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PRECISION LIVESTOCK FARMING: MONITORING MICROCLIMATE PARAMETERS IN DAIRY COW SHELTERS

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Abstract

Knowledge of microclimate parameters in dairy cow shelters allows farmers to monitor animal welfare and production process. The use of precision instruments offers facilities: economic, by increasing profit; farmers who can take real-time measures to adjust microclimate parameters. The purpose of this study was to monitor the microclimate parameters in a dairy cattle barn using precision livestock farming tools over a period of 9 months. This study aims to provide information about the environmental conditions in the barn and to identify potential issues to optimize the welfare and productivity of the cows. The data was collected and processed using the BlueMonitor software platform. For each analyzed parameter - temperature, relative humidity, carbon dioxide concentration, particle concentration, and dew point - central tendency statistics (mean) and dispersion statistics (SEM, SD, CV %) were calculated. Differences between monthly averages were tested for significance using the Fisher test, revealing significant variations across all parameters. Monitoring microclimate parameters using precision instruments in animal husbandry enables farmers to take real-time measures, ensuring dairy cows are provided with optimal conditions to express their productive potential.

Key words: *animal welfare, farm animal, microclimate parameters, precision farming.*

INTRODUCTION

The expansion of the global population, alongside mounting strain on natural resources and the impact of global warming, is shaping a new operational environment. Escalating world demand for food, amplified urbanization rates, rising input costs, heightened strain on water resources, and growing vulnerability of crops and animals to climate variations can lead to reduced food production (Mihai et al., 2023). The increasing demand for livestock products has led to challenges related to environmental sustainability, human health, and animal welfare on farms. A critical aspect of ensuring food security revolves around the rearing and utilization of cattle, given that this animal species serves as a primary source of raw material for various food products. Despite a decline in cattle livestock numbers in recent years, milk production has surged. This is attributed to farmers' focus on leveraging animals with high production potential while maintaining optimal conditions for animal welfare (Defta et al., 2023).

The well-being of animals raised for food is heavily influenced by human management practices. Various factors, such as housing and bedding conditions, space availability, transportation methods, stunning techniques, slaughter processes, and practices like castration and tail docking, can significantly affect their welfare. Animal welfare refers to the well-being of animals, encompassing both their physical and psychological health. It involves ensuring that animals are provided with appropriate living conditions, adequate nutrition, proper healthcare, and opportunities to express natural behaviors. Animal welfare also involves protecting animals from physical and mental suffering, distress, and unnecessary harm. Animal welfare is an ethical and moral consideration that emphasizes the responsibility of humans to treat animals with compassion,

respect, and dignity. It is recognized as an important aspect of responsible animal care and is promoted through legislation, regulations, industry standards, and public awareness initiatives (www.efsa.europa.eu).
Dairy cows are often perceived to have better welfare in pasture-based systems, but this cannot always be implemented as a farming system. This highlights the importance of considering different breeding systems and ensuring animal welfare in any farming system (Arnott et al., 2017).
As climate change has become an increasingly frequent topic in global agricultural production, heat stress (Vučković et al., 2019; Bohmanova et al., 2007; West, 2003; ST-Pierre et al., 2003) is a problem in animal husbandry, especially dairy cows (Gauly, 2013; Mihai et al., 2020; Gavrila et al., 2015). In this context, animal welfare (Gavrila et al., 2015) has become an increasingly intense concern for farmers. Monitoring the parameters in the shelter, with the help of Precision Livestock Farming (Chadda et al., 2021), allows obtaining a wide range of information that helps farmers make decisions in real time (Mihai et al., 2020; Lokhorst, 2018; Kelemen et al. 2016) to improve the quality of life of dairy cows and increase production. Also, the precision instruments (Shruthi et al., 2018) in animal husbandry help to know the impact of the dairy cows breeding on the environment (Berckmans, 2014).
Precision Livestock Farming (PLF) technologies have emerged as a promising solution in response to these concurrent needs, namely to ensure the welfare of animals during their intensive breeding. PLF technologies offer farmers opportunities to improve efficiency, reduce environmental impact, and promote animal health and welfare. They provide farmers with valuable insights, real-time monitoring capabilities, and precision management tools to ensure the health, comfort, and overall well-being of livestock. These include health monitoring (animals' health parameters in real-time), behavioral analysis (feeding patterns, movement, and social interactions), environment control (temperature, humidity, and air quality within livestock facilities), nutritional management, and reproductive health (estrus detection and reproductive abnormalities). However, their implementation presents challenges and raises concerns about animal welfare. The legal framework for PLF technologies is important, ensuring that regulations prioritize animal welfare. Initiatives like the Welfare Quality® project in the European Union (EU) promote animal welfare and sustainability (Papakonstantinou et al., 2024; Nica & Vidu, 2023).
While PLF technologies offer opportunities for sustainable livestock production, prioritizing animal welfare is vital for ethical and responsible farming practices.
Consumer demand for ethically produced products emphasizes the need for acknowledging animal dignity and welfare. Consumer education is essential in raising awareness about animal welfare standards and encourage support for products sourced from farms that prioritize animal welfare. It's important to communicate with consumers in a positive manner and respect their decision to pay extra for products from farms where animal welfare is a priority (Nica & Vidu, 2023; Siegrist & Hartmann, 2020; Schillings et al., 2021).

MATERIALS AND METHODS

a. **Data collection instruments**

Considering the specifics of the study, data were collected through the BlueMonitor software platform. The information obtained from the monitoring of the microclimate parameters in the sheds contributed to a good management of the integrated management activities in the Didactic Research and Development Agronomic Center Moara Domnească (dairy farm).
The technical specifications of the sensors are indicated in Table 1.
The calculation formula for determining the dew point:

$$T_d = T - \frac{100 - RH}{5} \quad (1)$$

were:
T_d – the dew point value in degrees Celsius;
T – the air temperature in degrees Celsius;
RH – the relative humidity in percentage.

The BlueMonitor platform offers in a standard Web interface all the design and working tools for SCADA automation applications (www.bluemonitor.ro). The BlueMonitor SCADA application uses PostgreSQL9.X as a database, for which customized settings can be applied considering the volume of processed data. The settings allow the response time improvement and, consequently, the speed of displaying data in the interface.

Table 1.Technical specifications of sensors

System specifications			
Model CL-200 (**temperature, CO_2, RH, PM2.5**)			
Real time clock	Yes		
Interface	RS-485		
Dimension (DxH)	Ø 150 mm x 53 mm		
Enviroment	Operating temperature	0 to +50°C	
	Storage temperature	-30 to +75°C	
	Humidity	10 to 90% RH Non-condensing	
Model ME3-NH_3 (**ammonia**)			
Response time (T_{90})	≤ 60 s		
Interface	RS485, MODBUS-RTU		
Enviroment	Operating temperature	-20 to +50°C	
	Storage humidity	15% to ~90% RH	
I/O specifications			
Sensor category	**Range**	**Accuracy**	**Resolution**
Temperature	-10 to +50°C	± 0.6°C	0.1°C
Relative humidity	0 to 100%	± 5%	0.1%
Carbon dioxide	0 to 9999 ppm	± 40 ppm ± 3% of measured value	1 ppm
Particle concentration	0~400 μg/m^3	-	1 μg/m^3
Ammonia	0-100 ppm	-	0.5 ppm
Dew point	Calculated using temperature and relative humidity		0.1°C

b. **Study area and material**

The study was carried out in the Didactic Research and Development Agronomic Center Moara Domnească (dairy farm), where Montbéliarde dairy cows are raised and managed through husbandry practices (25 dairy cows with an average body weight of 673 kg and an average daily milk production of 15 l per cow).

Information about the shelter:

- Dimensions: L = 79.5 m; l = 9.6 m; height up to the roof = 2.65 m; height of the roof = 5.5 m;
- Manure management: manure is collected from the barn using a scraper blade and temporarily stored in the septic pit;
- Ventilation system: the barn is equipped with a natural ventilation system. Each side wall has 24 ventilation windows (80 cm/110 cm) that allow air intake. The roof is equipped with 9 air exhaust openings (9 ventilation chimneys). Both front walls have 2 openings (80 cm/110 cm) at the top (in the roof area).

Microclimate and ventilation are important factors by which the air quality in dairy cow shelters is identified (Herbut et al., 2018). Good ventilation ensures a low concentration of harmful gases (Armstrong, 1994; Parois et al., 2018; Zou et al., 2019) and thermal comfort for dairy cows (Teye, 2008; Teye & Hautala, 2008).

In the shed of adult cows (free stall), sensors that monitor the air quality in the shelter are installed: temperature, relative humidity, ammonia, carbon dioxide and particle concentration.

c. **The investigated parameters:** temperature, relative humidity, ammonia, carbon dioxide, particle concentration and dew point: period in which data were collected: April-December.

d. **Data statistical analysis**

The values of the microclimate parameters in the shed were recorded through the BlueMonitor platform. Descriptive and

inferential statistics were used for data processing through:
- *Techniques of data organization and summative presentation*: numerical techniques: simple frequency analysis; graph;
- *Summative numerical indicators* of central tendency (mean) and dispersion (standard error of the mean- SEM, standard deviation - SD and coefficient of variation - CV %).
To test the significance of the differences in average amounts (Fisher, $p< 0.05$), 6 statistical hypotheses were formulated:
H1: Variations in temperature lead to differences between monthly averages;
H2: Variations in relative humidity lead to differences between monthly averages;
H3: Variations in ammonia concentration lead to differences between monthly averages;
H4: Variations in carbon dioxide concentration lead to differences between monthly averages;
H5: Variations in particle concentration lead to differences between monthly averages;
H6: Dew point variations lead to differences between monthly averages.

RESULTS AND DISCUSSIONS

BlueMonitor is an online *software* platform developed by *BlueNote Communications*, which offers a constantly updated image of monitored microclimate factors and implements procedures and applications for specific collected data processing (e.g. graphics).
The BlueMonitor platform offers in a standard Web interface all the design and exploitation tools for SCADA automation applications (www.bluemonitor.ro): web interface, through a standard *browser*; multi-role system of usage rights; interactive graphic objects; flexible alerts; automatic calculation of derived values (there are a number of functions with the help of which simple operations can be performed for the data collected through the sensors); custom charts and reports; detailed logs (helps to record system events and user activity in the interface) (Figure 1).
For each of the analyzed parameters, the specialized studies refer to maximum allowed limits (temperature: 10-14°C, humidity: 60-75%; carbon dioxide: 3000 ppm; ammonia: 20 ppm; particle concentration 500 particles/cm^3), so that the animals can have a healthy and productive life. The results obtained after data processing were compared with the standard values and those from the specialized literature (Vučković, 2019; Ngwabie et al., 2009; Strmeňová et al., 2015).

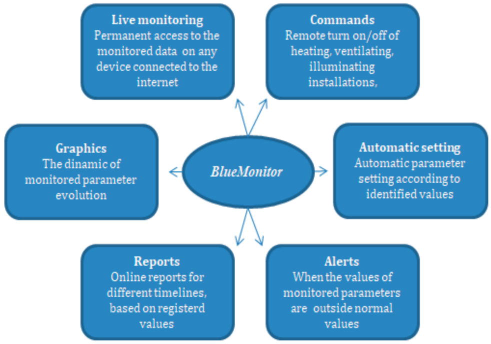

Figure 1. BlueMonitor monitoring facilities

Temperature
Cows are able to adapt to variable temperature and humidity conditions throughout the year (Kadzere et al., 2002). West (2003) states that this aspect can be confirmed through a fairly wide range both for temperature (-0.5°C to 20°C) and for humidity (60-80%). These ranges represent a thermoneutral zone that does not significantly induce physiological or behavioral changes in dairy cows. The critical level of shelter air temperature is generally considered to be in the range of 25-26°C (West, 2003) or 24-27°C (Brouček et al., 2009). The welfare of dairy cows is affected by higher values.
The temperature inside the shed is influenced by the time of year. For each month two days have been identified as monthly temperature maximum and minimum value.
Temperature monitoring has allowed the calculation of corresponding average values for each day and on a monthly level. For April, the temperature varied between 16.43-18.81°C (daily average), with an average of 16.95°C (monthly average). For this month the temperature values sent by the sensors did not exceed the permitted limits for this parameter (Figure 2).
In May, the highest temperature was generated by the system for May 24th, namely 24.05°C (daily average), with approx. 9°C more

compared to the standard maximum allowed for thermal comfort in the dairy cow shed.
From the data stored in the system, an average temperature for June of 23.85°C was determined, with limits between 17.77°C (daily average) and 29.39°C (daily average).

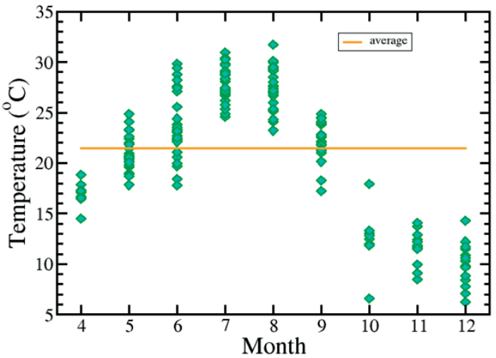

Figure 2. Temperature - daily average values corresponding to each month

July and August were the hottest months of the year. The average temperature in the shelter for these months was approx. 28°C, with a maximum of 31.69°C (daily average). For these months, the allowed limits have been exceeded. Notifications/alerts were received from the BlueNote platform, which enabled timely optimal measures to prevent hot air from entering the litter inside the shelter. The fact that measures were taken to recover the temperature inside the shelter also helped to reduce heat stress. The high temperature during this period was reflected in productivity.
For September, based on the data taken from the sensors in the shelter, a daily average temperature of approx. 22.18°C was registered, the maximum recorded for this month being 24.85°C (daily average), and the minimum 17.2°C (daily average).
As the warm season passed, an optimal temperature in the shelter was easier to maintain (Table 2).
The average temperature determined for the month of December was 9.75°C. The sensors in the shelter registered values that fall within the allowed limits for thermal comfort, i.e. the temperature varied between 6.22°C (daily average) and 14.28°C (daily average).
Through the analysis of variance by comparing the monthly means for the temperature, there were detected statistically significant differences ($p < 0.05$).

Table 2. Temperature: statistics and Fisher test

Month	Descriptive statistics		
	MEAN ± SEM	**SD**	**CV %**
April	16.95 ± 0.32	1.06	6.24
May	21.08 ± 0.30	1.68	7.98
June	23.85 ± 0.59	3.21	13.48
July	27.82 ± 0.29	1.60	5.76
August	27.30 ± 0.38	2.15	7.86
September	22.18 ± 0.41	1.94	8.76
Octomber	12.45 ± 1.09	3.09	24.79
November	11.60 ± 0.42	1.57	13.55
December	9.75 ± 0.50	2.08	21.31
Significance between months	191.2*		

Note: Fisher test, $p < 0.05$

Relative humidity

Monitoring the relative humidity is important especially in the warm season. The decrease in humidity in combination with an increased temperature influences the increase in the concentration of harmful gases.
Investigating the data stored in the BlueNote system, a high degree of variability was observed throughout the months investigated (Figure 3). The average of the investigated months was 77.43%.

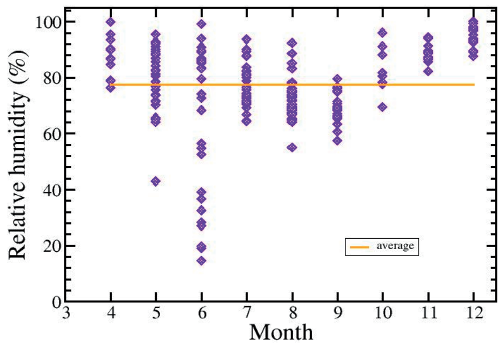

Figure 3. Relative humidity - daily average values corresponding to each month

For each month of the year, the average was determined, which varied between 66.63% (June) and 94.49% (December). It was observed that only in April, October, November and December the maximum value accepted as optimal for the microclimate in the shelter was exceeded.
In June, the lowest relative humidity was identified, namely lower by 12.74% compared

to the previous month and 10.35% compared to the following one. For the values in June, a high degree of variability was observed, three days (daily average) with a very low humidity (approx. 17.75%) compared to the allowed limit were identified. The coefficient of variation for this month was very high (40.44%), indicating high variability for this month's group of statistical units. The average determined for this distribution is not representative, as the coefficient of variability is higher than 30%. Analyzing each daily average for this month, humidity ranges from 14.57% to 99.13%.

The most homogeneous distribution of values was for the month of December, with a 3.93% coefficient of variability. It can be considered that the average determined for each of the value distribution, corresponding to the investigated months (except June) is representative for the statistical population, the value of the coefficient of variability being in each case less than 15%.

After a comparative analysis of the values for standard error of the mean (SEM) from the nine distributions corresponding to the investigated months, it was noticed that in June the standard error of the mean is approximately 3 times higher compared to the months of July, August, September and November and double compared to April and May. The most homogeneous distribution was determined for the month of December, with the standard error of the mean of 0.90 (Table 3).

Through the analysis of variance by comparing the monthly averages for the relative humidity, there were detected statistically significant differences ($p<0.05$).

Table 3. Relative humidity: statistics and Fisher test

Month	Descriptive statistics		
	MEAN ± SEM	SD	CV %
April	87.32 ± 2.23	7.39	8.46
May	79.37 ± 2.05	11.39	14.35
June	66.63 ± 4.92	26.95	40.44
July	76.98 ± 1.37	7.63	9.90
August	72.66 ± 1.34	7.48	10.29
September	69.16 ± 1.16	5.45	7.89
Octomber	82.81 ± 3.01	8.51	10.27
November	89.26 ± 1.01	3.78	4.24
December	94.49 ± 0.90	3.71	3.93
Significance between months 11.297*			

Note: Fisher test, $p < 0.05$

Ammonia

The ammonia concentration of the air in shelters is influenced by several factors, including: the amount and composition of manure and the period of stagnation in the shelter, the pH of the manure, the density of animals in the shelter etc.

In 2015, Strmeňová measured the ammonia concentration in two areas of a dairy cow shelter. In front of the feeding area, the average concentration was recorded as 10.89 ppm, while in the middle area between two rows of berths, the average concentration was 3.6 ppm.

The maximum value of the ammonia concentration recorded by the sensors in the shelter during the analyzed months was 18.2 ppm (daily average), in December (Figure 4).

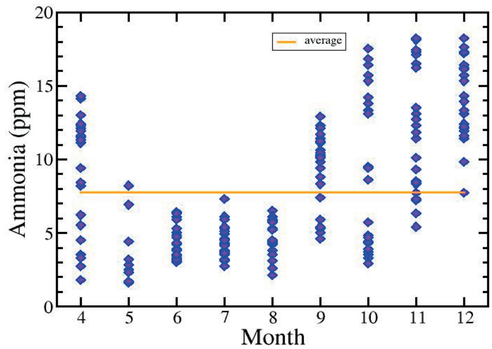

Figure 4. Ammonia concentration - daily average values corresponding to each month

The dynamics of ammonia concentration was investigated over nine months. The average for each month was determined and it was observed that the highest concentration was in December, respectively 11.15 ppm more compared to the month of May for which the lowest average was calculated. For June and July, the ammonia concentration averages were similar, with a variation between 4.33 ppm - 4.62 ppm.

The investigation of data from the BlueNote platform allowed for the establishment of an average for the investigated months (7.74 ppm). Compared to the average determined for the 9 months investigated, for the monthly averages, maximum variations of 6.44 ppm (December) and minus 4.71 ppm (May) were determined.

Fluctuations of the ammonia content in the air reflect in the degree of heterogeneity of the characteristic data groups of each month. The highest degree of variability was observed in October, the standard error of the mean for this month having the highest value (5.34). This aspect is also marked by the high value of the coefficient of variability (60.36 %). Comparing the results obtained for the coefficient of variability determined for each of the nine investigated months, it was observed that in December were the smallest fluctuations in the concentration of ammonia (Table 4).
Through the analysis of variance by comparing the monthly means for the ammonia, there were detected statistically significant ($p< 0.05$).

Tabel 4. Ammonia statistics and Fisher test

Month	Descriptive statistics		
	MEAN ± SEM	SD	CV %
April	8.63 ± 0.86	4.21	48.79
May	3.03 ± 0.30	1.51	49.60
June	4.62 ± 0.25	1.24	26.84
July	4.33 ± 0.23	1.11	25.78
August	4.45 ± 0.22	1.10	24.69
September	9.40 ± 0.54	2.59	27.60
October	8.85 ± 7.09	5.34	60.36
November	12.09 ± 0.85	4.21	34.82
December	14.18 ± 0.57	2.79	19.73
Significance between months	37.60*		

Note: Fisher test, $p < 0.05$

Carbon dioxide

The CO_2 concentration in the shelter varies depending on the amount of manure and litter in the shelter, the number of animals/m^2 and of course the quality of the atmospheric air.
In 2015, Strmeňová measured the CO_2 concentration in two areas of a dairy cow shelter. In front of the feeding area, the average concentration was recorded as 2121.50 ppm, while in the middle area between two rows of berths, the average concentration was 1856.50 ppm.
Accessing the BlueNote interface allowed the identification of a maximum value during the investigated months of 1242.43 ppm (the daily average for May^{1st}) (Figure 5).
For each of the investigated months, an average was determined based on the stored data, and the value distribution curve has a concave shape. The highest averages for the carbon dioxide content of the shelter air were determined in April and December.

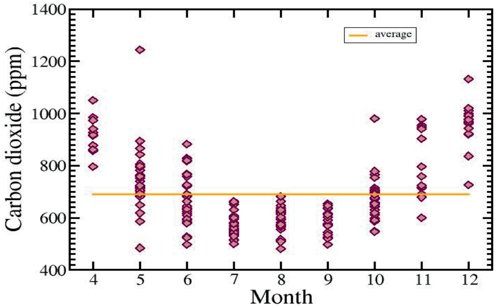

Figure 5. Carbon dioxide concentration - daily average values corresponding to each month

The largest fluctuations in the content of CO_2 in the air were monitored for May, with variations between 483.27 ppm (daily average) and 1242.43 ppm (daily average). This aspect is also confirmed by the high value of the variability coefficient (16.72%) and the standard deviation (125.89), which varies directly proportional to the degree of variability. The situation was similar in November.
The most homogeneous value distributions were recorded in April and August, with the coefficient of variability having a value below 8%. Similar situations were also determined in July, September, and December, however, for these months the variability coefficient was between 8.06-8.85% (Table 5).

Table 5. Carbon dioxide: statistics and Fisher test

Month	Descriptive statistics		
	MEAN ± SEM	SD	CV%
April	916.88 ± 21,13	70.09	7.64
May	752.54 ± 22,61	125.89	16.72
June	673.54 ± 18,11	99.23	14.73
July	568.67 ± 8,39	46.72	8.21
August	596.45 ± 7,84	46.76	7.84
September	584.30 ± 10,05	47.14	8.06
October	667.59 ± 14.64	81.54	12.21
November	793.78 ± 33,33	124.73	15.71
December	955.68 ± 20,52	84.63	8.85
Significance between months	59.08 *		

Note: Fisher test, $p < 0.05$

The lowest CO_2 concentrations were recorded in July, August, and September. The most likely explanation is that during those months, the cows spent more time in the outer paddock (Table 5).
After a comparative analysis of the monthly average values, it was observed that CO_2 varied

between 568.67 ppm (monthly average - July) and 955.68 ppm (monthly average - December), with a maximum difference from the investigated months average of 260.74 ppm (Table 5).
Through the analysis of variance by comparing the monthly means for the carbon dioxide, there were detected statistically significant differences ($p<0.05$).

Particle concentration

Particle concentration is an indicator of indoor air quality. According to the data recorded by the sensors in the shelter, the daily average on April 25rd, the maximum concentration in particles was 122.01 μg/m^3 (Figure 6).

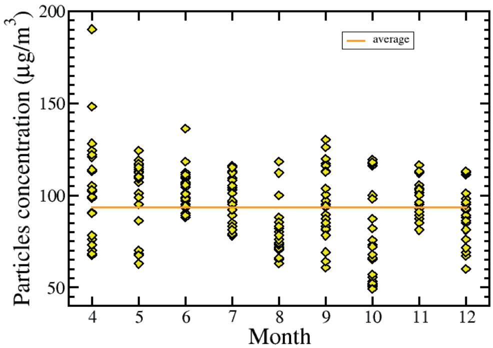

Figure 6. Particle concentration - daily average values corresponding to each month

Monthly averages vary between 74.27 μg/m^3 (October) and 103.06 μg/m^3 (April). The average of the analyzed months was 93.41 μg/m^3, with a maximum difference of 19.14 μg/m^3 compared to the monthly averages. A comparative analysis of the monthly averages, shows that higher values were observed in April (9.65 μg/m^3), May (7.86 μg/m^3), June (8.53 μg/m^3), July (6.25 μg/m^3) and November (5.41 μg/m^3), respectively lower in August (14.41 μg/m^3), September (0.97 μg/m^3), October (19.14 μg/m^3) and December (3.19 μg/m^3) compared to the average of the analyzed months (Table 6).
The comparative analysis of the values shows that the standard error of the mean (SEM) varies within very small limits, namely between 2.16 and 5.87, which indicates the homogeneity of the values recorded by the sensors in the shelter.

During summer months, the difference between the averages recorded for the particle concentration was of maximum 22.94 μg/m^3.

Table 6. Particle concentration: statistics and Fisher test

Month	Descriptive statistics		
	MEAN ± SEM	**SD**	**CV %**
April	103.06 ± 5.87	28.76	27.91
May	101.27 ± 3.76	18.44	18.21
June	101.94 ± 2.20	10.79	10.59
July	99.66 ± 2,52	12,36	12.40
August	79.00 ± 2.83	13.90	17.60
September	92.44 ± 5.42	26.57	28.74
Octomber	74.27 ± 5.01	24.57	33.08
November	98.82 ± 2.16	10.62	10.75
December	90.22 ± 3.01	14.76	16.36
Significance between months 7.271*			

Note: Fisher test, $p < 0.05$

Through the analysis of variance by comparing the monthly means for the particle concentration, there were detected statistically significant differences ($p<0.05$).

Dew point

Knowing the dew point, temperature and humidity values allows the temperature humidity index (THI) to be determined. Variations of this index influence the installation of thermal stress.
The investigation of the database collected (for temperature and relative humidity) by the sensors installed in the dairy cows shed at the Moara Domnească farm revealed a maximum monthly average of 23.22°C, in July. Average monthly values range between 8.65°C (December) and 23.22°C (July). A daily average for the dew point was established based on data recorded by sensors for temperature and relative humidity (Figure 7).

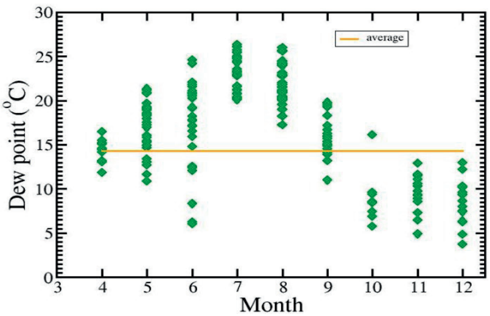

Figure 7. Dew point - daily average values corresponding to each month

The average of the analyzed months for this microclimate parameter was 16.92°C. As expected, the lowest values were recorded in the cold months of December, with a maximum difference of 8.27°C from the average of the investigated months (Table 7).

Table 7. Dew point: statistics and Fisher test

Month	Descriptive statistics		
	MEAN ± SEM	SD	CV %
April	14.42 ±0.39	1.31	9.09
May	16.95 ± 0.52	2.90	17.12
June	17.17 ± 0.92	5.04	29.35
July	23.22 ± 0.35	1.97	8.51
August	21.84 ± 0.40	2.24	10.30
September	16.01 ± 0.48	2.29	14.31
October	9.01 ± 1.11	3.15	35.02
November	9.45 ± 0.57	2.16	22.93
December	8.65 ± 0.59	2.45	28.36
Significance between months	64.958*		

Note: Fisher test, $p < 0.05$

Through the analysis of variance by comparing the monthly means for the dew point, there were detected statistically significant differences ($p<0.05$).

Interrelationships between microclimate parameters

a. ***Temperature, humidity and dew point***

Microclimate factors are closely interdependent, influencing animal well-being and implicitly productivity. The comparative analysis of the values for temperature and dew point shows that as the temperature increases, so does the dew point, i.e. a directly proportional variation. In contrast, an inversely proportional variation was observed between relative humidity and dew point.

The most homogeneous value group, both for relative humidity and dew point, was for the 30-35°C temperature range. This aspect is indicated by the very small value of the coefficient of variation (4.26% for relative humidity and 2.45% for dew point) (Table 8).

The highest coefficient of variation (33.03%) for the dew point parameter was determined for the temperature range 20-<25°C, which indicates a high degree of variation between the values (temperature and relative humidity) recorded by the sensors in the shelter for this temperature range (Table 8).

The value obtained for the coefficient of variation corresponding to the temperature range 6-<10°C and 25-<30°C, being higher than 15% but lower than 30% indicates that the average determined for this microclimate parameter has a moderate representativeness for the respective value group (Table 8).

b. ***Temperature and ammonia***

Temperature can be treated as a key factor for an optimal microclimate due to its impact on ammonia emissions (Mulvaney et al., 2008) compared to the impact of manure removal frequency, floor condition, cleanliness and feeding activity of cows (Zhang et al., 2005). Emission rates are influenced by the type of flooring and manure handling method (Parois et al., 2018). The lowest ammonia emission was determined for shelters with solid floors, smooth surfaces, draining, and exhaust with scraper or plow scraper (Zhang et al., 2005). In the shelter where microclimate parameters were monitored, the floor is made of concrete, the resting areas are equipped with rubber mats, and manure is removed with a scraper blade.

These features are part of the factors ensuring a low concentration of ammonia. Comparing values based on the months analyzed for temperature and ammonia, it was observed that an increase in temperature does not always lead to an increase in ammonia concentration.

Table 8. Relative humidity and dew point correlated with temperature

Temperature	Descriptive statistics					
	MEAN ± SEM		SD		CV %	
	Relative humidity	Dew point	Relative humidity	Dew point	Relative humidity	Dew point
6-<10°C	91.81 ± 1.46	7.03±0.42	5.29	1.51	5.76	21.61
10-<15°C	89.51±1.41	10.54±0.31	7.21	1.60	8.06	15.21
15-<20°C	83.86±2.31	15.22±0.52	10.86	2.45	12.95	16.11
20-<25°C	78.31±1.24	19.78±0.84	9,59	6.53	12.25	33.03
25-<30°C	74.92±1.11	23.56±0.69	7.83	4.81	10.46	20.42
30-35°C	74.62±1.42	25.55±0.28	3.18	0.63	4.26	2.45

For example, during the warmest months analyzed (July and August), the cows spent a lot of time in the paddock, which resulted in a reduction in manure volume and low ammonia concentration. In December, which had the lowest monthly average temperature, the monthly average ammonia concentration was highest due to reduced ventilation from closing the windows.

To reduce ammonia emissions from dairy cow shelters, it is important to manage air circulation and optimize temperature, especially during high temperature periods (Ngwabie et al., 2009). Temperature control is necessary in order to not create the possibility of hot air entering the litter inside the stable. Decreasing the average annual temperature by 1°C would reduce the annual ammonia emission by 5% (Bleizgys et al., 2013). Lowering the temperature in dairy cow sheds will lead to lower pH levels and biological processes that create ammonia in manure (Teye & Hautala, 2008). Seasonal temperature fluctuation and the initial pH of the floor surface play an important role in the amount of volatilized ammonia (Mulvaney et al., 2008).

The specific risk occurs when the temperature exceeds 20°C. An increase of temperature contributes to the intensification of ammonia emissions (Bleizgys et al., 2013). The variation in ammonia concentration is closely related to the variation in carbon dioxide concentration. There are studies that demonstrate that there is a positive correlation between these two gases (Ngwabie et al., 2009; Strmeňová et al., 2015).

c. ***Relative humidity and the concentration of harmful gases***

Relative humidity influences the concentration of harmful gases. For example, there are studies that concluded that when the temperature increased and the humidity decreased, the concentration of harmful gases increased (Strmeňová et al., 2015).

d. ***Consequences of the interaction of factors***

Another aspect frequently analyzed in dairy cow studies is related to heat stress. Heat stress is defined as the sum of external factors acting on an animal, leading to an increase in body temperature and causing a physiological response/reaction (Dikmen & Hansen, 2009). The problem of heat stress is associated with high air temperatures combined with high relative humidity in cow shelters (Hill & Wall, 2015).

Under unfavourable thermal conditions, dairy cows can dissipate body heat mainly by increasing their respiration rate and reducing the feed intake and milk production. In these situations, dairy cows try to maintain their homeostasis by seeking shade, reducing feed consumption and movements (Schutz et al., 2009).

It is essential to create conditions that allow the dissipation of dairy cows' body heat, as hyperthermia has a negative impact on the cow's health and therefore on productivity and reproductive activity. When the upper critical temperature is exceeded, the adaptation mechanisms fail to remove the generated excess heat.

Studies conducted in shelters and on pastures have shown that among the environmental conditions with the highest influence on the welfare of dairy cows are temperature and relative humidity, and that these can be ensured by applying appropriate solutions (Janni & Allen, 2001).

CONCLUSIONS

The average temperature was 21.43°C, with significant monthly fluctuations. Alerts were sent when temperatures exceeded comfort limits, allowing quick corrective actions. Relative humidity averaged 77.43%, with a 27.86% variation, requiring management to prevent humidity-related issues. Ammonia levels peaked in December and were lowest in May, averaging 7.74 ppm, with significant monthly differences ($p<0.05$). CO_2 concentrations also varied significantly ($p<0.05$), highest in December (955.68 ppm) and lowest in July (568.67 ppm), influenced by seasonal cow behavior. Particle concentration peaked in April and was lowest in October, averaging 93.41 µg/m³. The average dew point was 16.92°C, lowest in December. Monitoring these parameters is essential for preventing thermal stress and ensuring dairy cow welfare.

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REFERENCES

Armstrong, D.V. (1994). Heat stress interaction with shade and cooling. *J. Dairy Sci.,* 77(7), 2044-2050.

Arnott, G,. Ferris, C.P. & O'Connell, N.E. (2017). Review: welfare of dairy cows in continuously housed and pasture-based production systems. *Animal*, *11*(2), 261-273.

Berckmans, D. (2014). Precision livestock farming technologies for welfare management in intensive livestock systems. *Revue scientifique et technique* (international office of epizootics), *33*(1), 189-196.

Bleizgys, R., Bagdonienė, I. & Baledentienė, L. (2013) Reduction of the livestock ammonia emission under the changing temperature during the initial manure nitrogen biomineralization. *The Scientific World Journal*, 6.

BlueNote platform: www.bluemonitor.ro (last accesed on 07.10.2024).

Bohmanova, J., Misztal, I., & Cole, J.B. (2007) Temperature-humidity indices as indicators of milk production losses due to heat stress. *Journal of Dairy Science*, 90, 1947-1956.

Brouček, J., Novák, P., Vokřálová, J., Šoch, M., Kišac, P. & Uhrinčať, M. (2009). Effect of high temperature on dairy production of cows from freestall housing with natural ventilation*. Slovak J. Anim. Sci., 42(*4), 167-173.

Chadda, A., Jadoun, Y.S., Singh, J., & Kansal, S.K. (2021). Comparative analysis of beneficiaries and non-beneficiaries about scientific livestock farming practices. *Indian J. Anim. Res.*, doi: 10.18805/IJAR.B-4404.

Defta, N., Vidu, L., Mihai, R., Dragomir, N., Posan, P. & Oprea, I. (2023) Study on the Dynamics of Cattle Livestock, Milk Production and Fresh Dairy Products in Romania between 2016-2020. *Scientific Papers. Series D. Animal Science*, LXVI (2), 465-470.

Dikmen, S. & Hansen, P.J. (2009). Is the temperature-humidity index the best indicator of heat stressin lactating dairy cows in a subtropical environment? *J. Dairy Sci.*, 92, 109-116.

European Union. European Food Safety Authority. Animal welfare: www.efsa.europa.eu (last accesed on 28.10.2024)

Gauly, M., et al. (2013). Future consequences and challenges for dairy cow production systems arising from climate change in Central Europe – a review. *Animal, 7*, 843-859.

Gavrila, M.I., Marginean, G.E. & Vidu, L. (2015). Study on the interrelation between animal welfare and production in dairy cattle. *Scientific Papers: Series D, Animal Science*, LVIII, 58.

Gavrila, M.I., Marginean, G.E., Vidu, L. & Stanciu, N. (2015). The impact of modern technology on the welfare and milk production in dairy farms. *J. Biotech*., 208.

Herbut, P., Angrecka, S., & Walczak, J. (2018) Environmental parameters to assessing of heat stress in dairy cattle-a review. *International Journal of Biometeorology* 62, 2089-2097.

Hill, D.L., & Wall, E. (2015). Dairy cattle in a temperate climate: the effects of weather on milk yield and composition depend on management. *J. Animal*, 9(1), 138-149.

Janni, K.A., & Allen, D.M. (2001). Thermal environmental conditions in curtain sided naturally ventilated dairy freestall barns. *ASABE Paper, ASAE, St. Joseph*., *Livestock Enviroment IV*, 367-376.

Kadzere, C.T., Murphy, M.R., Silanikove, N., & Maltz, E. (2002). Heat stress in lactating dairy cows: a review. *Livest. Prod. Sci*., 77, 59-91.

Kelemen, A., Mărginean, G.E. & Vidu, L. (2016). Practical and theoretical aspects regarding the precision dairy farming concept in Romania. *Scientific Papers. Series D, Animal Science*, LIX, 210-217.

Lokhorst, K. (2018). *An introduction to Smart Dairy Farming*. Leeuwarden, NL: Van Hall Larenstein University of Applied Sciences Publishing House.

Mihai, R., Mărginean, Gh., Marin, M., Hassan, A.A., Marin, I., Fîntîneru, G. & Vidu, L. (2020) Impact of Precision Livestock Farming on welfare and milk production in Montbeliarde dairy cows. *Scientific Papers, Series D, Animal Science*, *LXIII*(2), 308-314.

Mihai, B., Posan, P., Marginean, G.E., Alexandru, M. & Vidu, L. (2023). Study on the Trends of Milk Production and Dairy Products at European and National Level. *Scientific Papers. Series D. Animal Science*, *LXVI* (1), 309-317.

Mulvaney, M.J., Cummins, K.A., Wood, C.W., Wood, B.H. & Tyler, P.J. (2008). Ammonia emissions from field-simulated cattle defecation and urination. *Journal of Environmental Quality*, 37*,* 2022-2027*.*

Ngwabie, N.M., Jeppsson, K.H, Nimmermark, S., Swensson, C. & Gustafson, G. (2009). Multi-location measurements of greenhouse gases and emission rates of methane and ammonia from a naturally-ventilated barn for dairy cows. *Biosystems engineering*, *103*(1), 68-77.

Nica, G. & Vidu L. (2023). The Stage of Research on Welfare Requirements in Livestock Farms. *Scientific Papers. Series D. Animal Science*, *LXVI*(1)*,* 317-327.

Papakonstantinou, G.I., Voulgarakis, N., Terzidou, G., Fotos, L., Giamouri, E. & Papatsiros, V.G. (2024). Precision Livestock Farming Technology: Applications and Challenges of AnimalWelfare and Climate Change. *Agriculture*, 14, 620.

Parois, S., Cabezon, F., Schinckel, A., Johnson, J., Stwalley, R. et al. (2018) Effects of floor cooling on behavior and physiology of lactating sows during acute heat stress*. Frontiers in Veterinary Science, Frontiers Media*, *5*.

Schillings, J., Bennett, R. & Rose, D.C. (2021). Animal welfare and other ethical implications of Precision Livestock Farming technology. *CABI Agriculture and Bioscience,* 2, 17.

Schutz, K.E., Rogers, A.R., Cox, N.R. & Tucker, C.B. (2009). Dairy cows prefer shade that offers greater protection against solar radiation in summer: shade use, behaviour, and body temperature. *Applied Animal Behaviour Science*, 116, 28-34.

Shruthi, K., Hiremath, G.M. & Amrutha, Joshi. (2018) An overview of use of precision farming technology by the farmers-A case study of North Eastern Karnataka. *Indian Journal of Agricultural Research, 52*(1).

Siegrist, M. & Hartmann, C. (2020). Consumer acceptance of novel food technologies. *Nature Food,* 1, 343–350.

ST-Pierre, N.R., Cobanov, B. & Schnitkey, G. (2003). Economic losses from heat stress by US livestock industries. *Journal of Dairy Science*, *86*(E. Suppl), 52-77.

Strmeňová, A. et al. (2015). Effect of microclimate parametres on the concentration of harmful gases during various periods of the day in dairy cattle housing, *Towards Climatic Services, Nitra, Slovakia,* 15th - 18th September.

Teye, K.F. (2008). *Microclimate and gas emissions in dairy buildings: Instrumentation, theory and measurements*. Helsinki, FI: University Publishing House.

Teye, K.F. & Hautala, M. (2008). Adaptation of an ammonia volatilization model for a naturally ventilated dairy building. *Atmospheric Environment*, *42*(18), 4345-4354.

Vučković, G. et al. (2019). Analysis of production traits and microclimate parameters on dairy cattle farms. *Biotechnology in animal husbandry*, *35*(4), 323-334.

West, J.W. (2003). Effects of heat-stress on production in dairy cattle. *Journal of Dairy Science*, 86, 2131-2144.

Zhang, G., Strøm, J.S., Li, B., Rom H.B., Morsing, S., Dahl, P. & Wang, C. (2005). Emission of ammonia and other contaminant gases from naturally ventilated dairy cattle buildings. *Biosystems Engineering*, 92, 355-364.

Zou, B., Wang, X., Mondaca, M.R., Rong, L. & Choi, Ch.Y. (2019). Assessment of optimal airflow baffle locations and angles in mechanically-ventilated dairy houses using computational fluid dynamics. *Computers and electronics in agriculture*, 165, 104930.