



Seasonal dynamics and climatic influences of greenhouse gases (CO₂, CH₄) and ammonia (NH₃) concentrations on loose housing cattle shed

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ABSTRACT

Measurement of gas concentrations is crucial for the calculation of emissions from livestock buildings. The study aimed to examine how the concentrations of greenhouse gases (CO₂, CH₄) and ammonia (NH₃) vary seasonally and influenced by climatic conditions in loose housing cattle sheds in India. Two dairy cow sheds with different layouts, floor types, and cleaning practices were selected for measurements during the summer, rainy, and winter seasons. The concentrations of CO₂, CH₄, and NH₃ exhibited significant variations, ranging from 405 to 717 ppm for CO₂, 0.01 to 16.12 ppm for CH₄, and 0.00 to 1.90 ppm for NH₃. The winter season showed higher levels of CO₂ and CH₄, while NH₃ concentrations were higher during the summer season. Notable differences were observed in CO₂ and CH₄ levels between sheds during feeding, as well as in CO₂ levels during cleaning activities. The study revealed a weak correlation between greenhouse gases, ammonia, and climatic conditions in the cattle sheds, except for a moderate positive correlation between CO₂ and relative humidity during winter which means other factors such as housing design, facilities and practices play a significant role.

Keywords: Ammonia, Cattle, Climatic conditions, Methane, Seasons

Globally, the livestock sector is responsible for around 65% and 18% of anthropogenic NH₃ and greenhouse gas (GHG) emissions (Steinfeld *et al.* 2006). In 2018, enteric fermentation and manure management were responsible for 46% of CO₂ emissions, 78% of CH₄ emissions, and 6% of NO₂ emissions in agriculture (FAO 2020). Greenhouse gases and ammonia have significant impact as they also contribute to climate change and ecosystem damage. The factors linked to gas concentration in livestock houses are feed type, flooring, bedding, the climatic factors (temperature, relative humidity and air velocity), the time of day, species, farm structure design, ventilation and manure removal system (Baldini *et al.* 2016).

Carbon dioxide is produced by animal respiration, the breakdown of urea in urine, and during storage of manure while CH₄ is primarily produced by enteric fermentation and a small portion by manure. Ammonia is almost entirely produced by animal excreta, which includes dung and urine (Samer 2016). The relationship between a housing solution and its associated floor type, as well as the manure collection, removal and storage system affect NH₃ and greenhouse gas emissions (Wu *et al.* 2012, D'Urso *et al.* 2021). Seasonally, the concentration of CO₂ and CH₄ was higher in winter compared to summer while NH₃ concentration was higher in summer compared to winter

(Kaasik and Maasikmets 2013; Rong *et al.* 2014) due to curtains applied to protect animals from cold. However, the difference between greenhouse gases and ammonia emissions was less pronounced between summer and winter (Mihina *et al.* 2012, Pu *et al.* 2021, Rong *et al.* 2014). Emissions from dairy farms in India can vary from those in other countries due to climate variations and housing design differences. So, aim of the present study was to investigate seasonal variations and influence of climatic conditions of NH₃ and greenhouse gases (CO₂ and CH₄) on loose housing cattle sheds in India.

MATERIALS AND METHODS

Experimental location and sheds: The study was carried out at Guru Angad Dev Veterinary and Animal Sciences University (GADVASU), Directorate of Livestock Farms in Ludhiana, Punjab (30.9°N 75.85°E). It involved a three-season experiment during 2022-2023: summer (April-June), monsoon (July-August), and winter (December-January).

Cattle sheds descriptions: Two loose houses, designated as C1 and C2, were selected for the study, oriented in an east-west direction and their dimensions is given Supplementary Fig. 1. C1 had a gable roof with ridge ventilation, while C2 had a shed type (single sloped) roof. C1 had a length of 60.9 m and a width of 48.5 meters, divided into two rows with three pens in each row. The shed's height from the floor to the eaves was 4.5 m, increasing to 9.14 m at the center ridge. It had completely open sides and was

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enclosed by two rows of steel fencing around its perimeter. Each pen within C1 had a covered area measuring 20.3 meters by 15.53 meters. The shed floor consisted of a solid surface in the central alley, feeding trough, and standing area, while the resting and open areas were covered with sand. C1 housed approximately 15-20 cows per pen and featured a feedline sprinkler cooling system, panel fans in both the standing and resting areas, and scrappers for manure removal from the standing area. Feeding of the cows took place three times a day, including a combination of concentrate, total mixed ration (TMR), and dry/green fodder. In the summer, the scrappers operated twice a day, while in winter, they ran once a day for manure removal.

The C2 shed had a length of 45.74 meters and a width of 21.18 meters. It had two sides enclosed, facing the east and west directions, with a brick boundary surrounding the open area of the shed. The roof height on both sides was 3.0 meters, and the covered area measured 45.74 meters by 6.54 meters. The floor in both the covered and open areas was made of brick paving, and there was a cemented feeding trough. Within the shed, there were approximately 15-20 cows accommodated within a length of 27.5 meters, while the remaining length was utilized for feed storage, equipment, and milking of the animals. To ensure proper ventilation, wall-mounted table fans were installed. Cleaning of the shed took place once a day using water flushing and a broom. The cows were fed three times a day, following a regular feeding schedule. The both sheds had consistent cattle density of 15-20 animals.

Greenhouse gases (CO₂, CH₄) and ammonia (NH₃) measurements: The greenhouse gases (CO₂, CH₄) and ammonia (NH₃) concentration were continuously measured by air quality monitoring station (AQMS) of Environment & Engineering Solutions in India. The AQMS utilized sensor technologies which includes non-dispersive infrared (NDIR) sensors for CO₂ and CH₄ detection, and electrochemical sensors for NH₃ detection, all measured in parts per million (ppm). The sensors have an accuracy of ±0.1 ppm and detection range of 400-5000 ppm for CO₂, and 0-100 ppm for both CH₄ and NH₃. The sensor suite includes additional components such as a glass fiber thimble for efficient air filtration, and a rotameter to regulate airflow. The sensor suite is equipped with inlet and outlet ports at the bottom to facilitate controlled intake and release of the sampled air. Air samples were

collected using an air pump with a flow rate of 5 litres/min at regular 15 min intervals. Continuous measurements are conducted in cattle sheds for 24 h with data recorded every 15 min with AQMS equipment as positioned marked in Supplementary Fig. 1. This monitoring was carried out for approximately one week per month in both sheds, covering different seasons. Data is acquired using a data logger and NEXTCOMM software, then organized into excel sheets for analysis.

Microclimatic conditions: Temperature and relative humidity (RH) inside the sheds were monitored using temperature and RH sensors fixed in Supreme International (New, Delhi) equipment for continuously 24 h. Additionally, air velocity was measured using a portable thermo-anemometer (METRAVI AV-04, India) three times a day (morning, afternoon, and evening) on a weekly basis per shed per month.

Statistical analysis: The data collected during the experimental period was organized in Microsoft Excel and subjected to statistical analysis using SPSS version 26.0 (SPSS Inc., IBM, Armonk, NY, USA). To assess significant differences (P<0.05) between variables, one and two way ANOVA analysis and Tukey's test for post-hoc analysis were applied, considering different sheds and seasons. Additionally, the relationship between climatic variables (temperature, relative humidity, and air velocity) and greenhouse gas concentrations and ammonia within different sheds was examined using the Pearson correlation coefficient. All figures had been generated using GraphPad prism 8.

RESULTS AND DISCUSSION

Greenhouse gases (CO₂, CH₄) and ammonia (NH₃) concentration: Table 1 and Supplementary Fig. 2 depicts the concentrations of greenhouse gases, specifically CO₂ and CH₄, as well as ammonia (NH₃) concentrations in cattle sheds on a monthly basis. The concentration ranges in the cattle sheds exhibit notable variations from 405 to 717 ppm for CO₂, 0.01 to 16.12 ppm for CH₄, and 0.00 to 1.90 ppm for NH₃. During the summer season, the average concentrations of CO₂, CH₄, and NH₃ exhibit a range of 405-717 ppm, 0.01-12.88 ppm, and 0.00-1.90 ppm, respectively while 406-651, 0.08-7.84 and 0.00-0.14 ppm in rainy season. Similarly, the winter season exhibits notable variations in overall concentrations of CO₂

Table 1. GHG and NH₃ concentration (ppm) during different months in cattle sheds

Shed	Gases	Seasons/months						
		Summer			Rainy		Winter	
		April	May	June	July	August	December	January
C1	CO ₂	456.1±40.65	428.8±34.58	431.3±34.79	416.6±14.25	441.4±36.73	508.3±74.17	490.2±53.57
	CH ₄	4.585±3.776	0.481±0.469	0.355±0.326	1.365±1.170	3.541±2.453	4.371±3.791	4.876±3.976
	NH ₃	0.024±0.064	0.160±0.256	0.245±0.296	0.005±0.007	0.004±0.011	0.064±0.088	0.128±0.027
C2	CO ₂	454.1±29.21	446.4±42.04	430.6±27.65	439.4±29.08	459.4±39.64	552.9±87.86	478.7±47.38
	CH ₄	5.260±4.308	0.363±0.367	0.454±0.422	3.533±2.416 ^c	3.988±2.546	4.280±3.603	4.357±3.413
	NH ₃	0.014±0.036	0.222±0.259	0.061±0.101	0.007±0.010	0.005±0.008	0.104±0.137	0.044±0.175

(409-879 ppm), CH₄ (0.49-16.12 ppm), and NH₃ (0.00-0.70 ppm) in the cattle sheds. During the winter season, carbon dioxide and methane concentrations were higher compared to other seasons, while ammonia concentrations were higher during the summer season.

To effectively reduce greenhouse gas and ammonia emissions, it is crucial to gain an understanding of the concentrations of these gases linked to various farms. This understanding becomes essential due to the wide range of variations among farms in terms of climatic conditions, building designs, feeding and cleaning methods, animal density, and manure storage systems. By comprehending the specific concentrations associated with different farm practices, it becomes possible to develop targeted mitigation strategies. Present findings were comparable with several previous studies such as D'Urso *et al.* (2021) (CO₂: 500-800; CH₄: 5-15), Divyalaxmi *et al.* (2017) (CH₄: 0-0.03; NH₃: 0.33-2.58), Joo *et al.* (2015) (CO₂: 443-789) and Kaasik and Maasikmets (2013) (NH₃: 0.24-2.38), and, regarding greenhouse gas concentrations. However, higher concentrations were observed compared to studies conducted by Ngwabie *et al.* (2014) (CO₂: 566-1335; CH₄: 20-107), Rong *et al.* (2014) (CO₂: 463-2716; CH₄: 2.1-219; NH₃: 0.3-15.5), Wu *et al.* (2012) (CO₂: 492-1066; CH₄: 7.93-57.3; NH₃: 0.5-8.62) and Ngwabie *et al.* (2011) (CO₂: 960±210; CH₄: 39.4±16.9), probably due to the higher stocking density of animals than their studies in addition to other differences. Furthermore, current results indicated that CO₂ and CH₄ concentrations were higher during winter compared to summer, while NH₃ concentration was higher in summer compared to winter. These seasonal variations align with the findings of Rong *et al.* (2014), Saha *et al.* (2014), and Kaasik and Maasikmets (2013). The higher concentrations of CO₂ and CH₄ observed during the winter season can be attributed to the presence of condensed and

moist air, which hinders the easy escape of these gases from buildings compared to the summer and rainy seasons. Notably, certain studies have reported unexpectedly high average ammonia concentrations in December and January, although the specific cause for this phenomenon remains unknown. During colder months, the activity of microorganisms responsible for ammonia production is less optimal, resulting in lower ammonia emissions. However, the disparity in emissions of greenhouse gases and ammonia between summer and winter is less pronounced, as indicated by studies conducted by Mihina *et al.* (2012), Rong *et al.* (2014), Pu *et al.* (2021).

Diurnal variations: Fig. 1 illustrates the changes in greenhouse gas (CO₂, NH₄) and ammonia (NH₃) concentrations throughout the day across different seasons in cattle sheds. Notably, carbon dioxide (CO₂) concentrations showed significant variations, both between seasons and during different time intervals. CO₂ levels exhibited a consistent variation from 08:00 to 16:00 h. In C1 shed, a similar pattern was observed for CO₂ in both summer and rainy seasons, with higher peaks during night time compared to daytime. In C2 shed, higher CO₂ emissions were observed at night during summer and in afternoon during the rainy seasons. In winter, CO₂ concentrations decreased after 8:00 AM, increased after 16:00 h, and remained higher during the night in both sheds. On the other hand, methane and ammonia did not show a clear pattern of increase or decrease throughout the day.

Greenhouse gases (CO₂, CH₄) and ammonia (NH₃) concentration during feeding and cleaning time: Table 2 provides data on gases concentration during feeding and cleaning activities in cattle sheds throughout the day. Significant differences were observed in CO₂ and CH₄ levels between sheds during feeding, as well as in CO₂

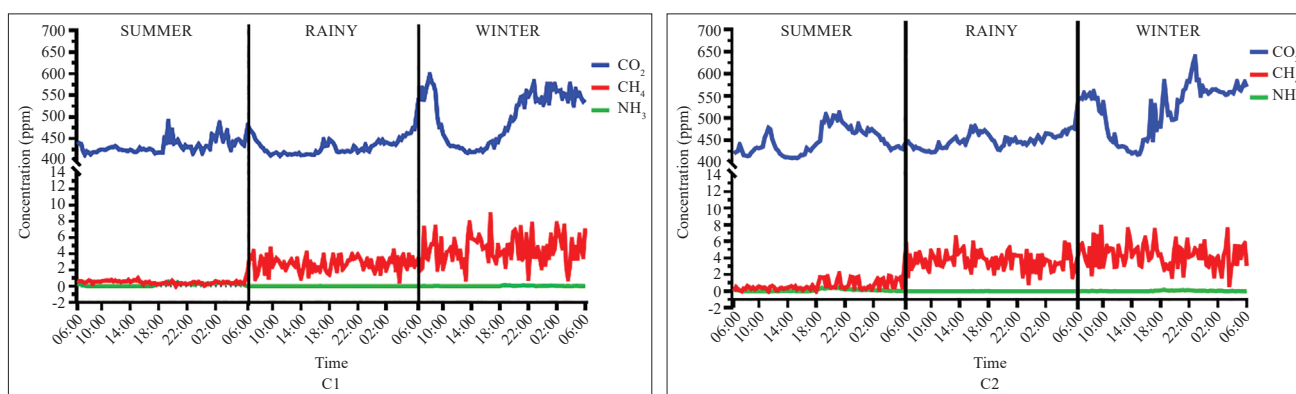


Fig. 1 Diurnal variations of GHG and NH₃ in C1 and C2 sheds.

Table 2. GHG and NH₃ concentration during feeding and cleaning times

Shed	Feeding time			Cleaning time		
	CO ₂	CH ₄	NH ₃	CO ₂	CH ₄	NH ₃
C1	429.8±17.72 ^b	2.567±1.779 ^b	0.017±0.050	426.6±7.96 ^b	2.651±1.90	0.002±0.003
C2	444.1±28.87 ^a	3.385±1.818 ^a	0.009±0.012	449.9±18.04 ^a	3.079±2.177	0.009±0.010
P-value	0.031	0.051	0.500	0.009	0.688	0.153

Table 3 Correlation coefficients between climatic variables and GHG and NH₃ in cattle sheds

Shed	Parameter	CO ₂	CH ₄	NH ₃	P-value
C1	Temperature(°C)	-0.598	-0.311	0.073	<0.001
	Relative Humidity (%)	0.382	0.150	-0.154	<0.001
	Air Velocity(m/s)	-0.298*	-0.407*	0.100	<0.001
C2	Temperature(°C)	-0.519	-0.237	0.041	<0.001
	Relative Humidity (%)	0.307	0.226	-0.206	<0.001
	Air Velocity(m/s)	-0.220*	-0.078	-0.103	<0.001

*Indicates significant difference for particular row.

levels during cleaning hours. The concentration of CO₂ and CH₄ was notably higher in C2 shed compared to C1 shed. This difference could be attributed to the lower height of the C2 shed, which may affect air circulation and ventilation, leading to higher greenhouse gas concentrations. A study by D’Urso *et al.* (2021) revealed that higher NH₃ emissions occur during cleaning activities due to the mixing of urine and faeces, while CO₂ and CH₄ emissions were higher during animal activity, followed by the cleaning process. Similar to present findings, Divyalaxmi *et al.* (2017) and Joo *et al.* (2015) reported lower concentrations and peaks of CO₂ and CH₄ during day-time. However, contrasting results were observed in studies conducted by D’Urso *et al.* (2021), Saha *et al.* (2014), and Wu *et al.* (2012), where greenhouse gases and ammonia exhibited peaks during daytime. This disparity can be attributed to the higher temperatures and increased animal activity that typically occur during daylight hours. Conversely, Pu *et al.* (2021) found no significant variations in greenhouse gas and ammonia emissions throughout the day.

Microclimatic conditions: The microclimatic conditions within cattle sheds between seasons and months is given in Supplementary Table 1 and Supplementary Fig. 3. In cattle sheds, the maximum and minimum temperatures during the summer and rainy seasons were recorded within the ranges of 33.80-41.52°C and 26.05-28.73°C, respectively. In the winter season, the maximum temperatures ranged from 18.61-23.76°C, while the minimum temperatures ranged from 9.36-13.88°C in cattle sheds. In summer and rainy seasons, average air velocity ranged from 0.0-4.3 m/s, while in winter it ranged from 0.0-1.22 m/s in cattle sheds.

Relationship of climatic conditions with greenhouse gases (CO₂, CH₄) and ammonia (NH₃): The correlation

coefficients between CO₂, CH₄, NH₃ and climatic conditions (temperature, relative humidity and air velocity) between cattle sheds is given in Table 3. There was a strong and significant negative correlation between CO₂ and air temperature. On the other hand, CO₂ shows a moderate positive relationship with relative humidity and weak negative correlation with air velocity. The methane shows moderate significant negative correlation with air velocity in C1 shed. NH₃ shows a poor positive correlation with both temperature and air velocity and poor negative correlation with relative humidity.

The correlation coefficients between greenhouse gases (CO₂, CH₄) and ammonia (NH₃) with climatic conditions are presented in Table 4 and Fig. 3. The greenhouse gases and ammonia were weakly correlated with climatic conditions except moderate positive correlation between RH and CO₂ during winter season.

Ammonia concentration was positively correlated with temperature in studies by Ngwabie *et al.* (2011), Wu *et al.* (2012), Kaasik and Maasikmets (2013), Rong *et al.* (2014), Saha *et al.* (2014), Pu *et al.* (2021), and while negatively with relative humidity as per Pu *et al.* (2021). The emission of NH₃ is influenced by temperature through two distinct mechanisms: the formation of NH₄⁺ in the aqueous phase and the release of NH₃. An increase in temperature within the range of 10°C to 40°C stimulates urease activity, leading to a significant production of NH₄⁺. Conversely, at temperatures below 10°C, urease activity slows down, resulting in reduced NH₃ emissions (Rong *et al.* 2014). Higher relative humidity (RH) can increase the dissolution of NH₄ in moist air, as NH₃ has a tendency to adsorb in water. This can result in lower measured concentrations of gaseous NH₃, as a larger portion of it remains in the

Table 4 Season-wise correlation coefficients between climatic variables and GHG and NH₃ in cattle sheds

Season	Variable	CO ₂	CH ₄	NH ₃
Summer	Temperature(°C)	-0.230**	-0.120**	0.120**
	Relative Humidity (%)	0.094**	-0.113**	0.153**
	Air Velocity(m/s)	-0.202**	-0.276**	0.100
Rainy	Temperature(°C)	-0.149**	0.058*	0.083**
	Relative Humidity (%)	0.203**	-0.011	-0.082**
	Air Velocity(m/s)	-0.098	0.018	0.101
Winter	Temperature(°C)	-0.215**	0.031	0.138**
	Relative Humidity (%)	0.443**	-0.041	0.029
	Air Velocity(m/s)	-0.130	0.071	-0.059

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

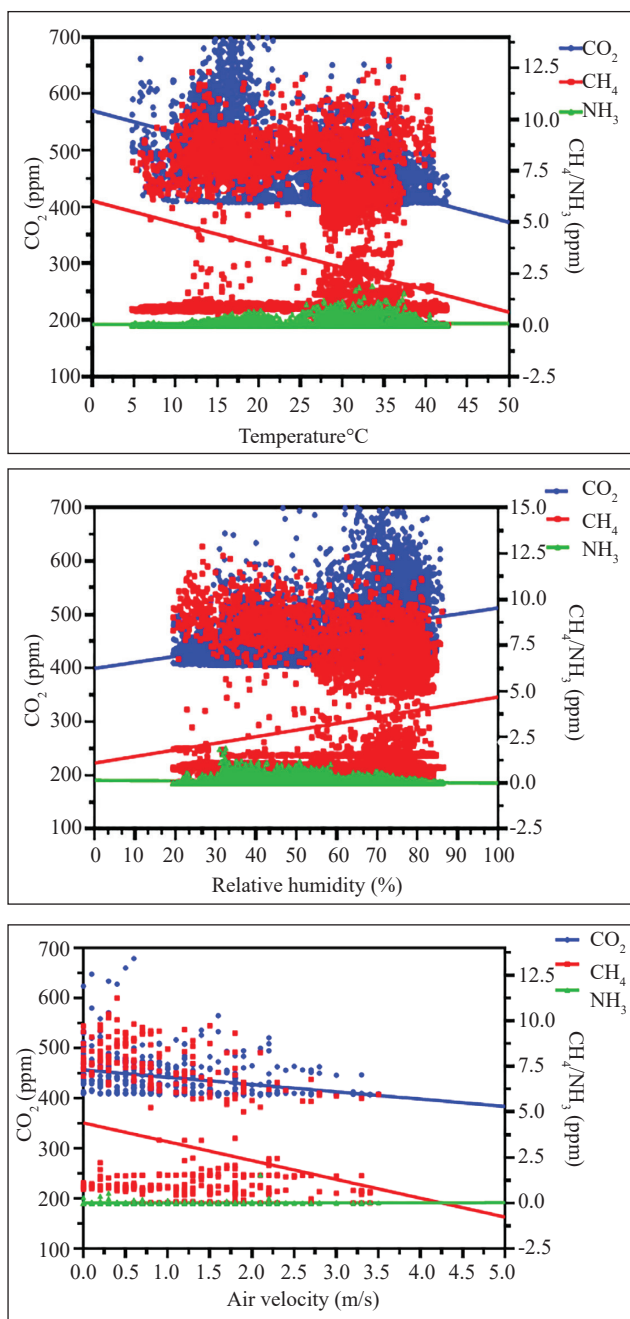


Fig. 3 Relationships between CO_2 , CH_4 , and NH_3 concentrations and climatic conditions.

aqueous phase (Saha *et al.* 2014).

Kaasik and Maasikmets (2013) found that CO_2 concentration decreased with temperature but increased with relative humidity. Saha *et al.* (2014), Kaasik and Maasikmets (2013) reported a negative correlation between CH_4 concentration and temperature. Wu *et al.* (2012) observed a positive correlation between air velocity and ammonia emissions, indicating that higher air velocity led to increased ammonia release. Conversely, D'Urso *et al.* (2021) found a negative correlation between air velocity and gaseous emissions, suggesting that higher air velocity was associated with lower gaseous emissions.

Temperature and air velocity play a significant role in

the concentration of CO_2 and CH_4 in barns, while relative humidity (RH) has a lesser impact (Joo *et al.* 2015). Studies by Kaasik and Maasikmets (2013), Saha *et al.* (2014), Joo *et al.* (2015) and D'Urso *et al.* (2021) have shown that higher ventilation rates and increased wind speed during the summer result in lower CO_2 and CH_4 concentrations. This indicates that improved airflow and higher wind speeds contribute to reducing CO_2 and CH_4 levels in barn environments.

The concentrations of carbon dioxide (CO_2) and methane (CH_4) tend to be higher during the winter season, which can be attributed to the presence of condensed and moist air. Conversely, ammonia concentrations are typically elevated during the summer seasons. The relationship between greenhouse gas (CO_2 , NH_4) and NH_3 concentrations with climatic conditions during different seasons shows a weak association. However, there is a more substantial correlation observed between two cattle sheds, indicating that factors such as housing design, facilities and practices play a significant role. Further investigation is needed to understand the underlying factors influencing these correlations and to determine any potential causal links between the gases and climatic conditions in cattle sheds.

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