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*Article*

# Assessment of a Low-cost Portable Device for the Gas Concentration Monitoring in Livestock Housing

**Provvidenza Rita D'Urso [1], Claudia Arcidiacono [1*] and Giovanni Cascone [1]**

[1] Department of Agriculture, Food and Environment (Di3A) - Building and Land Engineering Section, University of Catania, via Santa Sofia n° 100, 95123 Catania, Italy; provvidenza.durso@phd.unict.it (P.R.D.); carcidi@unict.it (C.A.); gcascone@unict.it (G.C.)

* Correspondence: carcidi@unict.it; Tel.: 0039095 7147576; 95123, Catania, Italy;

**Abstract:** The increasing regulatory pressure to monitor and reduce GHG emissions and air pollutants requires cost-effective methods for their surveillance. The most common technique used for scientific investigations on gas concentration monitoring in barns are accurate but expensive and with a complex maintenance. This research study analysed the potential use of a low-cost portable measurement devices for the measurement of ammonia ($NH_3$) and carbon dioxide ($CO_2$) concentrations in an open dairy barn. A comparison between gas concentrations acquired at different heights from the floor by using portable devices and those acquired by a photoacoustic infrared multigas spectroscope (i.e., reference measurement) in the same sampling locations was carried out to determine the precision of the low-cost portable devices. The performance of low-cost portable devices was statistically analysed by the application of the one-way analysis of variance, correlation analysis and regression analysis. The results showed a significant difference between gas concentration values at various heights from the floor for both $NH_3$ and $CO_2$. The correlations between concentrations acquired by the low-cost portable device and the INNOVA were statistically significant ($r=0.83$; $P<0.001$) for gas concentrations monitored at 0.4 m from the floor. Compared with the reference measurement device, the low-cost devices were effective in the monitoring of $NH_3$ concentrations at 0.40 m from the floor though it underestimated them in the barn at increasing of the height from the floor, whereas the device was not adequate for $CO_2$ concentrations. In detail, the relative measurement error of the low-cost devices compared to INNOVA was reduced close to the floor during $NH_3$ concentration measurements. Within these limitations, this device could be useful for monitoring $NH_3$ concentration in the barn and to assess variation in $NH_3$ concentrations mainly related to the animal occupied zone. Further efforts are needed in this field of research to identify low-cost device that could simplify emission estimation from open dairy barns.

**Keywords:** low-cost sensors; portable device; environmental monitoring; gas concentrations; dairy barn; photoacoustic infrared spectroscope

## 1. Introduction

The relevant role of agriculture in climate change has been underlined in the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) in 2015, dealing with the issues such as food production, security and GHGs emissions [1]. Specifically, 92 countries have included the livestock sector in order to achieve their national reduction emission targets [2]. Although Europe has implemented policies for improving air quality (e.g., the Directive 2008/50/EC, the Directive 2010/75/EC and the Directive 2016/2284/EU), the text 'A Europe that protect: Clean air for all' [3], adopted by the European Parliament on 13 March 2019, underlines that the costs of air pollution control in Europe are significantly lower in the agricultural sector than in other sectors where more stringent emission controls have already been implemented. In Italy, the emission from farms is assessed by a monitoring and control plan carried out by the farmers through the utilization of regional guidelines [4]. However, Italian law on emissions to the atmosphere requires in cattle sector that only dairy houses with over 200 heads need an emission authorisation (D.Lgsl. n. 152/2006 [5]; D.Lgsl. n. 128/2010 [6]). For a lower number of livestock units there is no control on emissions, though high levels of gas concentrations are likely to be reached for both large and small herds [7-8].

Livestock activity has a significant influence on environmental balances both locally and globally (in terms of air and climate quality, water and soil quality, biodiversity, and landscape quality) [9]. The effects of emissions have many impacts not only on the environment but also on other fields, as they can affect animal welfare and farmer safety [7, 10-12].

The increasing regulatory pressure to reduce GHG emissions and air pollutants requires cost-effective methods to allow their regular surveillance. In this context, the monitoring of air pollution is the basis for the application of efficient emission mitigation strategies [13].

According to Wang et al. [14], the available technologies for measuring gas concentrations can be subdivided into three categories (a) rapidly responding sensors providing concentrations over time (e.g., electrochemical cells, chemiluminescence, fluorescence, photoacoustic spectroscopy, and long path optical instruments), (b) cumulative-concentration devices which carry out only time-averaged values (e.g., denuders, passive samplers, and adsorption bottles), and (c) instantaneous-devices which give snap-shot measurements. The operating principles, advantages, limitations and cost of these technologies were classified in a study by Hassouna et al. [15].

One of the most common techniques used for scientific investigations on gas concentration monitoring in dairy barns is the photoacoustic infrared multigas spectroscopy. In the literature, several research studies have measured gas concentrations in NV dairy barns by using photoacoustic infrared spectroscopes [16-22]. The photoacoustic infrared spectroscopy is based on the analyses of acoustic waves produced from gases that are exposed to radiation [23-24]. Among the most commonly used devices, the photoacoustic infrared spectroscope (INNOVA, Lumasense Technology, Denmark) is a widespread technology for continuous measurement of gas concentrations, but the cost of the instrumentation and routine maintenance is too high [14]. In detail, the purchase price of this kind of equipment and costs of routine maintenance are relatively high and, thus, these devices are not suitable for environmental control carried out by farmers. Generally, the use of this instrument for scientific purposes and, in particular, for determining emission factors under specific barn characteristics and constraints (e.g., barn structure, climatic conditions, barn management, and herd size) requires long term measurements [25]. Therefore, the use of several instruments during the same period in more than one barn would require higher costs and complex maintenance compared to low-cost devices.

However, simplified measurement systems are emerging, equipped with less accurate sensors than scientific instruments, yet with a much lower cost, easier use, and the possibility of monitoring several points continuously at the same time [26].

Based on the background above described, the purpose of this research study was to validate innovative low-cost devices for gas concentration monitoring. The following objectives were pursued by investigating the performance of each low-cost device against an advanced photoacoustic infrared spectroscope: (i) studying the profiles of gas concentrations acquired by the two instruments; (ii) assessing the performance of the low-cost device; (iii) identifying the potential use in an open dairy barn.

## 2. Materials and Methods

### *2.1. Description of the barn*

The site of the experiment was located in the province of Ragusa (Southern Italy), which is a geographical area with the highest number of dairy barns in the Mediterranean basin. Data were acquired in a cubicle free-stall dairy barn from 11th to 18th June 2021.

The open structure (Fig. 1) was defined by three sides completely open and one side closed by a continuous wall with four small openings. The rectangular plan (i.e., 55.50 m long and 20.80 m wide) was covered by a concrete floor with a roof made of fibre-reinforced concrete corrugated panels. The heights at the ridge vent and at the eave were 7 m and 4 m, respectively.

**Figure 1.** Indoor view of the barn characterised by completely open sides.

Different functional areas can be distinguished in the plan view of the barn (Fig.2): the feeding area, subdivided in the feeding alley, the manger, and the feeding passage; the resting area with 64 head-to-head cubicles in two rows and three pens; the service alley for herd management; offices; and boxes for calves, located in the south-west side.

Besides the fact that natural ventilation of indoor space was assured by the open structure, the barn was equipped with sprinklers and fans in the feeding alley and a fogging system with fans in the resting area. The fans located in both the resting area and the feeding alley had a tilt angle of 20° from the horizontal plane. In detail, fans in the resting area had a rotation axis located at 2.75 m from the floor along the longitudinal axis of the barn, whereas the fans in the feeding alley had a rotation axis at 2.70 m from the floor and parallel to the longitudinal axis of the feeding alley.

Fifty-seven Friesian cows were milked twice a day in the morning and in the afternoon. The floor of the barn was made of concrete and was cleaned by a tractor with scraper every morning. A mixed ratio was delivered at 12 a.m. for *ad libitum* consumption. The barn was equipped by a cooling system made of fans located in both the resting area and the feeding alley. The fans were operated every 20 minutes to move air in the barn. Moreover, during the milking sessions the cooling system was switched off.

*2.2. Measurement devices*

Measurement of $NH_3$ and $CO_2$ concentrations were continuously carried out at three sampling locations (SLs) located in the central area of the barn along a vertical axis (Fig. 2). The first, the second and the third SLs (i.e., named SLA, SLB and SLC hereafter, respectively) were located at 0.40 m, 1.55 m and 2.70 m from the floor, respectively. Data were acquired from 9 to 14 April 2022.

The measurements were carried out by using three low-cost portable devices (SKY2000-M2, Digitron Italia, Ferentino (Fr), Italy) and a photoacoustic infrared multigas spectroscope as reference measurement device (Lumasense Technology A/S, Ballerup, Denmark). In each SL, a small box contained the sampling points for both low-cost and reference devices (Fig. 3). An air-filter was attached to the end of each sampling tube to

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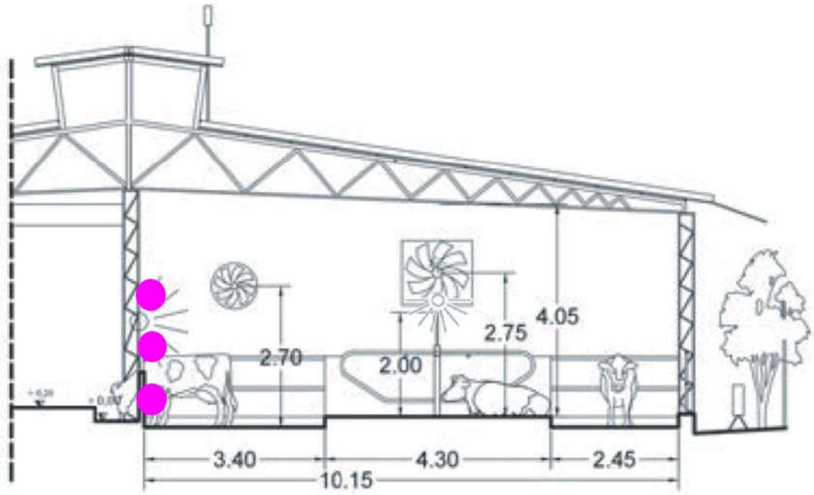
keep the sampler free of particles. Each sampling point was attached to a sampler tube in PTFE (polytetrafluoroethylene) that linked the sampling point to the measurement device.


(a)




(b)

**Figure 2** – Position of sampling points in the barn. In the plan view of the barn (a) the localisation of the sampling pole was located in the central area of the barn. The section of the barn (b) shows the vertical distribution of the sampling points in the sample pole at different heights from the floor.

The three low-cost devices were portable instrument suitable to continuously measure gas concentrations of $NH_3$ and $CO_2$. Each low-cost device had an internal sampling pump linked to a sampler tube with an air filter to allow air sampling. In detail, the measurement of $NH_3$ concentrations were carried out by a chemical sensor in the low-cost device characterised by a range of 0-100 ppm, a resolution of 0.01 ppm and a precision of 2%FS. The $CO_2$ concentrations were measured by an infrared sensor enclosed in the low-cost devices characterised by a range of 0-4000 ppm, a 1 ppm resolution and a precision of 2%FS. The measurement frequency was 2 minutes and 30 seconds for both gases. The calibration of each instrument was performed by the company just before the measurement activity. The beginning of the measurement was synchronised for all the three devices in order to acquire gas concentrations at the same time in the three different SLs.

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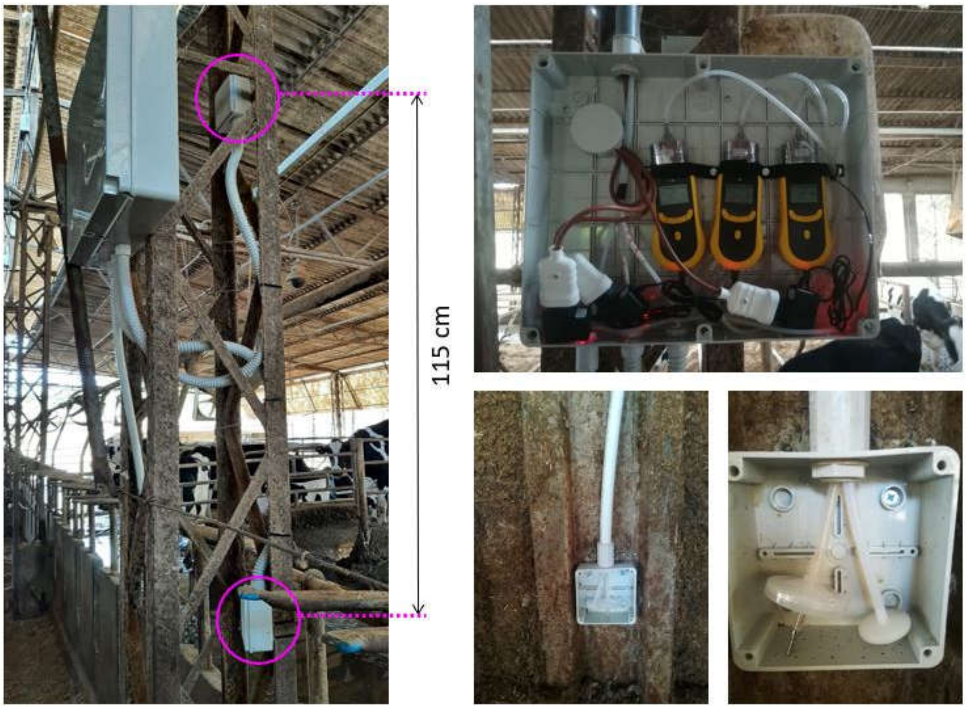



**Figure 3** – Installation of the low-cost system in the barn with a large box to contain the three low-cost measurement devices and small perforated boxes to contain the sampling points for both low-cost and reference devices. The distance between two different consecutive sampling points was 1.15 m. In the small boxes, each sampling tube was equipped with an air filter, for both low-cost and reference devices.

The reference instrument INNOVA was a photo-acoustic analyzer composed of a Multigas Monitor mod 1412 i and a multipoint sampler 1409/12. The system had 3 inlet channels and tubes that connect each channel into the multipoint sampler 1409/12 to the respective sampling location. The device is able to perform simultaneous measurement of different gases (i.e., $NH_3$ and $CO_2$), but not contemporaneously in all the SLs. Based on the evidence reported in the study by Rom and Zhang [23], the measurement cycle (i.e., composed by the numerical sequence of the SLs) was optimised to reduce bias related to detection of very different concentrations (i.e., high and low concentrations) between two adjacent SLs. According to the findings described in a recent study by D'Urso et al. [27], three repetitions of a measurement for each SL were recorded by the instrument before switching to the following SL. Gas concentrations were continuously acquired according to a measurement cycle, established before the experiment (i.e., SLA, SLB, and SLC). The SITs used for the experiments were Normal (5s). The detection limits, declared by the manufacturer, are the following: 0.2 ppm for $NH_3$ and 1.5 ppm for $CO_2$. The INNOVA was calibrated before the measurement campaign by the company.

*2.2. Data processing and statistical analyses*

Data of $NH_3$ and $CO_2$ concentrations acquired by using the low-cost devices and data acquired by INNOVA were organised in a spreadsheet based on the time of the day and the location where the measurement was carried out (i.e., SLA, SLB, and SLC). A specific dataset was implemented by carrying out the computation of the relative measurement error $\varepsilon_i(\%)$ of the low-cost devices, according to the following relation:

$$\varepsilon_i = \frac{|GC_{rif} - GC_i|}{GC_{rif}} * 100 \ (\%)$$

where $GC_{rif}$ (ppm) was the reference value of gas concentrations acquired by the INNOVA analyser and $GC_i$ (ppm) was the gas concentration value measured by the low-cost devices. The reference value of gas concentrations was obtained by the mean value of gas concentration between the second and the third repetitions for $NH_3$ and $CO_2$ [27].

Moreover, correlation analyses were carried out between $NH_3$ concentrations and $CO_2$ concentrations acquired by means of the two instruments at different heights from the floor. Moreover, a linear regression was carried out for a correlation factor r higher than 0.8. To deepen the statistical analyses, a one-way analysis of variance (ANOVA) was applied to assess the occurrence of significant differences between gas concentrations at different heights for both $NH_3$ and $CO_2$ acquired by the two instruments. Finally, a post-hoc analysis was carried out for each ANOVA and the mean values were separated by Tukey's honestly significant difference at $P<0.05$.

## 3. Results

### *3.1. Gas concentrations*

Based on the results of the ANOVA (Table 1), gas concentrations acquired at different SLs were significantly different, showing an uneven distribution of the gas along the vertical axis of the barn. In detail, $NH_3$ concentrations measured by the reference device decreased from the floor to the roof of the barn. In detail, $NH_3$ concentrations acquired at SLA were significantly different ($P<0.001$) than those acquired at SLB and SLC, with the highest $NH_3$ concentrations measured at 0.40 m from the floor in SLA. The same significant differences were found for $NH_3$ concentrations acquired by the portable devices with the highest $NH_3$ concentrations in SLA. However, the mean value of gas concentrations in SLB and SLC measured by the portable devices were lower by about 1 ppm than those acquired by the reference instrument. With regard to $CO_2$ concentrations, the results of ANOVA showed that the lowest gas concentration was detected in SLB, whereas there was not a significant difference between gas concentrations at SLA and SLC. This result was not found by the portable devices that recorded the highest $CO_2$ concentrations in SLC. In detail, based on the ANOVA gas concentrations measured at SLA, SLB and SLC were significantly different ($P<0.001$) with a decrease of the gas from the SLC to the SLA. Moreover, the results obtained by using the portable devices showed underestimation for gas concentrations in SLA and overestimation for gas concentrations in SLB and SLC.

**Table 1.** Results of the ANOVA ($P<0.05$) carried out for gas concentrations of $NH_3$ and $CO_2$ at three groups of sampling locations (i.e., SLA, SLB and SLC) for each gas.

| SL | Mean of $NH_3$ INNOVA analyser (ppm) | Tuckey post-hoc test | | SL | Mean of $NH_3$ portable device (ppm) | Tuckey post-hoc test | |
|---|---|---|---|---|---|---|---|
| A | 3.51 | A | | A | 3.63 | A | |
| B | 1.71 | | B | C | 0.77 | | B |
| C | 1.69 | | B | B | 0.68 | | B |

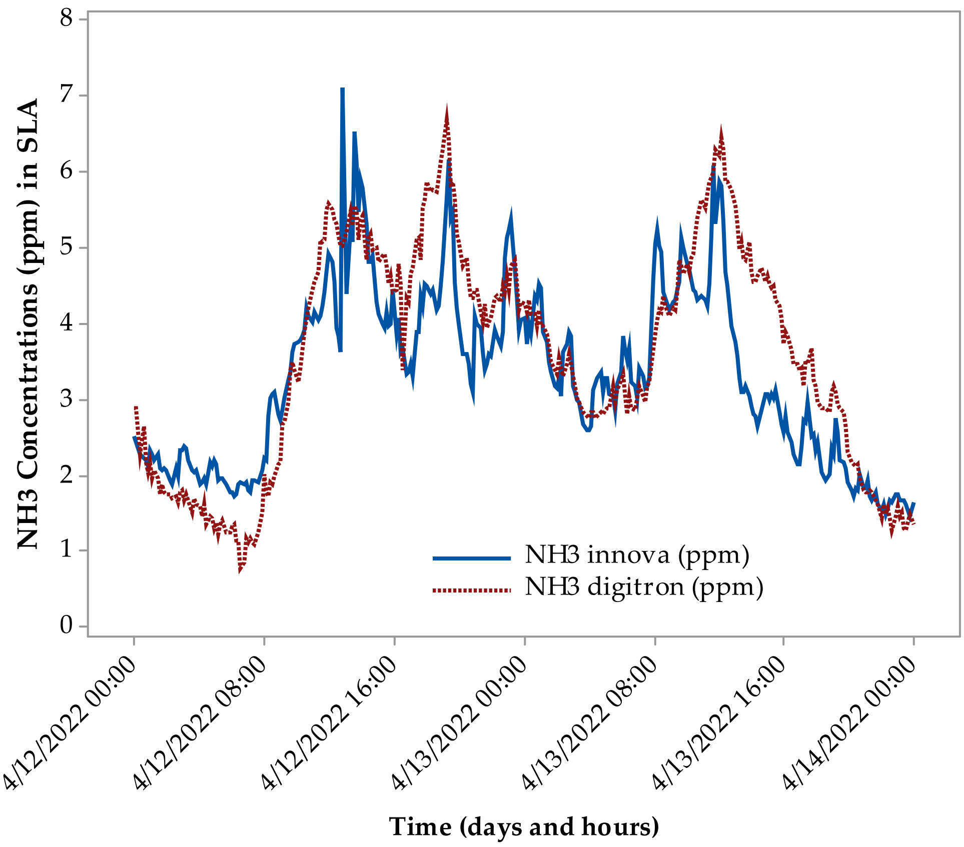
| SL | Mean of $CO_2$ INNOVA analyser (ppm) | Tuckey post-hoc test | | SL | Mean of $CO_2$ portable device (ppm) | Tuckey post-hoc test | | |
|---|---|---|---|---|---|---|---|---|
| C | 598.62 | A | | C | 779.6 | A | | |
| A | 596.44 | A | | B | 575.59 | | B | |
| B | 558.95 | | B | A | 444.83 | | | C |

* Rows with a different letter (A, B, C) are significantly different.

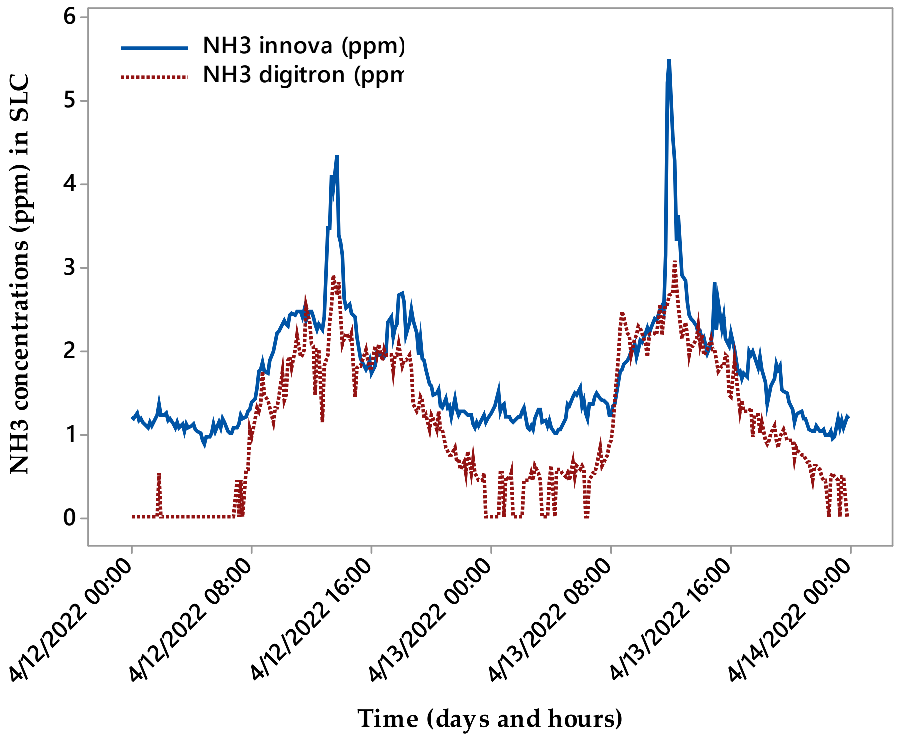
The correlation analyses carried out between gas concentrations acquired by INNOVA and portable devices were significant ($P<0.001$) for all the heights from the floor considered for both $NH_3$ and $CO_2$. However, the Pearson correlation of $NH_3$ concentrations measured by INNOVA and $NH_3$ concentrations measured by portable devices was 0.83, 0.48 and 0.66 for SLA, SLB and SLC, respectively. Regarding the measurements of $CO_2$ concentrations, the Pearson correlation of measurements by

INNOVA and measurements by portable devices was 0.18, 0.57, 0.41 for SLA, SLB and SLC, respectively. Therefore, a good level of correlation (Pearson coefficient > 0.7) was found only in SLA for $NH_3$.

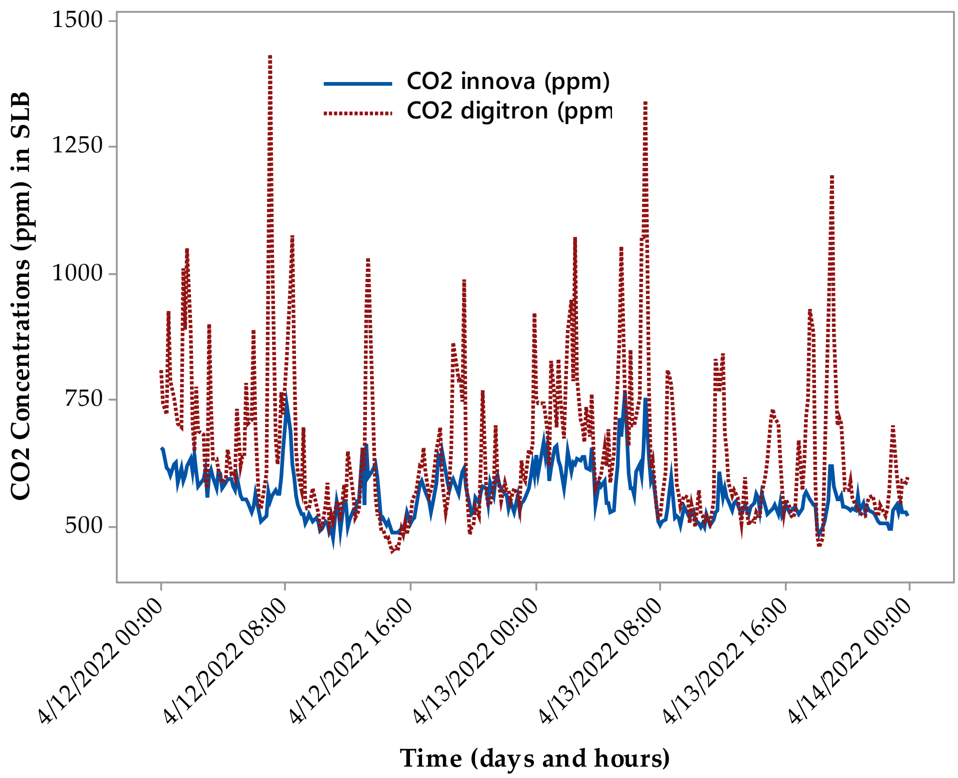
Figure 4 shows the trend of gas concentrations having r>0.5, acquired at different SLs by using the two measurement devices. A good fit was found between $NH_3$ concentrations acquired by the reference and the portable device (Fig. 4a) with an overestimation of $NH_3$ concentrations for portable devices, especially after peaks of $NH_3$ concentrations. The graphs show that the $NH_3$ concentrations acquired by the portable devices were lower for SLs located at a greater height from the floor (Fig. 4b), thus underestimating the values in comparison to the Innova device; whereas $CO_2$ concentrations acquired by portable device at 1.55 m from the floor were higher than those of the reference (Fig. 4c).




(a)




(b)




(c)

**Figure 4.** – Trends of gas concentrations having r>0.5 during two days of measurements. In detail, the graphs show $NH_3$ concentrations acquired in the SLA (a) and SLC (b), and $CO_2$ concentrations acquired in the SLC (c) by using the two measurement devices.

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Based on the outcomes, the $NH_3$ concentrations acquired by INNOVA and $NH_3$ concentrations acquired by the low-cost devices were strongly correlated in SLA. The linear regression model, applied to describe the relationship between $NH_3$ concentrations acquired by the two devices, is shown in Fig. 5. The regression equation (P>0.001 and $R^2_{adj}$ = 68.6%) is the following:

$$NH_{3\ portable\ device}(ppm) = 0.371 + 0.926\ NH_{3\ INNOVA\ analyser}(ppm)$$

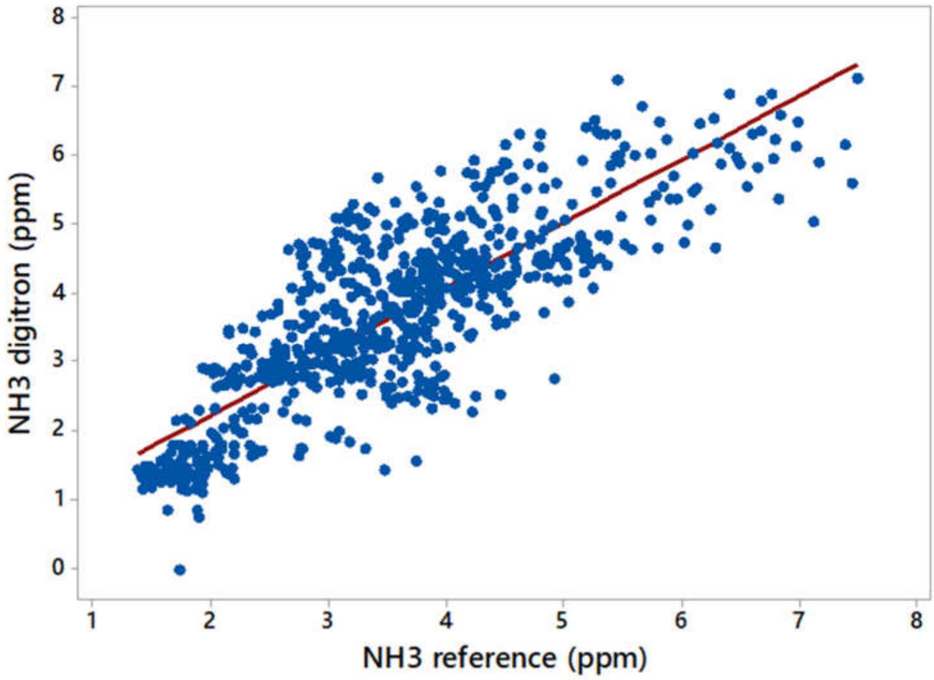



**Figure 5.** – Linear regression analysis between $NH_3$ concentrations (ppm) acquired by the INNOVA analyser (reference) and $NH_3$ concentrations (ppm) acquired by the low-cost device in SLA.

*3.2. Analysis of the measurement errors*

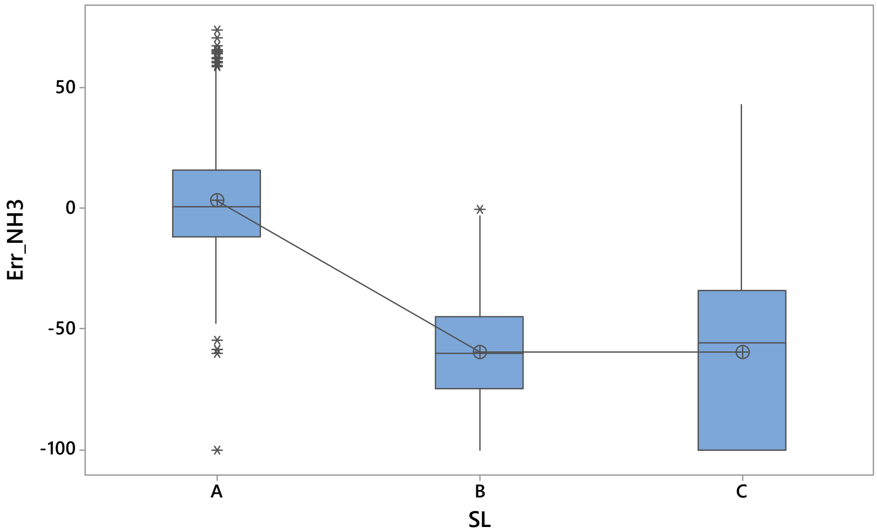
The results of the ANOVA (Table 2) showed that the position of SLs significantly influenced the relative error of gas concentrations for both $NH_3$ ($p<0.001$) and $CO_2$ ($p<0.001$). In detail, the lowest error for the portable devices was recorded during the measurement of $NH_3$ concentrations in the SLA. There was not a significant difference between the error of gas computed in the SLB and those in SLC. In these two groups, $NH_3$ concentrations were underestimated of about 60% when the measurement was carried out by the portable devices. With regard to $CO_2$ measurements by portable devices, the results showed that the error computed at SLB was the lowest, whereas the absolute value of error measurement for $CO_2$ was about 30%. In detail, the portable device underestimated measurements in SLA and overestimated measurements in SLC.

These results were also represented in the boxplot reported in Fig. 6a and 6b. Moreover, it was also found that the relative error carried out by portable devices at SLC had the highest variability for both $NH_3$ (Fig. 6a) and $CO_2$ (Fig. 6b). This latter finding is valuable for suggestions related to protocols applied in open dairy barns.

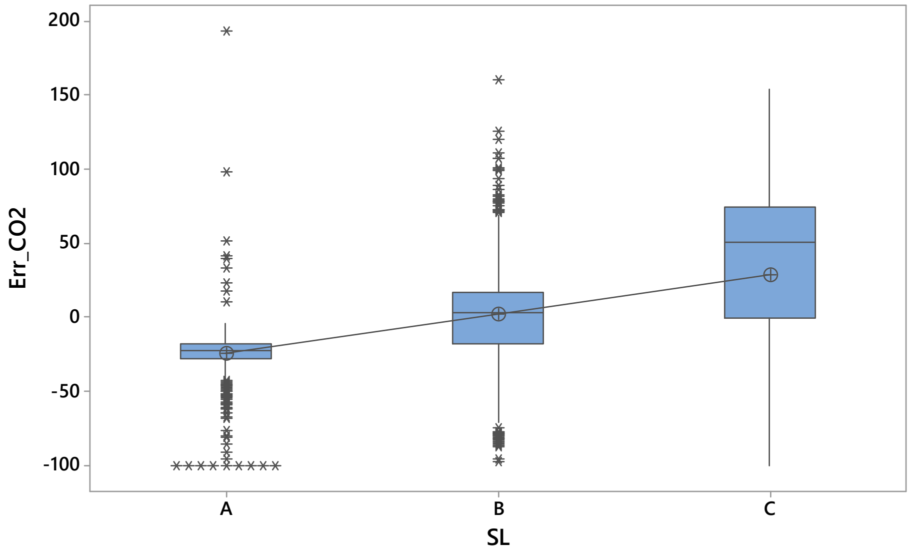
**Table 2.** Results of the ANOVA (P<0.05) carried out for the relative error $\varepsilon_i$ (%) related to the measurement of gas concentrations of $NH_3$ and $CO_2$ at three groups of sampling locations (i.e., SLA, SLB, and SLC) by using the portable devices.

| SL | Mean of error for NH3 portable device (%) | Tuckey post-hoc test* | | |
|---|---|---|---|---|
| A | 3.39 | A | | |
| C | -59.20 | | B | |
| B | -59.33 | | B | |
| **SL** | **Mean of error for CO2 portable device (%)** | **Tuckey post-hoc test*** | | |
| C | 28.82 | A | | |
| B | 1.90 | | B | |
| A | -24.47 | | | C |

* Rows with a different letter (A, B, C) are significantly different.




(a)




(b)

**Figure 6.** – Boxplot of the error of gas concentrations for measurements carried out at SLA, SLB and SLC by portable devices for both $NH_3$ (a) and $CO_2$ (b).

## 4. Discussion

### *4.1. Gas concentrations measured by the reference instrument*

The gas distribution analysed in this study was heterogeneous in the barn as it was found in other studies in the literature [25, 28]. Based on the measurements acquired by the INNOVA analyser (i.e. reference), the vertical pattern found in this barn is different compared to that found by Mendes et al. [29]. In detail, in the study of Mendes et al. [29] it was found that the variability of $NH_3$ concentrations increased from the animal occupied zone (AOZ) to the top of the barn, whereas $CO_2$ decreased from the floor to the top of the barn. These results were found for a mechanical ventilated dairy barn.

In the present study, the vertical pattern of gas concentration was described for an open dairy barn. The results showed how the highest gas concentrations were acquired at the floor level being lower along the vertical axis of the barn, and the highest $CO_2$ concentrations were recorded at the top of the barn.

One of the influencing factors on gas distribution is the place where gaseous production occurs. As it was described in the study of Baldini et al. [30], the $NH_3$ concentration is mainly produced at the floor level in the AOZ, and then $NH_3$ rises upward very fast due to its bulk density (equal to 0.66 kg/m$^3$ in standard conditions). Since $NH_3$ is lighter than air (bulk density of 1.293 kg/m$^3$ in standard conditions), the movement of the gas tends to be upward along the vertical axis. However, the presence of the air flux of the fans modifies the flow pattern of the air in the barn, and consequently modifies the gas concentrations in air, because it moves $NH_3$ towards the outdoor environment, increasing the dilution of the gas and, thus, its distribution in the barn. In detail, the tilt angle of the fans provided ventilation at about 1.55 m from the floor in the AOZ, where the SLB was located. Besides the fans that smooth the concentration gradients inside the barn [31], another factor is the prevailing air direction that is related to the orientation of the building downwind, therefore, even in the absence of fan activation, there is always a dilution of gas concentrations along the longitudinal axis of the barn due to the building choice for barn orientation.

Regarding the $CO_2$ concentrations, the main difference compared to $NH_3$ is that the $CO_2$ concentrations are mainly produced from animals in the AOZ, where the SLB was located. Since the gas concentrations are diluted at that location due to the fans and the main air direction, the $CO_2$ concentration was the lowest at SLB as it was found in the results of Table 1.

### *4.2. Performance of the portable device*

The results of this study showed that the analysed portable device was found to be affordable only for measuring $NH_3$ gas concentrations at SLs located close to the floor of the barn. However, it is well known that chemical sensors, like those used as measurement analyzers in the portable devices to measure $NH_3$, suffer from saturation [32]. In fact, the results of the experiments carried out in this study (Fig. 4a) showed a shift of the values for $NH_3$ measurements; this effect produced overestimation at high values of measured gas concentrations (Fig. 4a).

With regard to $NH_3$ measurements carried out at SLB and SLC, the high influence on the value produced by the air velocity and the distance of the source of production, both mentioned in section 4.1, produced a reduction of $NH_3$. In detail, the portable devices underestimated the measurement by about 1 ppm for values of $NH_3$ below 2 ppm.

The results of the analysis on the measurement by portable devices are not satisfactory for $CO_2$ because the instrument produced high errors compared to the reference. Moreover, although the correlation between $CO_2$ concentrations measured by INNOVA analyser and those measured by the portable device at SLB was correlated by 0.57, the Fig. 4c showed that the sensor of $CO_2$ was not accurate for the application in dairy barns because overestimated the measurement value. In detail, based on the matching of monitored data with direct observation of herd management, it was found that the $CO_2$ concentrations increased fast when the groups of cows were moved to the milking parlor;

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this $CO_2$ increase in the environment could be attributed to the movement of the air and also to a decrease in the performance of the infrared sensors due to ambient particulate matter. At this regard, further experimental analyses would be required to confirm this conclusion.

Since the $CO_2$ is generally used as tracer gas to estimate emissions in this barn typology [33-35], the $CO_2$ measured by the Digitron is not adequate for this purpose because it would increase uncertainty in the estimation.

Therefore, the use of the portable device could be reduced to gas concentration monitoring rather than emission estimation. The potential use of the Digitron device would thus be related to the monitoring of $NH_3$ concentrations, especially when carried out by farmers. In fact, portable devices, thanks their cheaper price compared to other instruments, could be acquired by the farmer to measure the gas concentrations in the barn. In fact, self-monitoring of barn environment by the farmer could provide information on exceeding the safety thresholds [13] for workers in the barn. Another application of the portable device could be the verification of the gas presence in the air to assess the application of mitigation strategies as well as the welfare conditions of the cows; in fact, in the literature it was found that the welfare conditions are related to the animal breeding conditions [12, 36].

The use of low-cost devices for monitoring purpose is not still common among farmers, due to the reduced information on safety regulations, but their application could increase awareness of the risks in livestock barns. Moreover, an effective design and fine-tuning of low-cost devices could be promising also for emission estimation with the consequence that current databases, models and emission factors, based above all on data related to northern European contexts [37], could be updated.

## 5. Conclusions

The outcomes of this research study highlighted that the specificbarn structure, characterised by the absence of perimeter walls, influenced indoor conditions with effects on the distribution of gas concentrations along the vertical axis of the barn. Moreover, the presence of the cooling systems in both the feeding alley and the resting area was another factor that influenced gas distribution because it contributed to move the air along the longitudinal axis of the barn.

This research study was carried out to assess the application of a low-cost device (SKY2000-M2, Digitron Italia, Ferentino (Fr), Italy) for monitoring $NH_3$ and $CO_2$ in open dairy barns. Statistical analyses were carried out to find out the relations among the acquired gas concentration values by applying a rigorous approach. Based on the results, the portable device could be used for the monitoring of $NH_3$ concentrations, whereas the device is not accurate enough for $CO_2$ to be adequate for the purpose.

The monitoring of gas concentrations at housing level will make it possible to support farmers in the barn management in order to increase environmental performance of the farm as well as improve animal welfare and quality of production. The use of low-cost devices for scientific purpose, provided that a specific design and fine-tuning is carried out, could be useful to investigate the emission production in contexts characterised by different barn typologies, housing system, climatic conditions, and mitigations strategies that has not been investigated yet. Moreover, the application of low-cost devices could contribute to the estimation of emission factors in order to update emission inventories from the livestock housing systems monitored.

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