensure the operators' safety and animal welfare. In fact, high concentration of NH_3 inside the animal houses also represents potential health hazards to humans and animals (Reece et al., 1980; Dohnam et al., 1995).

In general, the release of ammonia from manure deposited on building floors depends on the characteristics of the manure, livestock management practices, climatic conditions within the buildings, and animal behaviour (Bjerg et al., 2013a; Bjerg et al., 2013b).To compute ammonia emissions, knowledge of the ventilation rate is also required and involves high uncertainties for naturally ventilated barns (Kiwan et al., 2012).

Although studies of agricultural NH_3 have increased in recent years, reliable field measurements of NH_3 at animal facilities (animal houses, and manure storage and treatment) are a major need. Understanding and control of NH_3 at animal facilities depend on sampling/measurement techniques, including devices, instruments, and procedures (Ogink et al., 2013).Accurate and reliable techniques provide high quality data that are essential to research as well as abatement of NH_3 emissions (Calvet et al., 2013).

In Italy, at present, few research studies (Fabbri et al., 2007; Costa et al., 2012) have regarded ammonia

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concentration surveys and the evaluation of how the different housing types and different techniques of manure management affect the emission of ammonia from livestock buildings, although ammonia concentrations in the breeding environment inside the barn could be of relevance and, as a consequence, ammonia emissions from livestock buildings.

The main objective of this work was to verify the levels of ammonia concentrations in different functional areas of barns for dairy cows through the measurement of the concentrations of ammonia at different heights from the floor of the breeding environment, also in relation to the main inside microclimatic variables and outside climate conditions. A secondary objective regarded the quantification of ammonia emissions from the breeding environment. Although some limits have affected this computation, an effort to seek for an approximate estimate of the ammonia release in the environment was performed.

2 Materials and methods

2.1 Threshold limits of ammonia (MAC: Maximum allowable concentration)

Acceptable levels of ammonia concentrations for the working environment of the stockman and/or the living environment of livestock lie below nationally defined and established maximum allowable concentrations (MAC values).The definitions of threshold limits are shown below:

- TLV (Threshold Limit Value) expresses the airborne concentration of a substance to which nearly all persons can be exposed day after day without adverse effects.
- TLV-TWA (Threshold Limit Value -Time Weighted Average) is the allowable concentration for a normal 8-hour workday or 40-hour work week.
- TLV-STEL (Threshold Limit Value - Short Time Exposure Limit) is the maximum concentration for a continuous 15-minute exposure period (maximum of four such periods per day, with at least 60 minutes between exposure periods, and provided that the daily TLV-TWA is not exceeded).
- TLV-C (Threshold Limit Value - Ceiling) is the absolute exposure limit that should not be exceeded at any time.

These Threshold Limit Values are not a clear demarcation line between dangerous and non-dangerous concentrations, or a relative index of toxicity, however, they serve as a guideline for the prevention of health risks in the workplace. These levels vary from 20 to 50 p.p.m. depending on animal type, working time (exposure) and country. In Italy these limits for ammonia were fixed to 25 ppm for TLV-TWA and 35 p.p.m. for TLV-STEL (ISPESL, 2008).The same limits were proposed by U.S. Department of Labor and TLV-C was fixed to 50 p.p.m.(OSHA, 2013).Kirkhorn and Garry (2000) argued that current limits for ammonia were not appropriate for animal confinement workers, and recommend alower ammonia limit of 7.5 p.p.m.

2.2 The livestock buildings under study

The barns under study were two naturally ventilated dairy houses located in an area of the Province of Ragusa highly suited to livestock breeding, where most of the naturally ventilated barns present in Sicily (Italy) are located. These livestock buildings were free-stall barns with a cubicle resting area. Both buildings, named Building A and Building B in the following, are the result of a functional rearrangement of the indoor areas which modified an old type of management which involved breeding on litter. The trials were carried out from July to September 2013.

2.2.1 Building A

The Building A was a free-stall barn open on three sides which is located in ContradaPozzilli in the municipality ofVittoria (Ragusa, Italy), at an altitude of approximately 230 ma.s.l.The Building A was about 55.50 m long and about 20.80 m wide, had a ridge height of 7 m and an eave height of 4 m. Its bearing structure was made partly of reinforced concrete columns and beams and partly by steel pillars and trusses.The roof was symmetric with a central ridge vent, and composed of fibre-cement sheets supported by the bearing structure made of steel trusses and purlins. The building was oriented to north-east. The sides facing to south-east, north-east and north-west were fully open, whereas the side to south-west was fully closed (Fig.1).

At the centre of the barn, the feeding passage, 4.20 m wide, divided the barn in two symmetric areas: in one side there were boxes for calves and the farmer office, on the other side the feeding and the resting areas for dairy cows.Adjacent to the feeding alley, the resting area was divided in 64 head-to-head cubicles arranged in two rows and equipped with sand beds.A service alley was adjacent to the resting area, and two side passages constituted walkways for the cows to move from the feeding alley to the service alley.

The alleys, made of concrete, were cleaned by a mechanical tractor with scraper that was used by the operator once a day, at about 09:00 AM. In the scraper a hard rubber was applied to the blade to ensure a better cleaning effect.

The milking parlour was located in a specific building outside the barn.The first milking was carried out at about 5:30 AM and the second one at about 5:30 PM.Inside the barn 45 dairy cows (Friesian) were bred. They were divided into three groups of 15 cows, grouped according to the stage of growth.

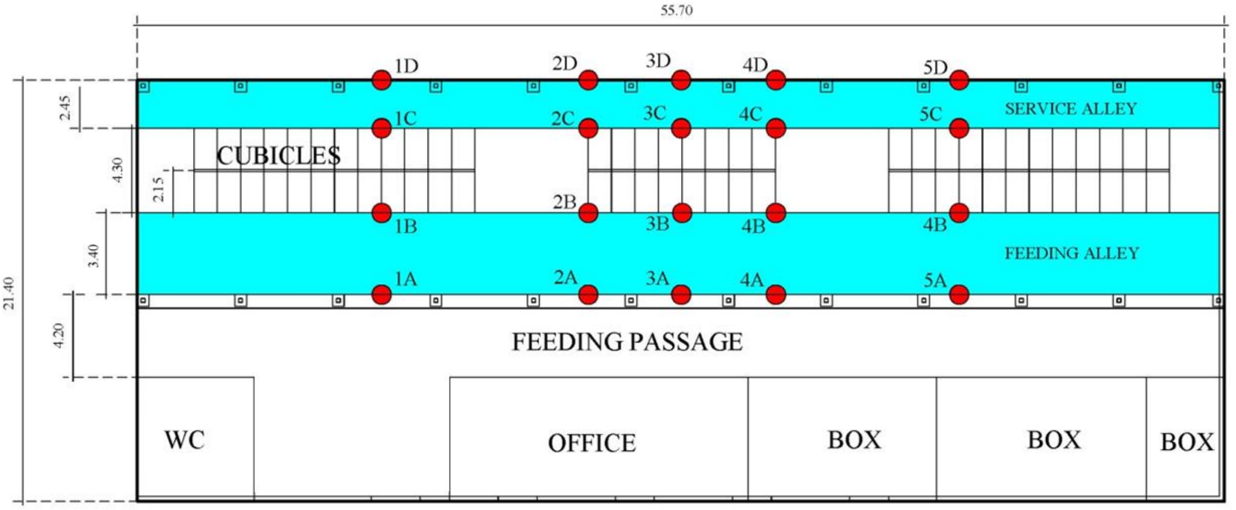

Figure 1Plan of Building A with sampling points localisation.

2.2.2 Building B

The Building B was a free-stall barn open on two sides which is located in Contrada Castiglione (Ragusa, Italy) at an altitude of approximately 330 ma.s.l..The building had a rectangular plan, with a bearing structure composed of steel pillars and trusses.The structure of the roof was similar to that of Building A.The Building B was 65.0 m long and 23.0 m wide, and it was divided into two symmetric areas by the feeding passage. On the north side, there was a set of multiple boxes in which calves until the age of about 1 year were housed, while on the other side there were the manger, the feeding alley, and one row of cubicles equipped with straw beds for dairy cows.

Unlike Building A, the Building B had ventilation openings in the long walls at a 2.20 m height above the floor to prevent the air from going directly on the animals, whereas it is open in the other two sides to facilitate the passage of the bulldozer and the feed mixing truck.The distribution of functional areas of the barn derived from a structural reorganization that, while maintaining unchanged the bearing structure, substituted the litter with one row of cubicles.In this new layout, the service alley was not accessible to the cows yet it was utilized only by the operators (Fig. 2).In this barn 50Friesian cows were bred, four of which belong to the Jersey breed.

The cleaning was done twice a day: at approximately 9:00 AM, after the first milking, and at approximately 7:00PM, with some variations depending on the season. Although this routine was more time-consuming compared to that carried out in Building A, in which the cleaning was done only in the morning, this management choice was justified by the fact that the cows of Building B were not yet accustomed to the cubicles of the resting area. As it was only three years since the breeding reorganization has been carried out, the cows often consider the feeding alley as a resting area and, as a consequence,they breathe more ammonia when they are in lying. The choice of providing the cubicles with straw bed, besides straw being a low-cost material, was made to facilitate bed cleaning and make cows get accustomed to the new functional organization of the areas.

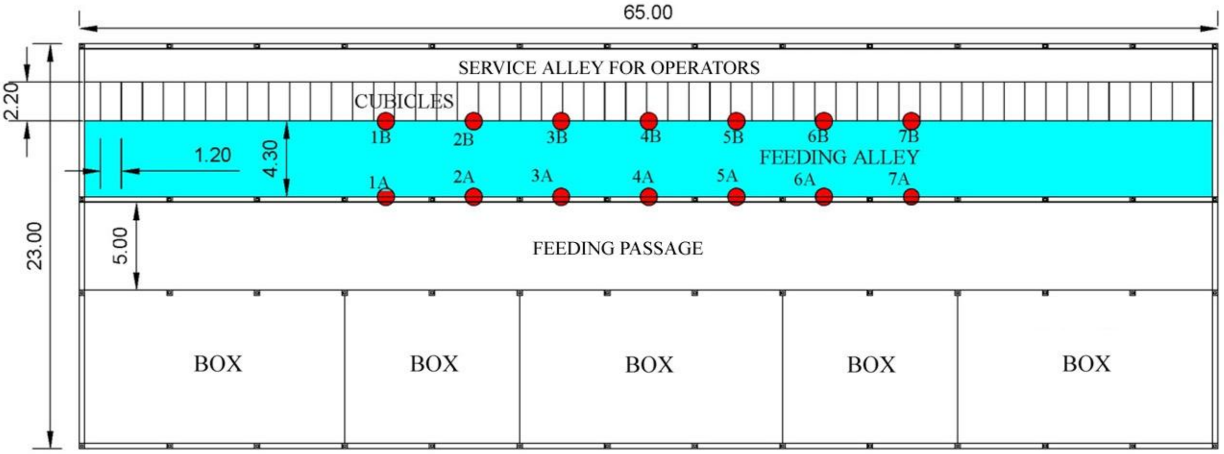

Figure 2 Plan of Building B with sampling points localisation.

2.3 Measurement of ammonia concentrations and indoor and outdoor microclimatic data

The measurement of gas concentrations inside the breeding environments wasconducted on predefined points by using a portable measuring device.In this research work, ‘point sampling’ was the selected method in which samples are taken at a selected single point or at multiple points within animal facilities.In detail, sampling locations were fixed in animal and human respiration zones, since animal and human exposure were investigated.

Selection of measurement technique was based on research objectives, coupled with the existing economic capabilities of the research institution. A single-use sensor for ammonia concentration measurement, although it is relatively inexpensive, was not considered since it would have broadened the sampling time.For ammonia concentration measurement, a dry method with a passive sampling technique was selected. The choice derived from the good precision of the method with a low cost of the device, which allows direct readout of measurements, good sensitivity and short response.

Frequency of sampling was subject to some technical restrictions like the capacity and response time of the measuring device and the time needed to perform the manual measurements at the different locations and heights.

A portable measurement device, Dräger X-AM 5000 (Dräger, Germany), was used for monitoring ammonia concentrations, within the functional areas examined. This instrument detects ammonia through an electrochemical sensor situated at the top. It has a detection range between -25 and 200 p.p.m. of $NH_3$with an error of 2–3% when temperatures are between -20 ℃ and 50 ℃. The response, i.e., the time to perform the gas concentration measurement, varies from 1 to 30 sec.The instrument set has two alarm values for ammonia concentration (A1 and A2): in both cases the alarm signal is optical, acoustic and also shown by vibration.The alarm A1 activates at a concentration ≥20 p.p.m. of NH_3, whereas the alarm A2 activates at a concentration ≥40 p.p.m. of NH_3.

As regards microclimate variables in the barn, the air temperature, the air relative humidity and air velocity were measured with the aim to analyse the concentration of NH_3 in relation to microclimate variables at the ground level. To compute ventilation rate, instead, within the objective of emission estimation, sampling location were fixed at the centre of the building and at the roof vent.

In the trials a portable instrument, AM-4205 (manufactured by Marcucci, Italy), was utilised to measure the air velocity (ms^{-1}), air temperature (℃) and relative humidity. The instrument accuracy is ± 2% for relative humidity and air velocity, and about 0.8 ℃ for temperature. The air velocity measuring range of the instrument is 0.4–25 ms^{-1}.

In addition to the instrumentation already described, a data-logger CR10X (Campbell, UK) connected to sensors of air temperature and relative humidity (Rotronic Italy s.r.l., Italy) was present in Building A as it was used for other research activities (Porto et al., 2013a; Porto et al., 2013b; Porto et al., 2014). Also connected to the data-logger were sensors for the measurement of velocity and direction of indoor air (anemometers WindSonic, Gill Instruments Ltd., UK), and wind speed and direction outside the barn.

The air temperature sensor was a platinum thermo-resistance (Pt 100 ohm 0℃) with a measure interval between–40℃ and +60℃ and precision of ±0.2℃ (at 20℃). The hygrometer was a transducer with a sensibility of ±0.04%RH/℃ and precision of ±2% (at 20℃).This combined sensor was placed inside a shelter to avoid inaccuracies due to direct radiation on the sensor. The anemometers were two-dimensional sonic sensors characterized by a measuring interval of 0–60 ms^{-1}, a precision of ±2% (at 12 ms^{-1}), a resolution of 0.01 ms^{-1}, and a threshold of 0.01 ms^{-1}.The direction sensor had a measuring interval of 0–359°, a precision of ±3% (at 12 ms^{-1}), and a resolution of 1°.

The sensors inside the barn were located at a height of about 2.0 m above the floor, while outside sensors were located at the ridge vent above the roof of the barn.All the measured parameters were recorded at intervals of five seconds by a data-logger that every five minutes computed the average values and stored them in memory locations.

2.4 Sampling layout in the buildings analysed and data collection sessions

As regards sampling points, it was decided to work on representative points in relation to the areas in which animals deposited the most of their manure. The numbers of sampling points located in the functional areas of the two buildings were respectively 20 in Building A and 14 in Building B.The difference in the number of points fixed in the two barns was due to the presence of a single row of cubicles in the second barn (Building B), compared to the first one (Building A) which had two rows of stalls.

The position of the sampling points is illustrated in the building plans (Figs. 1 and 2). The measurements of ammonia concentrations were made at three different heights above the floor (10 cm, 20 cm and 40 cm) in order to analyse the presence of the gas in points where animals breathe for most of the day when they are in lying, feeding and standing positions. Sampling points, indicated by numbers, were located in the corner between walls and the floor of the feeding and service alleys. In these positions the cleaning may be less effective and, as a consequence, ammonia concentration may increase.

Four sampling sessions were carried out during the daylight hours in order to evaluate the daily trend of emission and their relationship with the microclimatic conditions.

2.5 Techniques to quantify ammonia emissions in naturally ventilated barns

In this study, three techniques to measure airflow rates were applied: natural tracer gas technique (H_2O balance), heat balance, and natural ventilation theory. In some works carried out in similar environments (Samer et al., 2011; Samer et al., 2012), these were the most utilized techniques.

In H_2O balance technique, moisture from animal respiration and evaporation from manure is used as a natural tracer gas, and the ventilation rate $\dot{V}_{H2O}$ throughout the building can be determined by calculating the mass balance of H_2O flow. The calculations of moisture balance were based on several studies (Albright, 1990; Hellickson and Walker, 1983).

In heat balance method, the concept of energy conservation is applied to sensible heat. The general form of an energy balance for a control volume is the difference between gains and losses and it is equal to the change of storage (Hellickson and Walker, 1983; Albright, 1990; Lindley and Whitaker, 1996).

Another method to obtain the ventilation rate from measurements is based on the natural ventilation theory. Natural ventilation is the movement of air through openings of a building due to the natural forces produced by wind and temperature difference; the air exchange rate is determined by thermal buoyancy forces and wind pressures at the ventilation openings (Albright, 1990; Hellickson and Walker, 1983; Kittas et al., 1997).

Ammonia emissions were calculated according to the following equation:

$$E_{ammonia} = VR \times C_{NH3} \qquad (1)$$

where VR is the ventilation rate (m^3h^{-1}) and C_{NH3} is the ammonia concentration (mg/m^3).The VR was computed as $\dot{V}_{H2O}$ and $\dot{V}_{HB}$ as well as $\dot{V}_{NV}$, following the three chosen techniques, respectively. The computation was carried out for Building A, where some characteristics of the herd, which were needed to compute the VRs, were the following: the live weight of the cows was 650 kg, the milk production was 32 $lday^{-1}$ and the number of days of pregnancy was fixed to 135 on average.

2.6Statistical analyses on collected data

First of all, the analysis of variance (ANOVA) was performed on collected data. If the ANOVA resulted significant, the Tukey Honest Significant Difference (HSD) test, which performs multiple comparisons between the means and evaluates the confidence intervals for the differences, was carried out.

Percentiles were utilized to compute outliers values of datasets. The k^{th} percentile is the value that separates the first k% of the data, which have to be ordered in growing sequence, from the remaining data. The index of the k^{th} percentile is given by the following relation:

$$I_k = (n+1) \times k / 100 \qquad (2)$$

By performing a linear interpolation, the precise value between the two data of the group, which have the index of the sequence equal to the integer number before and after I_k, is computed. The main percentiles are the following: Q_1 is the first quartile or 25th percentile; Q_2 is the second quartile or 50th percentile (median); Q_3 is the third quartile or 75th percentile; Q_3-Q_1 is the interquartile range (where 50% of the data are included).

The outlier values x, those abnormally too big or too small, which are too different from the rest of the data, were calculated as follows:

$$x \geq Q_1 - 1.5\left(Q_3 - Q_1\right) \text{ or } x \geq Q_3 + 1.5\left(Q_3 - Q_1\right) \qquad (3)$$

2.7 Criteria for selection of the dried material and the acidification treatment

Within the trials carried out for this work, on September 24, 2013 an experiment was carried out in the Building A with the aim of applying a method for the reduction of ammonia emissions. This method had the purpose to acidify the slurry and to reduce the ammonia volatilization, through the high absorbent power of the dry material used.

Among dried vegetal materials, a residue of coffee industry processing was selected and, particularly, the husks (parchment and silver skin) that are discarded during the roasting process. This compound has the characteristics suitable to usage requirements of this case study and, specifically, high level of absorption, low pH (acidic), easy availability in the area, and low cost. A specific investigation showed that in Sicily (Italy) there are about 18 companies in the coffee roasting activity and four of these are in the territory of Ragusa. The amount of this debris material that the companies produce is equal to about 20 kgton^{-1} of green roasted coffee. These companies give the product, and they support these costs, to companies that use it for composting. For these reasons, the material chosen has the appropriate characteristics (feasibility and sustainability) to the considered utilisation.

The dried vegetal material was previously treated with a weak acid (acetic acid) in order to lower its initial pH (6.5) and to take to a value of about 5.5 that is unlikely to damage the hooves of dairy cows which walk on it.

3 Results and discussion

Table 1 reports the maximum values and the minimum values of all the measurements of ammonia concentrations in the feeding areas and service areas of the two buildings under study, as well as the mean values of the ammonia concentrations computed for all sampling sessions at 10 cm above the ground, in each day of the trials. This table shows that the highest values were found on July 2, 2013 in Building A, within the feeding area. However, also in other days of the trials, values higher than the threshold of the MAC were found and, in particular, the highest values were found in the feeding area compared to the service area. This condition could be explained by the fact that the service area is more exposed to the air flows that are generated by natural ventilation on the side of the barn which is fully open and, therefore, it causes the dispersion of the gas outside the barn. On the contrary, the feeding area is located in the central area of the barn and, therefore, is less affected by the movements of the air; also cows tend to stay for much time in this area of the barn, as they feed, so the manure accumulates in larger quantities.

In the analysis of the data distribution, only two outliers' values of ammonia concentration were found, according to the statistical analyses performed. They were found on 9 July (Building A): an outlier with value 0 p.p.m. at 11:00 AM and an outlier with a value of 32 p.p.m. at 01:00 PM.

According to the research scope declared in the introduction, the main objective of this work was to verify whether or not the levels of ammonia concentrations, in the naturally ventilated Sicilian barns, were higher than threshold values, which can be dangerous for workers that spend their working hours in the barns and for the animals that live in those breeding environments. Tofulfil this aim, Table 2 shows the number of times that the values of ammonia emissions are in four distinct ranges defined by the threshold values TLV-TWA, TLV-STEL, and TVL-C. The values of ammonia concentration, relative to all the sampling dates and within the two areas examined (feeding and service areas), were grouped into intervals according to the TLV.Values corresponding to less than 20 p.p.m. are defined by the TLV-TWA, the values between 20 and 35 p.p.m. are identified by the TLV-STEL, values between 35 p.p.m. and 50 p.p.m. are under the TLV-C, and finally values greater than 50 p.p.m., i.e., above TLV-C, represents dangerous values for health.

From the analysis of Table 2 it was observed that on July 2, 2013 higher rates of gas concentration were found in Building A, with values greater than 35 p.p.m. and in some cases higher than 50 p.p.m.A similar condition also occurred on July 23, 2013 in Building B while in the other days these values were much lower. Higher percentages of values above the TLV-TWA threshold were found in the feeding area compared to those in the service area, as already observed in Table 1 for maximum, minimum and mean values of ammonia concentrations. In Building A, the number of ammonia concentration values above TLV-TWA threshold was always higher than those found in Building B.These results could be related to the different microclimate conditions of the building environment which will be analysed in the following of the text and to the different amount of slurry production of the herd observed during the trials which, in turn, depended on the cow weight and the diet.

Figure 3 shows the trend of ammonia concentrations compared to the evolution of inside temperature at 2 m above the ground on July 2, 2013. In Figure 4 the trend of ammoniaconcentrations compared to the variation of inside air temperature recorded at 10 cm above the ground on July 23, 2013 in Building B is reported. In both cases the ammonia concentration is inversely proportional to inside temperature, as in the warmer hours of the day the lowest values of ammonia are recorded.Similar results were found in the other days of trials (data not shown).This is probably due to the buoyancy effect that determines an upward movement of the air, which disperses the gas, and to the effects of indoor air velocity during the central hours of the day.

Table 1 - Maximum values and minimum values of all the measurements of ammonia concentrations.

	Maximum values (p.p.m.)		Minimum values (p.p.m.)		Mean values (all sampling sessions at 10 cm)	
Day of trial	Feeding area	Service area	Feeding area	Service area	Feeding area	Service area
2 July 2013 (Building A)	69	58	4	6	19 .7	18
9 July 2013 (Building A)	35	42	5	4	16 .7	15 .6
23 July 2013 (Building B)	53	/	3	/	14 .8	/
24 September 2013 (Building A)	44	24	6	4	15	6 .7

Note: Concentrations in the feeding areas and service areas of the two buildings under study, and mean values of the ammonia concentrations computed for all sampling sessions at 10 cm above the ground, in each day of the trials.

Figure 5 shows the trend of ammonia concentrations compared to the evolution of inside air relative humidity (RH) at 2 m above the ground on July 2, 2013. The ammonia concentration was influenced to a small extent by relative humidity. Similar trends were observed in the other days of the trials (data not shown).In general, relative humidity should be kept between 50% and 70% in closed livestock environments. Lower relative humidity is likely to produce a dusty environment while higher relative humidity can lead to wet litter and high ammonia concentrations.

The graph of Figure 6 shows the trend of the ammonia concentration in relation to the velocity of indoor air. The concentrations of ammonia were lower during the central hours of the day corresponding to the maximum velocity of indoor air (approximately 1.3 ms^{-1}), which determines the dispersion of the gas from inside to outside through the open sides of the barn, showing that ventilation affected at higher extent the level of ammonia concentration, as expected in semi-open livestock buildings.

Table 2 - Number of times that values of ammonia concentration lied in the four ranges defined by the threshold values TLV-TWA, TLV-STEL, and TVL-C.

Date/Building	Ammonia (NH_3) (p.p.m.)	Feeding zone		Service zone	
		n.	%	n.	%
2 July Building A	$x< 20$	28	56	30	60
	$20\leq x<35$	14	28	13	26
	$35\leq x<50$	7	14	6	12
	$x\geq50$	1	2	1	2
	Tot.	50	100	50	100
9 July Building A	$x< 20$	32	64	34	68
	$20\leq x<35$	17	34	12	24
	$35\leq x<50$	1	2	4	8
	$x\geq50$	0	0	0	0
	Tot.	50	100	50	100
23 July Building B	$x< 20$	44	83 .9	/	/
	$20\leq x<35$	7	12 .5	/	/
	$35\leq x<50$	4	7.1	/	/
	$x\geq50$	1	1.8	/	/
	Tot.	56	100	/	/
24 September Building A	$x< 20$	27	67.5	39	97.5
	$20\leq x<35$	12	30	1	2.5
	$35\leq x<50$	1	2.5	0	0
	$x\geq50$	0	0	0	0
	Tot.	40	100	40	100

In Table 3, the maximum, minimum and mean values of the inside air temperature and relative humidity are summarised for each day of the trials. By comparing the ammonia concentration values measured in the different days of the sampling sessions, reported in Table 1, with the microclimatic variables, reported in Table 3, a general decrease of ammonia concentration values is observed in relation to a natural decrease of inside air temperature from the summer season to autumn.

In Table 4, the maximum, minimum and mean values of the inside air velocity and outside wind speed, and the frequency of wind direction are summarised for each day of the trials. Outside variables were not recorded on 23 July and 24 September, 2013.

As previously observed, in the day of trial July 2, 2013 the highest concentrations of ammonia were recorded. This outcome could be explained by the fact that air temperature was high and the air was more still inside the barn in comparison to July 9, 2013.

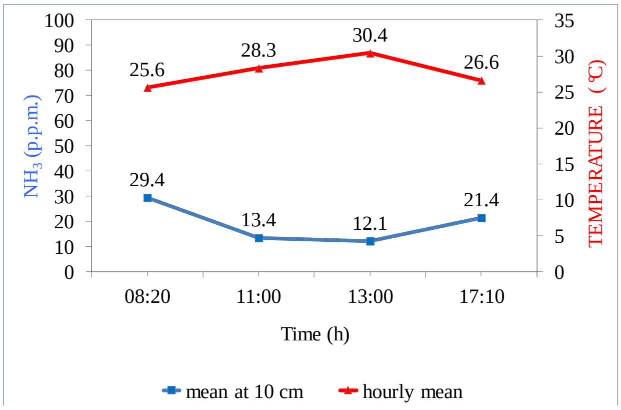

Figure 3 - Indoor air temperature and ammonia concentration at 10 cm in the Building A, on July 2, 2013.

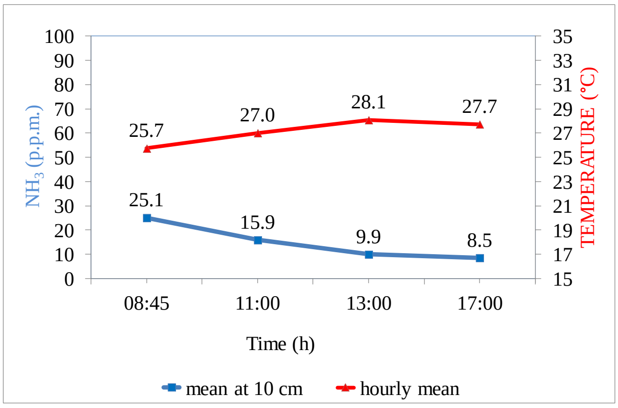

Figure 4 - Indoor air temperature and ammonia concentration at 10 cm in the Building B, on July 23, 2013.

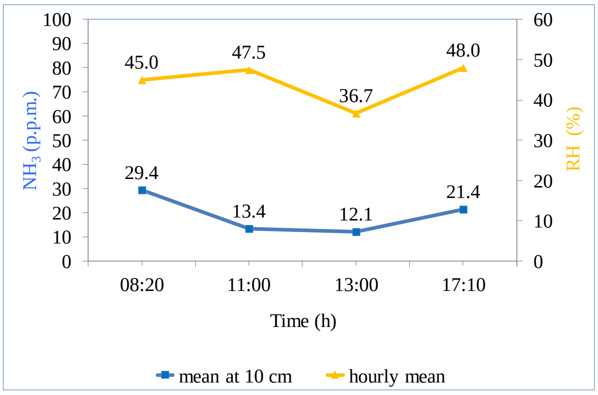

Figure5 - Indoor relative humidity and ammonia concentration at 10 cm in the Building A, on July 2, 2013.

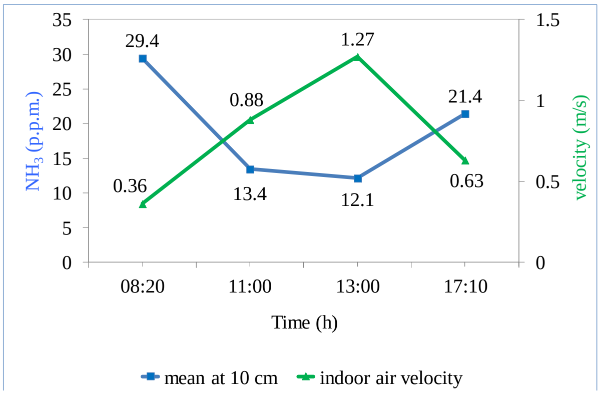

Figure 6 – Indoor air velocity and ammonia concentration at 10 cm in the Building A, on July 2, 2013.

From Table 4it comes out that the prevailing winds are from South–East as well as from South-West on 2 July whereas from South-West on 9 July. Hot and humid air was, therefore, released from Southern summer winds in that period. As a consequence the ventilation of the Building A was generally along the longitudinal axis of the barn.

On the basis of the variables analysed above an estimation of the ammonia emission based on the relations described in Section 2 was carried out. The H_2O balance technique gave unreliable results being less adequate for summer analyses, as already found by Samer et al. (2012).The techniques referring to natural ventilation theory and the heat balance, instead, gave different but acceptable results which could be considered as estimates of the emissions from the breeding environment analysed.

Table 3 - Maximum, minimum and mean values of inside air temperature and relative humidity in each day of the trials.

	Inside air Temperature (℃)		
Day of trial - Building	max	min	mean
2 July - A	27.4	20.3	25.2
9 July - A	25.9	23.3	24.6
23 July - B	28.8	25.2	27.1
24 September - A	27.3	18.9	23.3
	Inside air Relative Humidity (%)		
Day of trial - Building	max	min	mean
2 July - A	51.7	28.7	39.5
9 July - A	61.4	36.3	45.0
23 July - B	61.4	48.4	54.1
24 September - A	74.0	46.9	59.9

In Figure7 the ammonia emission estimated by using the Natural ventilation method is shown for July 2, 2013 in Building A. The ammonia emission values related to the cows housed in the Building A ranged between 0.44 and 0.14 kgh^{-1} whereas the values related to the HPU (heat production unit) were between 0.31 and 0.10 kgh^{-1}HPU^{-1}.The Heat balance method yielded ammonia emission values ranging between 0.005 and 0.27 kg/h and 0.004 and 0.19 kgh^{-1}HPU^{-1} (Fig. 8).These values are generally higher than those found in the literature (Ngwabie et al., 2009; Bjerg et al., 2012; Wu et al., 2012) due to the higher ammonia concentrations values recorded.

Table 4 - Maximum, minimum and mean values of inside air velocity, wind speed, and frequency of wind direction, in two days of the trials.

<table>
<tr><td rowspan="2">Day of trial - Building</td><td colspan="4">Inside air velocity (ms⁻¹)</td></tr>
<tr><td>Max</td><td colspan="2">Min</td><td>Mean</td></tr>
<tr><td>2 July - A</td><td>1.6</td><td colspan="2">0.2</td><td>0.8</td></tr>
<tr><td>9 July - A</td><td>1.9</td><td colspan="2">0.2</td><td>1.0</td></tr>
<tr><td rowspan="2">Day of trial - Building</td><td colspan="4">Outside wind speed (ms⁻¹)</td></tr>
<tr><td>Max</td><td colspan="2">Min</td><td>Mean</td></tr>
<tr><td>2 July - A</td><td>3.6</td><td colspan="2">0.3</td><td>2.3</td></tr>
<tr><td>9 July - A</td><td>4.3</td><td colspan="2">0.2</td><td>2.5</td></tr>
<tr><td rowspan="2">Day of trial - Building</td><td colspan="4">Frequency of wind direction</td></tr>
<tr><td>0 °-90 °(N-E)</td><td>90 °-180 °(E-S)</td><td>180 °-270 °(S-W)</td><td>270 °-360 °(W-N)</td></tr>
<tr><td>2 July - A</td><td>0</td><td>61</td><td>52</td><td>7</td></tr>
<tr><td>9 July - A</td><td>0</td><td>6</td><td>111</td><td>3</td></tr>
</table>

However, it could be observed that ammonia emission trend reported in Figure8 shows that the lowest values are in the warmest hours of the day when ventilation is high. Since this trend highly follows the temperature difference between inside and outside, it could fit for closed breeding environments where the buoyancy effect is much higher than the wind effect. In semi-open barns, instead, ventilation is the main driving force. When the air velocity inside the barn increases, ammonia concentrations decrease whereas ammonia emission increases due to the high ventilation rates.

In the following of the text, the results of the statistical analyses carried out on ammonia concentration data, collected in the two considered breeding environments, are reported. Specifically, data means of ammonia concentrations were analysed and compared in different conditions:

- At different heights above the ground (i.e., 10 cm, 20 cm, and 40 cm);
- In the two different functional areas of the considered area of interest inside Building A;
- At the different hours of the sampling sessions in the two buildings analysed in order to compare measurements before and after cleaning operations.

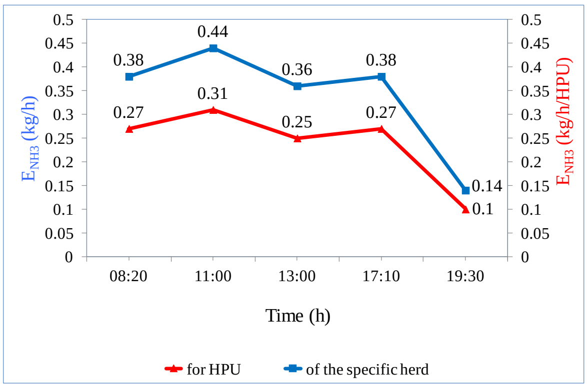

Figure 7 - Ammonia emission estimated by using the Natural ventilation method, on 2 July 2013 in the Building A.

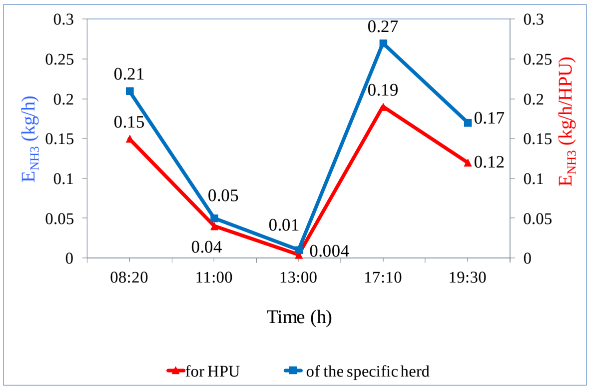

Figure8 - Ammonia emission estimated by using the Heat balance method, on 2 July 2013 in the Building A.

In all these analyses, the *p*-values of ANOVA tests for difference in means resulted <0.05, therefore, the tests were significant at the 5% level and there was evidence that the population means were not the same. Consequently, post-hoc tests were carried out to compare pairs of treatments simultaneously in order to investigate which data means were significantly different. In Table 5 statistical analyses on the three datasets related to ammonia concentrations at 10 cm, 20 cm and 40 cm of height from the barn floor were reported. As regards the acquisitions carried out on 23 July, which are related to Building B, the statistical analyses showed that the mean of the measured ammonia concentrations at 10 cm and 20 cm were quite always significantly different from those at 40 cm. In almost all the acquisitions carried out in the other days analysed, which are related to Building A, the mean of the measured ammonia concentrations at 10 cm were significantly different from those at 20 cm and 40 cm.

From the statistical analysis performed on the data collected in Building A (Table 6), the data means of ammonia concentrations collected in the two functional areas analysed, i.e., the feeding area (a+b) and the service area (c+d), resulted significantly different on September 24, 2013 at all sampling sessions, only at 8:00 AM (before the cleaning activity) on July 2, 2013, and at 5:00 PM on July 9, 2013.Therefore, it appears that significant differences in data means occurred when there was a difference in the amount of manure deposited in the functional areas where the cows live.

The comparison between the measurements before and after cleaning operations, reported in Table 7, showed that the effectiveness of the cleaning routine is statistically detected in Building A on July 2, 2013 and in Building B on July 23, 2013, while in the other two days there was not always a significant difference between the means of the measurements before and after the cleaning operations.

From these analyses the introduction of good management practices was desirable, such as two cleaning operations (one in the morning and one in the evening) and a manual cleaning operation of the feed barrier to release the manure deposits, which could be carried out periodically, e.g., once a week.In the trials, it was observed, in fact, that the cleaning action of the tractor with scraper was not completely effective because the feeding area is a critical point for the ammonia emissions.

As concerns the ammonia emission reduction technique, which was proposed and adapted to the specific case study, the dried vegetal material was mixed with the weak acidic solution and spread over an area of about 20 m^2, after three hours from the operations of cleaning in the morning, along the feeding alley of Building A. The chosen area was near the feed barrier where they had created many urine puddles.It was observed that the cows did not show discomfort in walking on the treated area and the puddles of urine were quickly absorbed. After a few hours, the ammonia concentration was measured in two points within the treated area and it was found that there has been a reduction of approximately 50% of ammonia levels compared to the ammonia concentration recorded at the same points before the treatment.

Table 5 - Statistical analyses on datasets related to ammonia concentrations at the heights of 0 cm, 20 cm, and 40 cm above the barn floor.

	Sampling sessions									
2 July	8:00		11:00		13:00		15:00		17:00	
	Mean	Group	Mean	Group	Mean	Group	Mean	Group	Mean	Group
10 cm	29.40	A	13.40	A	12.10	A	12.10	A	21.40	A
20 cm	19.00	B	8.90	A	5.05	B	15.05	B	10.70	B
40 cm	8.55	C	2.95	B	1.30	B	1.30	B	2.55	C

	Sampling sessions									
9 July	8:00		11:00		13:00		15:00		17:30	
	Mean	Group	Mean	Group	Mean	Group	Mean	Group	Mean	Group
10 cm	19.50	A	20.40	A	14.45	A	14.55	A	11.70	A
20 cm	14.70	A	11.80	B	6.05	B	8.55	B	6.70	B
40 cm	7.65	B	4.30	C	1.5	C	1.95	C	1.55	C

	Sampling sessions							
23 July	8:45		11:00		13:00		17:00	
	Mean	Group	Mean	Group	Mean	Group	Mean	Group
10 cm	25.07	A	15.87	A	9.92	A	8.50	A
20 cm	17.86	AB	9.71	A	7.57	A	6.50	A
40 cm	8.43	B	2.14	B	0.85	B	1.07	B

	Sampling sessions							
24September	8:00		11:00		13:00		16:00	
	Mean	Group	Mean	Group	Mean	Group	Mean	Group
10 cm	16.70	A	13.00	A	7.05	A	6.70	A
20 cm	9.70	B	4.85	B	2.30	B	1.35	B
40 cm	4.95	C	1.95	B	1.10	B	0.00	B

In this work, floor constructive solutions to reduce ammonia emissions were not analysed since they may regard the design of new barns whereas for existing ones other solutions should be proposed. Besides pre-excretion and post-excretion ammonia reduction option that have already been developed and assessed (De Boer et al., 2002; Børsting et al., 2003;Vaddella et al., 2010; McCrory and Hobbs, 2001),there are some new possible promising ammonia reduction options that need further development and evaluation (Wheeler et al., 2011).These techniques also include those of slurry acidification and addition of urease inhibitors (Eriksen et al., 2008; Kay et al., 2008).Within the techniques of slurry acidification, the use of a dried vegetal material with high absorption power, such as wastes of the food industry, could be recommended. In this direction, this research proposed the use of coffee residues, however, this technique belongs to the group of novel techniques which need to be further developed and tested.

The limits of the work depending on the type of measurement instrument available for the trials can be summarised as follows: it was not possible to carry out a continuous and simultaneous data recording of the concentrations of ammonia in the barns due to the available device; it was not possible to make an accurate assessment of air exchanges between the interior and the exterior of the buildings based on simultaneous multiple measurements at the defined inlets and outlets of the barn. However, the aim of this work was to verify whether the problem of ammonia emissions existed in semi-open barns in Sicily (Italy) and to what extent the building characteristics and the climatic conditions affected the emissions.

Therefore, a point sampling measurement with statistical analyses was considered satisfactory to assess the existence of the problem. Relations between the type of building and the localisation of the emissions as well as the connection between the measured microclimatic variables and the ammonia release were analysed in order to produce guidelines suitable to reduce emissions.

The measuring instruments used in the trials were simpler than the equipment used in the works reported in the literature. However, the simplicity, the lower cost in comparison to that equipment and the good accuracy of the measurements may constitute good characteristics for a tool which could be more easily used by a farmer to control ammonia level. This usage would be suitable especially for the control of the ammonia level in specific areas of the barn, both for animal welfare and for operators' safety.

4 Conclusions

Ammonia monitoring is important for the well-being of livestock and stockmen. High ammonia concentrations can lead to poor feed conversions, reduced weight gains, and increased susceptibility to disease. When a person is constantly exposed to ammonia, sense of smell is adversely affected and ability to detect ammonia decreases, until the ammonia concentration has reached 50–60 p.p.m. or higher, which are dangerous values for human health. As regards the environment, the increase of the ventilation rate decreases the ammonia concentration in the premises, but maximizes the emission of ammonia in the environment.

Based on these issues and concerns, the objectives of this research were achieved by defining an experimental protocol for measuring both ammonia concentration within different breeding environments at different heights from the barn floor and the main internal microclimate variables and external climatic ones.High levels of ammonia concentrations and emissions were found and the relationship between these levels and the internal microclimate variables as well as the assessment of the cleaning routine effectiveness were analysed.

Table 6 - Statistical analyses on ammonia concentrations data collected in the two functional areas: the feeding area (a+b) and the service area (c+d), at the different sampling sessions in Building A.

Day of trial	Building	Sampling session	NH_3Mean (a+b) Feeding zone	Group	NH_3Mean (c+d) Service zone	Group
2 July	A	8.00	37.60	A	21.20	B
		11.00	13.70	A	13.10	A
		13.00	13.40	A	10.80	A
		17.00	19.50	A	23.30	A
9 July	A	8.00	17.40	A	21.60	A
		11.00	19.80	A	21.00	A
		13.00	14.00	A	15.10	A
		17.00	16.80	A	6 .60	B
24 September	A	8.00	19.30	A	12.10	B
		11.00	20.60	A	5.40	B
		13.00	6.30	A	7.80	A
		17.00	11.90	A	1.50	B

Table 7 - Statistical analyses on ammonia concentrations data collected in the different hours of the sampling sessions in the two buildings analysed.

Day of trial	Building	Session	Mean	Grouping	P-value
2 July	A	8:00	19.00	A	0.00
		11:00	8.90	B	
		13:00	5.05	B	
		17:10	10.70	AB	
		19:30	10.15	B	
9 July	A	8:20	19.50	A	0.01
		11:00	20.40	A	
		13.00	14.45	AB	
		15:30	14.55	AB	
		17:30	11.70	B	
23July	B	8.45	25.07	A	0.00
		11.00	15.85	B	
		13.00	9.92	B	
		17.00	8.50	B	
24 September	A	8.00	16.70	A	0.00
		11.00	13.00	AB	
		13.00	7.05	B	
		16.00	6.70	B	

In this work, a technique for the ammonia emissions reduction in the breeding environment was also tested, by using a process residue of the coffee industry. This technique could be regarded as feasible in this field since the experiment showed a reduction of approximately 50% of the emissions and the choice of this dried vegetal material is suitable due to its easy availability in the territory.

All the limits of this research considered, which have been analysed and described in this work, this study contributes to the improvement of the knowledge ground regarding ammonia emissions within naturally ventilated dairy houses located in South-Eastern Sicily and lays the groundwork for further investigation in this field.

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