

Farm Constructions in Relation to the Quality of the Environment



JANALENDELOVÁ

Institut of Agricultural Engineering, Faculty of Engineering Slovak University of Agriculture in Nitra, Slovakia
jana.lendelova@uniag.sk



INGRID KARANDUŠOVSKÁ

Institut of Agricultural Engineering, Faculty of Engineering Slovak University of Agriculture in Nitra, Slovakia



MIROSLAV ŽITŇÁK

Institut of Agricultural Engineering, Faculty of Engineering Slovak University of Agriculture in Nitra, Slovakia



MILADA BALKOVÁ

Institut of Agricultural Engineering, Faculty of Engineering Slovak University of Agriculture in Nitra, Slovakia

Environmental research and progress in the introduction of innovations and the construction of new facilities also offer significant structural challenges in the construction of stables in our breeding practice. The aim of the article was to verify the quality of the environment in two different types of buildings in terms of the production of harmful gases and the state of heat load indicators in a small-scale renovated building using motor ventilation and many innovative solutions - in comparison with a large-scale, excellent modern building, which by its parameters surpassed the novelty of many construction solutions on a global scale and highlighted the trend of low-energy solutions in precision breeding. The effects of a high concentration of animals in the old building predicted the emergence of unsuitable living conditions for both animals and people. But the integration of major innovations in the past transformed the old building and created much better conditions for both animals and people. On the other hand - according to the new assignment of the project as well as the high-quality execution of building structures and technological equipment of the new barn, it was assumed that in this new building, it would be possible to create much better well-being of animals in a more hygienic environment and with less heat load for the animals even without the installation of motorized ventilation. During hot summer days, there were no significant differences in the heat load indices THI and ETIC between the small-volume building with forced ventilation compared to the index values in the large-volume building with natural ventilation. In the large-volume building without motorized ventilation, NH_3 and CH_4 levels were lower by more than 34.2% and 41.5% ($P < 0.01$), which, including other open design conditions, predicts more effective conditions to ensure the required environmental hygiene.

Keywords: gas concentrations; heat stress index; barn volume; technical solution

Dairy cow farming is one of the largest sources of NH_3 and CH_4 within livestock production (Poteko, 2019). Their high concentration in production buildings has a negative effect on both

livestock and livestock breeders. Poor ventilation can increase the relative humidity and the concentration of harmful gases such as carbon dioxide and ammonia. The concentration of carbon dioxide depends to a large

extent on the type of building, the ventilation system and the density of the animals. A significant source of CH_4 is the manure because it contains cellulose that is degraded by methane-producing bacteria (Maurer et al., 2016). Ammonia contributes to eutrophication and soil acidification, and it exerts an adverse impact on biodiversity and ecosystems (Witkowska & Sowińska, 2017). Many factors influence the concentrations of harmful gases, in especially high temperature, emitting area and emission source, etc. Due to climate change, even in temperate climates, the issue of high air temperatures and increased heat load is increasingly becoming more common and affects high producing dairy cows the most (Herbut, 2019). One option to reduce heat load in dairy cows and increase air quality is by using flow cooling through natural and forced ventilation. Natural ventilation is dependent on weather and structural design and is often not adequate in summer. Then it is required to provide cooling by forced ventilation or by a combination of several methods (evaporative cooling, shading, spraying of animals, etc.) (Fournel, 2017). To assess the quality of the environment, in scientific practice, combined methods are used - part of practical measurements and part of theoretical calculations, or the detection of production or health indicators. The worst combination is when extremes in both high concentration of pollutants and high heat load of animals occur. The article is devoted to the comparison of the state of air chemistry and the level of heat load in two structurally different types of barns.

Material and Methods

The research was performed during the summer season in two types of dairy cattle barns, in the same farm. The barns differed in herd size, housing system, and manure management.

The new PUR panel-hall building “A” for 444 dairy cows had two internal feeding corridors, the length of the building was 85.4 m, the width of the building was 51.8 m. The total height of the 3-sector counter roof in the ridge was 18.2 m. The steel structure system with 4 longitudinal rows of columns was made in a module of 5 m. The height of the wall was $h_s=8$ m on the south side, $h_n=7$ m on the north side. The front walls were made of PUR-panels with a thickness of 40 mm, 8 gates for the entry of the mechanisms were made up of remote-controlled green plastic blinds. The roller shutter system was also used on the side walls, where a fully openable roller shutter 85 m long and 4.8 m high was made above the 2.2 m high fixed wall. The roof area was composed of three roof boards - the southern area made of PUR-panels 1,500 m² (with slope of 15°),

the middle area made of double-cavity polycarbonate corrugated roofing 1,865 m² with a slope of 15° and the northern roof (PUR-panel) area 1,440 m² with a slope of 24°. Two large vertical slits were made along the entire roof, which ensure the removal of air through natural ventilation. The upper continuous intermediate vertical opening in the ridge was 3.3 m high, the second vertical roof opening was high of 1.5 m.

The dimensions of massive old brick building “B” for 158 dairy cattle were 70 m in length and 11.5 m in width. The height of the side (longitudinal) wall was 4.3 m and a ridge height was 9.7 m. An outdoor feeding area with a length of 70 m and a width of 3.25 m was added to the building. The ceiling parts were removed due to the increase in the volume of the building from the original 2,329.6 m³ to 5,154.1 m³. The ridge of the roof was opened to a width of 350 mm and parts of the roof covering were illuminated by five vertical strips 1 m wide. In the old building, there was an air volume of 34.3 m³ per animal, a floor area of 4.85 m² per animal indoors and 6.37 m² per animal including the outdoor covered feeding area. Five basket fans were installed in the longitudinal axis above the double cubicles, each with a capacity of 16,500 m³h⁻¹ (total 82,500 m³h⁻¹).

The concentrations of CH_4 , NH_3 , N_2O , and CO_2 were measured using a photo-acoustic multi-gas analyser 1309 (Inova, Denmark). Gas concentrations were measured at 4 indoor locations in the object A and 4 indoor locations in the object B and 1 outdoor location. Air was sampled from the various locations using 10–30 m long polytetrafluoroethylene (PTFE) tubes with an inner diameter of 3.2 mm. The air temperature and relative humidity were measured every 5 min using datalogger Comet. The two types of indexes were used to evaluate the heat load of animals. The temperature humidity index (THI) combines the air temperature and relative humidity into one value to estimate the heat load. We assessed heat stress according to the levels set as follows: mild heat stress $72 < \text{THI} < 79$, moderate stress $80 < \text{THI} < 89$ and severe heat stress $\text{THI} > 89$ (Armstrong, 1994; Hoffmann et al., 2019). The Equivalent Temperature Index for dairy Cattle (ETIC - calculated according to Wang et al., 2018) takes into account - in addition to temperature and relative air humidity - air velocity and solar radiation (Hempel et al. 2019). We valued ETIC according 4 categories: mild category $18 \leq \text{ETIC} < 20$, moderate category $20 \leq \text{ETIC} < 25$, severe category $25 \leq \text{ETIC} < 31$, emergency category $31 \leq \text{ETIC}$ (Hempel et al. 2019). The quality of the workers’ working environment was evaluated according to Law No 355/2007 and DECREE No 99/2016.

The aim of this study was to compare the concentrations of harmful gases and microclimatic properties of indoor air in two different building and benefits of construction types of dairy housing in the summer season with an emphasis on the evaluation of the effect of structural innovation on air chemistry and animal heat load indexes, as well as parameters of the quality of the employees' environment.

Data on climatic parameters, gas concentrations in two barns with different housing systems were processed statistically. Since all variables had a normal distribution, single factor ANOVA was performed. The significance of differences between the mean values of gas concentrations in barns was determined by Tukey's test. All calculations were made using Statistica 10 for Windows (StatSoft, CZ).

Result and Discussion

During the assessment of indoor climate parameters, no significant differences were found between objects A and B ($p > 0.05$), however, the pre-ventilation fans were not operating in building A during the research as per the methodology. The intention of the breeder was to provide the new building with a large-cubicle space with low-energy, quiet and low-emission operation.

The optimum temperature in dairy cow housing is 8–16°C (Kołacz and Dobrzański, 2019). As expected - in neither building was the optimal temperature ensured. In the location of Central Europe, this is almost impossible during the day in summer. Moreover, the methodology of the experiment was aimed at monitoring situations during days with

extremely high outdoor air temperatures, so that air chemistry and heat load were assessed for critical cases. The climatic data were recorded during the period with outdoor air temperature $30^{\circ}\text{C} < T_{\text{ext}} < 32^{\circ}\text{C}$, relative humidity $47\% < \text{RH}_{\text{ext}} < 53\%$ and airflow velocity $0.2 \text{ m}\cdot\text{s}^{-1} < v_{\text{ext}} < 1.2 \text{ m}\cdot\text{s}^{-1}$. The average values from climatic measurements at 65 indoor points in the building A without the use of motor ventilation were: $T_{\text{int,AVG}}=32,61\pm 0,71^{\circ}\text{C}$, $\text{RH}_{\text{int,AVG}}=50,94\pm 2,86\%$, $v_{\text{int,AVG}}=0,47\pm 0,28\text{m}\cdot\text{s}^{-1}$. According the two heat indexes were not found a significant differences in that values; the $\text{THI}_{\text{A,AVG}}=82,09\pm 0,89$ and $\text{ETIC}_{\text{A,AVG}}=26,12\pm 0,71$ (Figure 1). Heat stress level was not significantly different ($P > 0,05$) compared these two buildings - it was moderate (for THI) and severe (for ETIC) category, but there were different possibilities to modify this level. For old one - very limited possibilities, for new one there were a lot of technical solutions.

According to results of the evaluation of on-farm climatic measurements at the 16 indoor points in the building B using motor ventilation we found, that the average values were: $T_{\text{int,AVG}}=32,22\pm 0,45^{\circ}\text{C}$, $\text{RH}_{\text{int,AVG}}=52,92\pm 2,14\%$, $v_{\text{int,AVG}}=0,37\pm 0,23\text{m}\cdot\text{s}^{-1}$. The Temperature-Humidity Index was higher that limit level with value of $\text{THI}_{\text{B,AVG}}=81,93\pm 0,87$ and Equivalent Temperature index for Dairy Cow was $\text{ETIC}_{\text{B,AVG}}=26,07\pm 0,71$, which is about the limit level (Figure 2).

Mean concentrations of greenhouse gases and ammonia differed significantly ($P < 0.01$) between facilities. Building A (new) was characterized by lower ($P < 0.01$) mean concentrations of GHGs and ammonia compared to building B (Figure 3). The detected amounts of all gases were lower than

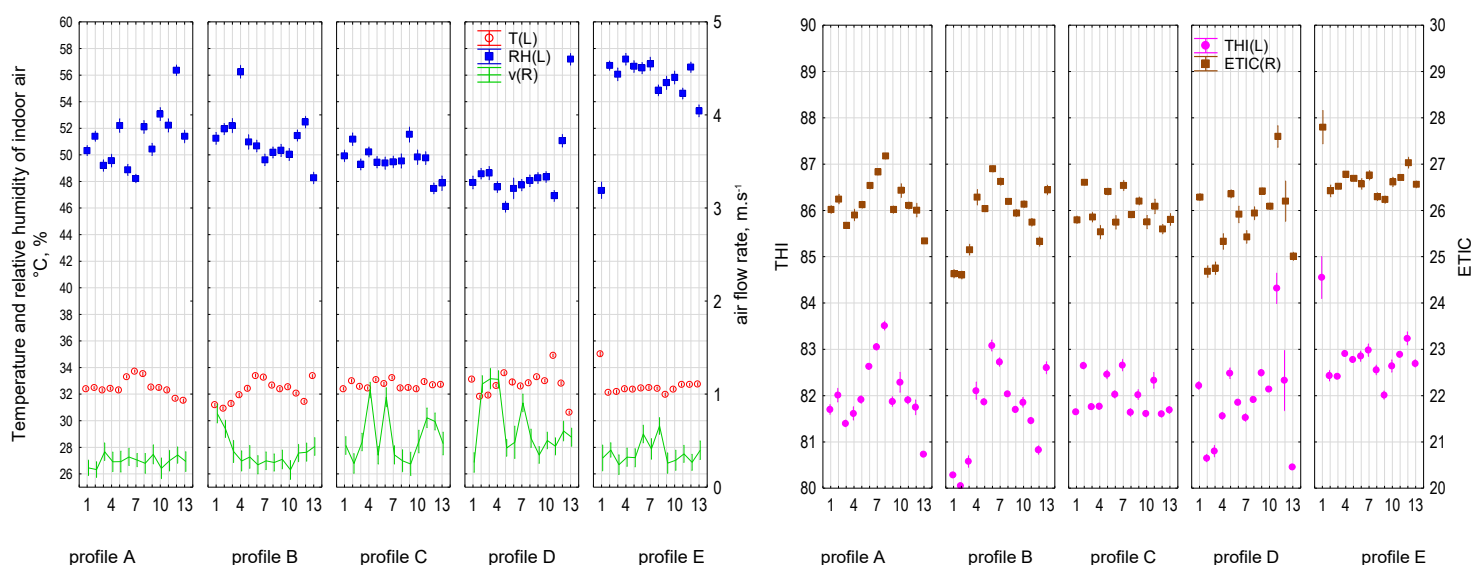


Figure 1. Results of microclimate conditions in low-volume new barn A.

the recommended environmental limits for workers and animals during the experiment.

The average CO₂ concentration in the new barn (A) was 9.8% lower than in barn B. The most significant improvement in view of chemistry was observed for NH₃, which was 34.2% lower in the new facility, and

CH₄ concentrations were 41.5% lower than in the old facility.

Microclimatic parameters are an important physical factor of the working environment, which in Slovakia is subject to Act No. 355/2007 and decree no. 99/2016 Coll.

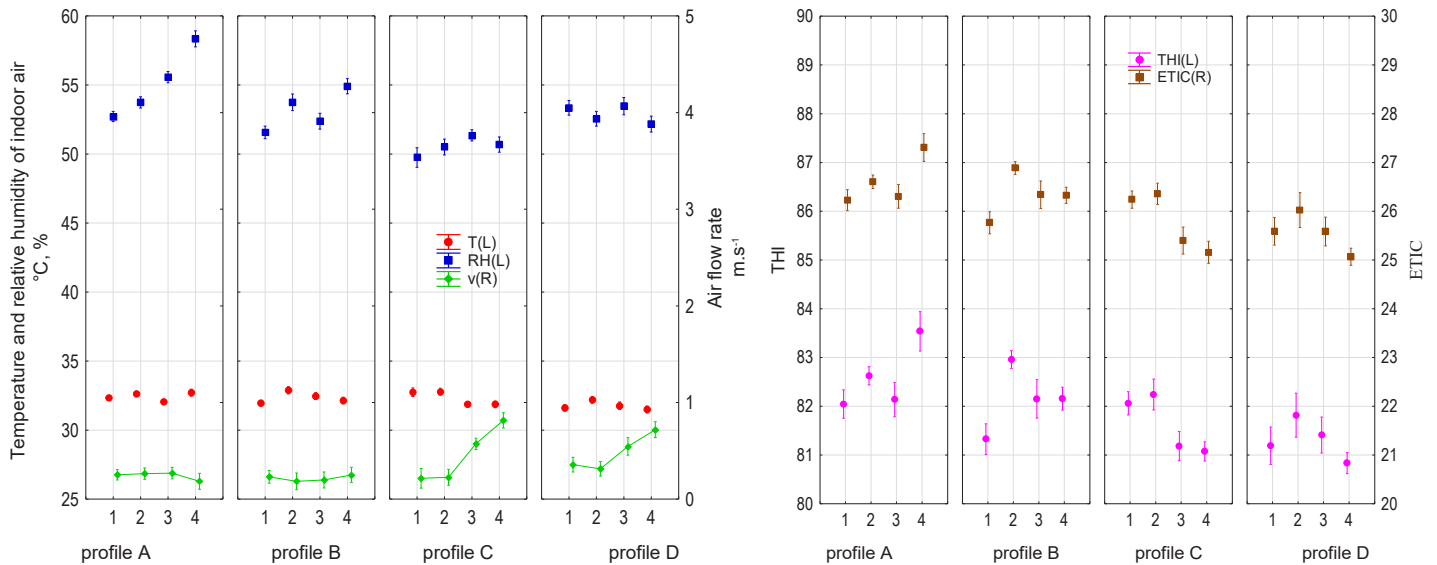


Figure 2. Results of microclimate conditions in large-volume old - reconstructed barn B.

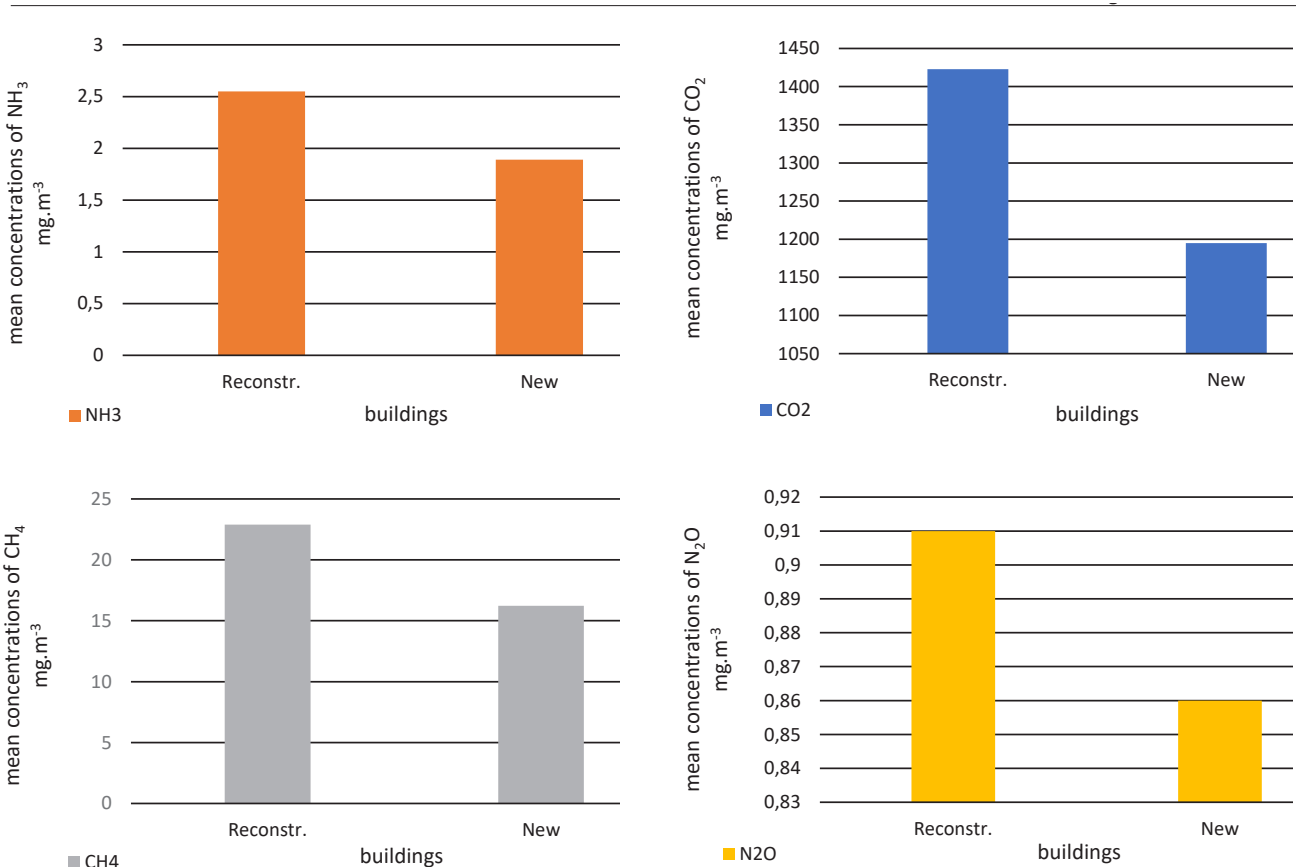


Figure 3. Results of mean concentrations of ammonia and greenhouse gases measured in reconstructed and new barn.

For working class “1b”, the optimum temperature is $T_{op}=22-25^{\circ}\text{C}$, permissible relative humidity $RH=30-70\%$ and permissible air velocity $v \leq 0.3 \text{ m}\cdot\text{s}^{-1}$.

A new structural barn design and innovative housing technology have increased the comfort of the housed animals and the air quality in terms of ammonia production, greenhouse gases as well as microclimatic parameters which are also supported by the findings of other researchers (Witkowska, 2017; Dimov et al. (2019)). The productivity of labour has also increased, the cubic volume of the environment has increased from the original $V_B=34.3\text{m}^3$ to the new $V_A=82.5 \text{ m}^3$ per cow.

The design of ventilation openings in buildings with natural ventilation is also an important element subject to beneficial innovative changes Li et al. (2020). In accordance with his testing, the design of the side walls of barn A of our experimental farm stands out, where the wall openings occupied the area (AR_w), protected by a controllable roller shutter system, $AR_w=882 \text{ m}^2$.

The vertical openings between the roof slabs (AR_r) with the area of the upper opening $AR_{r,1}=280 \text{ m}^2$ and the lower vertical opening $AR_{r,2}=127 \text{ m}^2$ effectively helped the flow regime. In total, there were 2.7 m^2 of structural openings per animal in barn A which positively influenced lower concentrations of harmful gases.

Conclusions

Large-cubature buildings prevent quick changes in the environment and large openings are a guarantee to the possibility of rapid air exchange. If the roof covering is thermally insulated and sufficiently protects the overheating of the structures, the larger air volumes around the animals, act as a buffering factor for the cleaning period of the buildings even in cases of midday solar radiation. More detailed research is needed to assess the overall decline in production parameters attributable to the occurrence of extreme summer heat situations at a particular farm location and the balance of benefits of using motor ventilation. ■

Acknowledgement

The research presented in this scientific paper is supported by the Ministry of Education, Science, Research and Sport of the Slovak republic, by the project VEGA 1/0709/21: “Scientifically justified proposals for technological solutions of housing facilities ensuring optimal microclimatic conditions for livestock and their practical verification”.

References

- [1] Armstrong, D. (1994). Heat stress interaction with shade and cooling. *J Dairy Sci* 77(7), 2044–2050.
- [2] Dimov, D., Marinov, I., Penev, T., Miteva, Ch. & Gergovska, Z. (2019). Animal hygienic assessment of air carbon dioxide concentration in semi-open freestall barns for dairy cows. *Bulgarian Journal of Agricultural Science*, 25(2), 354–362.
- [3] Fournel, S., Rousseau, A.N., Laberge, B. (2017). Rethinking environment control strategy of confined animal housing systems through precision livestock farming. In: *ö*, 155, 96–123.
- [4] Hempel, S., Menz, C., Pinto, S., Galan, E., Janke, D., Estelles, F., Müschner-Siemens, T., Wang, X., Heinicke, J., Zhang, G., Amon, B., del Prado, A., Amon, T. (2019). Heat stress risk in European dairy cattle husbandry under different climate change scenarios - uncertainties and potential impacts. *Earth Syst. Dynam. Discuss*, 1–38.
- [5] Herbut, P., Angrecka, S., Godyn, D., Hoffmann, G. (2019). The physiological and productivity effects of heat stress in cattle - a review. *Ann. Anim. Sci.* 19, 579–593.
- [6] Hoffmann, G., Herbut, P., Severino, P., Heinicke, J., Kuhla, B., Amon, T. (2019). Animal-related, non-invasive indicators for determining heat stress in dairy cows. *Biosystems Engineering*, 199, 83–96.
- [7] Kolacz, R., Dobrzanski, Z. (2019). Animal hygiene and welfare. Univerzity of Environmental and Life Sciences, Wroclaw, Poland, pp. 41, 78–79.
- [8] Maurer, D., Koziel, J.A., Harmon, J.D., Hoff, S.J., Rieck - Hinz, A.M., Andersen, D.S. (2016). Summary of performance data for technologies to control gaseous, odor, and particulate emissions from livestock operations: *Air Management Practices Assessment Tool (AMPAT)*.
- [9] Poteko, J., Zähler, M. & Schrade, S. (2019). Effects of housing system, floor type and temperature on ammonia and methane emissions from dairy farming: A meta-analysis. *Biosystems Engineering*, 182, 16–28.
- [10] Wang, X., Gao, H., Gebremedhin, K. G., Bjerg, B. S., Van OS, J., Tucker, C. B., Zhang, G. (2018). A predictive model of equivalent temperature index for dairy cattle (ETIC). *Journal of Thermal Biology*, 76, 165–170.
- [11] Witkowska, D. & Sowinska, J. (2017). Identification of microbial and gaseous contaminants in poultry farms and developing methods for contamination prevention at the source. *Poultry Science*, London: IntechOpen.