EFFECT OF WEATHER CONDITIONS ON CONTENT OF CARBON DIOXIDE IN BARNS

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Abstract: The most important condition for optimization of the inside climate in livestock buildings is its compliance with the physiological state of animals. However, in most large and small-scale farms the microclimate in cow barns is far from the standard parameters. One reason for this discrepancy is the lack of the forecasting system of barn microclimate parameters variation depending on the changes in external conditions. The research was aimed at identifying the relationship between the level of carbon dioxide in the barn and external climatic conditions. The study results proved the concentration of carbon dioxide in the barn to be about 80 % dependent on the wind speed, outside and inside air temperature under natural ventilation of the barn.

Key words: cow barn, inside climate, carbon dioxide.

Introduction

Owing to intensification of milk production, the gain in animal productivity and higher requirements to the housing conditions of animals, the provision of optimal indoor climate for cattle has become a particularly important and urgent task. Environmental pollution with animal waste (manure effluents, emissions of greenhouse gases) is directly related to the solution of this problem. Ventilation emissions of livestock houses contain carbon dioxide (CO_2), ammonia (NH_3) and other atmosphere pollutants. The most dangerous is carbon dioxide, increased content of which in the earth's atmosphere leads to climate warming due to the greenhouse effect. One barn emits 0.279 m^3 of carbon dioxide per hour [1]. Investigations in the Institute for Building, Mechanization and Electrification of Agriculture in Warsaw in four barns [2] showed that in daytime the average CO_2 concentration was within the range of 1237-1520 ppm, while at night the maximum value was 2990 ppm that is lower than the maximum acceptable level of 3000 ppm. Practically the same results were obtained by another group of researchers from the Agricultural Academy in Szczecin [3]. The focus of the research associated with dynamic pattern of animal housing conditions is on improvement of measuring techniques and devices of inside climate parameters. The overall objective of our investigations was to reduce the environmental impact of a cattle farm through optimization of microclimate parameters.

In most agricultural enterprises the microclimate in livestock buildings is far from the standard parameters. The premises have elevated concentrations of ammonia, carbon dioxide and water vapor, depending, among other things, on natural and climatic conditions. CO_2 concentration is closely related to the air temperature. There is a number of scientific evidence of adverse effect on farm animals when the concentration of carbon dioxide is 3 000 ppm or higher; this also applies to dairy cows [4].

Materials and methods

The study was conducted in autumn and winter in the territory of Leningrad Region of Russia in a tied-housing barn with 150 cows. The size of the barn was 18 m x 72 m, with the height at the top point of the barn being 4.5 m. The barn had a natural ventilation system, with the airflow coming through the side windows and the gateway at the end of the building and exhausting through the shaft on the roof. The overall air volume and per cow air volume were 4665.6 m^3 and 31.1 m^3, correspondingly. Manure was removed by a TNS-2B scraper conveyor twice a day and loaded in a special mobile container. The average daily manure output was 8.3 tons. The average bedding manure moisture content was 83-85 %. The cows were milked in the stalls in the milk pipeline three times a day.

To study the barn climate an installation was designed for data monitoring and recording. Electronic sensors measured the chemical composition of the air. The sensor unit was a device, which structurally united the analog sensors of temperature, relative humidity and air flow rate, and the level of CO_2, NH_3, H_2S (Fig. 1). Similar portable installation was designed for measurements in additional points in the barn (Fig. 2).

CO_2 concentration was measured by EE85 sensor with the analog signal of 4-20 mA. The air from the duct flew through the probe into the EE85 enclosure and back into the duct. Inside the enclosure the air diffused through a membrane into the CO_2 sensing cell. As there was no flow through the sensing cell, this was very well protected against dust. The measurement principle was non-dispersive infrared technology, based on absorption of infrared radiation by molecules of the designated component depending on its concentration. The air velocity was measured by EE65 transmitter with the analog signal of 4-20 mA operating on a hot film anemometer principle. The air temperature and relative humidity were measured by DVT-02 sensor designed to measure these parameters in gaseous non-aggressive environments. The analog signal of 4-20 mA was supplied to the logger with 5 minutes interval. The logger was an electronic device with a storage capacity of 270 million records allowing to collect and archive the information from the sensors and to transfer it to a computer for further processing and analysis through the USB port. The output parameters were displayed in the form of EXCEL tables [5].

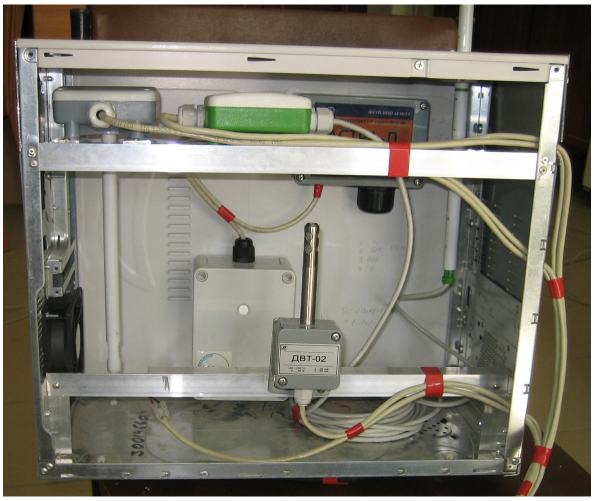

Fig. 1. **Sensor block in the installation for inside climate monitoring**

Fig. 2. **Portable installation for inside climate monitoring**

The procedure to determine carbon involved continuous measurement of gas concentration in the intake and exhaust air and the air flow rate through the building, and then calculation of the emission rates [6]. Measurements were made at five main points, as shown in Fig. 5, and two additional ones. Monitoring results were processed by known methods of mathematical statistics to determine the mean values, standard deviation of values under study for the specified periods. The average duration of the experiments was 24 hours [2; 3].

The monitoring results were processed by the known methods of mathematical statistics, with the mean values, standard deviations of the studied variables over set periods being defined. The average duration of the experiments was 24 hours [7; 8].

Results and discussion

The graphs (Fig. 3-4) show the variation patterns of the average daily concentration of carbon dioxide, ambient air temperature and wind speed for 26 days. When the outside air temperature increased, the carbon dioxide content in the barn air decreased, and vice versa. The minimum value of the daily average concentration of CO_2 was recorded at 1500 ppm, and the maximum – at 2380 ppm. During the day, the air concentration of CO_2 in the barn varied non-uniformly. In daytime, the concentration was minimal – 1350 ppm owing to the opened barn gate (at a temperature above 0 ºC) and bigger air inflow. At night, the CO_2 concentration increased two times or more, up to 3160 ppm, and exceeded the regulatory parameters (2500 ppm). Thus, the airflow rate is important in the cow barn (in daytime – 0.25 $m \cdot s^{-1}$, at night – 0.02 $m \cdot s^{-1}$), which, in its turn, depends on the wind speed and direction. It should be noted that animal houses have a considerable length and width, measuring in tens or even hundreds of meters. CO_2 is therefore not evenly distributed along the barn length and width; the wind direction has a significant impact in this respect. The carbon dioxide concentration is lower on the windward side of the building than on the leeward side. Fig. 5 and Fig. 6 show that CO_2 varies 2.0-2.5 times along the length of the barn, and 1.1-1.3 times along the width of the barn. In Fig. 5 the wind has the northwest direction, the wind speed is 3 $m\cdot s^{-1}$ and the air temperature is 9.2 ºC. In Fig. 6, the wind is of south-west direction, the wind speed is 0.3 $m\cdot s^{-1}$, the air temperature is 6.6 ºC. In the first case (Fig. 5), the level of CO_2 concentration increases from the leeward wall to the windward wall, in the second case (Fig. 6), under the wind direction towards the end face of the building and the opened gates, the CO_2 concentration in the draughty passages and opposite the gate is lower than near the walls.

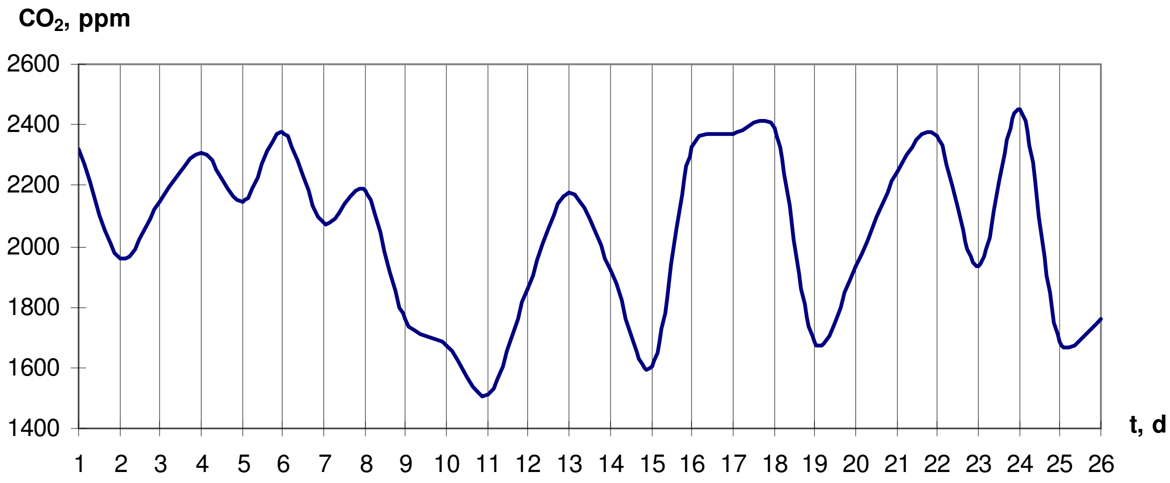

Fig. 3. **Average daily concentration of carbon dioxide in the barn**

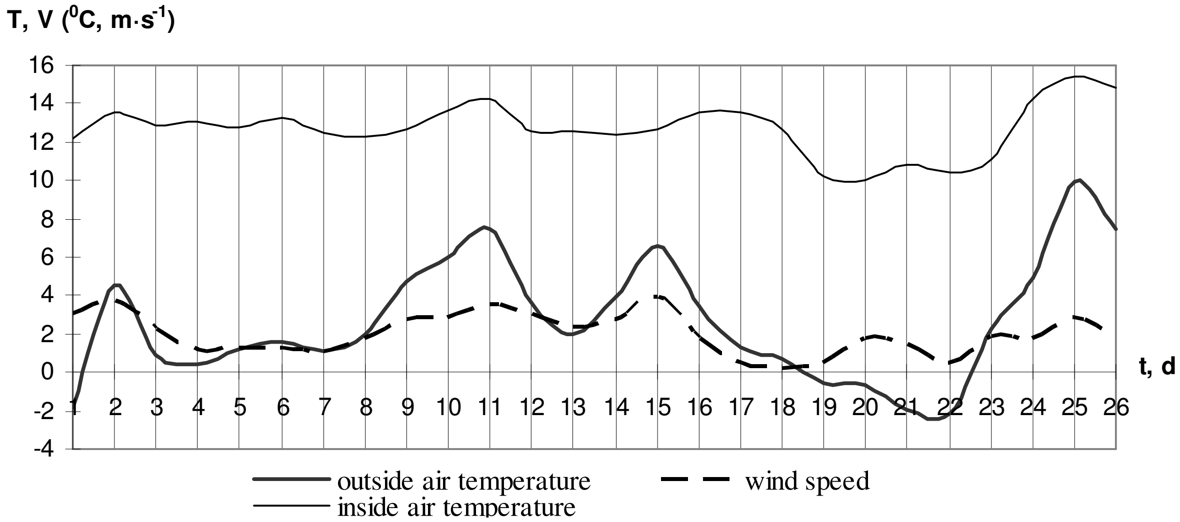

Fig. 4. **Average daily outside air temperature and wind speed**

By monitoring the results a mathematical model (1), which describes the dependence of carbon dioxide concentration in the barn from external environmental conditions, was created:

$$CO_2 = -2443.23+1325.14\cdot T_в+1308.47\cdot V_н-771.38\cdot T_н-43.61\cdot T_в^2-6.14\cdot V_н^2-14.22\cdot T_н^2-106.43\cdot T_вV_н+$$
$$+55.29\cdot T_вT_н+17.24\cdot V_нT_н,\; R^2=0.808; \quad (1)$$

where CO_2 – carbon dioxide level in the air, ppm;
$V_н$ – wind speed, $m\cdot s^{-1}$;
$T_н$, $T_в$ – outside and inside air temperature, ºC;
R^2 – multiple correlation coefficient.

The above mathematical model may be applied to predict the concentration of carbon dioxide in the particular barn under study depending on the outside air temperature and wind speed. This will allow for timely adjustment of the climate inside the barn, thereby improving animal welfare and increasing their productivity.

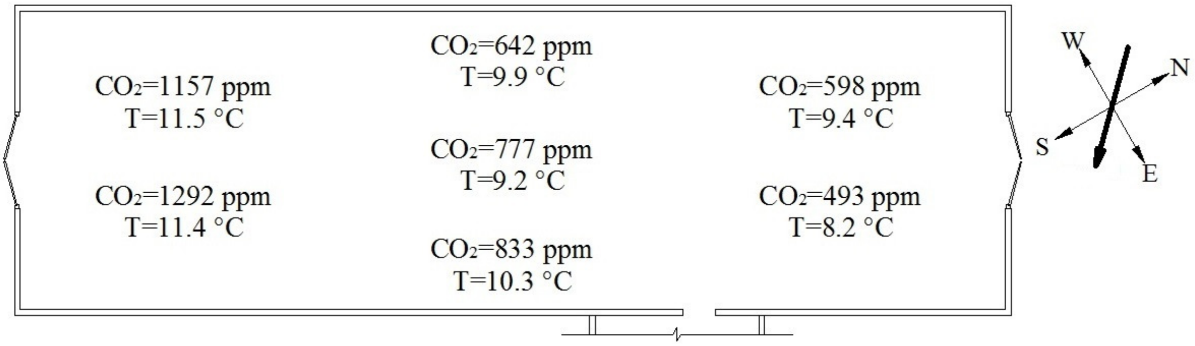

Fig. 5. **Distribution of CO_2 concentration in the barn under northwest wind direction**

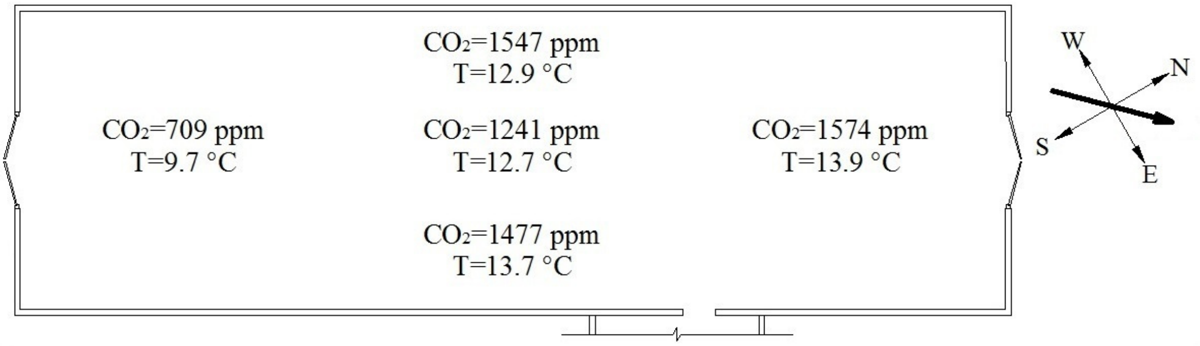

Fig. 6. **Distribution of CO_2 concentration in the barn under south-west wind direction**

Conclusions

1. Stationary and portable installations were designed to monitor the main regulated parameters of the inside climate in the livestock houses, CO_2 included. Within set periods these installations record the values of the microclimate parameters, archive them and transfer to the computer via USB ports for further processing and analysis.
2. Results of CO_2 concentration monitoring in the air of the cow barn for 150 cows during the autumn and winter of 2015-2016 revealed the significant influence of meteorological conditions on the parameter under study. CO_2 concentration was observed to decrease with higher outside temperature and wind speed. The minimal average daily CO_2 concentration was registered at 1500 ppm, maximal average daily CO_2 concentration – at 2380 ppm. At night the maximal CO_2 concentration was 3200 ppm and exceeded the maximum acceptable value, as set by the Russian regulations, by 700 ppm.
3. The wind direction along with the wind speed has also a certain importance in this respect. The inside climate in the building with substantial dimensions depends upon the position of the main barn axis in respect to the wind direction. The level of CO_2 concentration increases 2.0-2.5 times from the leeward wall to the windward wall along the length of the barn, and 1.1-1.3 times along the width of the barn.
4. Derived mathematical dependences show that CO_2 concentration in the barn under study with the natural ventilation system is 80 % dependent on the wind speed, outside and inside air temperature.

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