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Calculation of Air Exchange to Reduce CO_2 by Periodic Ventilation of Cattle Buildings

B.M. Fediai[1], D.V. Guzyk[2]
1PhD, docent, Poltava National Technical Yuri Kondratyuk University, Poltava, Ukraine, fed_bn@ukr.net
2PhD, docent, Poltava National Technical Yuri Kondratyuk University, Poltava, Ukraine, guzikd@rambler.ru

Abstract. The outdoor cattle keeping permits changing the air exchange intensity to prevent hazards during the day. It is important to organize such air exchange during the outdoor run which would provide the required air quality, including the CO_2 concentration in the internal airspace by the moment of the cattle's return to the stalls. The analytical solution of the problem of determining the changes in the average airspace CO_2 concentration for a certain period of time at predetermined air exchange intensity is considered in the article.

Key words: periodic ventilation;internal air; CO_2 concentration; air exchange.

Introduction. Agriculture is one of the main sectors of the Ukrainian economy and the EU economy, which shows a significant dynamic development in recent years. Breeding complexes are an integral part of the industry, including complexes for breeding cattle. The competitiveness of these complexes' production in the national and foreign markets depends primarily on its quality. The latter, together with the output volume, depends by 20 % on the microclimate parameters inside the building [1, 7 – 9]. It is known, that the air parameters of the working area, where livestock is kept, are provided by the heating and ventilation systems. At this, the purpose of the general air exchange ventilation system is the control of hazards penetrating the inner space, such as excessive heat, moisture, noxious gases (mainly CO_2) and others.

Related Work. Method of animals keeping, outer climate conditions, space-planning solution of the cattle keeping room significantly affect the microclimate parameters, heat and air regimes in the working area [3, 6, 7] and determine the possibility of using this or that type of general air exchange ventilation [5]. At the same time, investments into implementation of modern energy-saving heating and ventilation systems in rooms for keeping cattle requires the relevant technical and economic substantiation. On this basis, at the pre-project and project stages, the possibility to analyse the impact of various engineering measures on the air exchange and heat regimes of the room and on the respective technical equipment's operating characteristics, determining its of energy consumption level, is very important.

Recent studies and publications. The intensity of the air exchange, in the general air exchange ventilation system, is determined according to the task of preventing the dominant of the hazards. In case if the dominant hazard is CO_2, the estimated air exchange is determined by the balance of hazards indoors and is characterized by the equation [2,4, 7]:

$$L_{CO2} = a_{CO2}\, n \,/\, (k_{out} - k_{int}),\ \text{m}^3/\text{h}, \qquad (1)$$

where a_{CO2} – CO_2 exhalation intensity per one cow, g/h; n – number of cows in the cattle keeping room, head; k_{int} – average room CO_2 concentration in the internal air, g/m^3; k_{out} – the average CO_2 concentration in the outer supply air g/m^3.

At this, the supply air flow to the room space in the amount determined by the equation (1), due to aeration or mechanical ventilation, is adopted constant over time, regardless of livestock indoors. Also, the carbon dioxide concentration, averaged according to the room space, is taken as constant over time and equal to the normalized maximum permissible concentration of the above hazard.

The outdoor mode of keeping animals allows to apply periodic air ventilation with variable air exchange intensity during the animals outdoor run and their stay in the stalls area. However, the equation (1), in the form as it is, does not give the possibility to determine the CO_2 concentration change in time at specified air exchange intensity over a certain time period.

Purpose of article. Development of the mathematical model of air exchange in cattle building in conditions of periodic ventilation - it is the purpose of the article

Materials and methods. To solve this problem, let’s make the design scheme (Fig. 1).

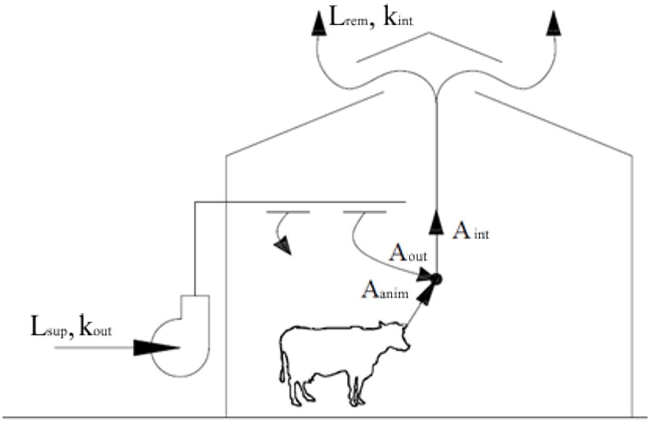

Fig. 1. The design scheme of air exchange in the cattle building at periodic ventilation

To facilitate making the analytic model, let’s introduce the simplifying assumptions, according to which: the CO_2 concentration is constant and averaged as to the room space V, m^3; ventilation in barns is balanced, i.e. the amount of supply air L_{sup}, m^3/h, is equal to the number of air removed – L_{rem}, m^3/h. According to the obtained design scheme, CO_2 with the outer supply air enters to the internal barn space for the time period of $d\tau$, h, in the amount of

$$A_{out} = L_{sup}\, k_{out}\, d\tau, \text{ g}, \tag{2}$$

an animal exhales CO_2 in the amount of

$$A_{anim} = a_{CO2}\, n\, d\tau, \text{ g.} \tag{3}$$

However, for an infinitesimal time interval $d\tau$, h, part of CO_2 is removed from the barn with exhaust air in the amount of

$$A_{int} = L_{rem}\, k_{int}\, d\tau, \text{ g.} \tag{4}$$

The difference between the number of hazards, coming and removed from the premises for the time period $d\tau$, h, refers to the internal room space and means the time change in the CO_2 concentration in the internal air of a barn – dk_{int} g/m^3. That is, from the above, we can write:

$$(L_{sup}\, k_{out}\, d\tau + a_{CO2}\, n\, d\tau - L_{rem}\, k_{int}\, d\tau) \,/\, V = dk_{int}, \text{ g/m}^3. \tag{5}$$

In case of the balanced ventilation, i.e. with $L_{sup} = L_{rem} = L$, m^3/h, and after some algebraic manipulations, the equation (2) becomes:

$$d\tau = \frac{V\, d\, k_{int}}{L\, k_{out} + a_{CO2} n - L\, k_{int}}, \text{ h.} \tag{6}$$

Let's integrate the equation (6):

$$\int\limits_{\tau_{init}}^{\tau_{fin}} d\tau = \int\limits_{k_{init}}^{k_{fin}} \frac{V\, d\, k_{int}}{L\, k_{out} + a_{CO2} n - L\, k_{int}}, \text{ h,} \tag{7}$$

where τ_{fin}, τ_{init} – final and initial time moments, h, respectively; k_{fin}, k_{init} – respectively averaged according to the volume CO_2 concentration, g/m^3, for the time moments τ_{fin} and τ_{init}.

Solving the equation (7) with respect to k_{fin}, g/m^3, and having done some mathematical transformations, we obtain:

$$k_{fin} = \frac{a_{CO2}\, n\, Z}{L} + k_{out} Z + k_{init}(Z - 1), \text{ g/m}^3, \tag{8}$$

where

$$Z = \left(1 - e^{-\frac{L}{V}\left(\tau_{fin} - \tau_{init}\right)}\right).$$

In the equation (8), the ratio L / V, h^{-1}, describes the air exchange multiplicity N.

It should be noted, that the equation (4), with the given boundary conditions for time τ, h, and CO_2 concentration, g/m^3, also enables determining the intensity of air exchange by means of the graphic-analytical method that will provide the desired reduction in the carbon dioxide concentration in the internal air of a barn for the required period of time.

A special case of the equation (6) is the case of the air exchange absence, that is, when $L = 0$. In this case, the equation (6) becomes:

$$d\tau = \frac{V\,dk_{int}}{a_{CO2}\,n}, \text{ h.} \tag{9}$$

The solution of this equation (9) as to the final CO_2 concentration, g/m^3, within the time interval, h, from τ_{fin} to τ_{init} will look like:

$$k_{fin} = \frac{a_{CO2}\,n\left(\tau_{fin} - \tau_{init}\right)}{V} + k_{init}, \text{ g/m}^3. \tag{10}$$

A special case of the equation (8) is the case of CO_2 flow absence into the internal room space. Such a situation is possible in the case of room ventilation during the outdoor run, when there is no cattle in the barn. Then the equation (8) becomes:

$$k_{fin} = k_{out}\,Z + k_{init}\,L\,(Z - 1), \text{ g/m}^3. \tag{11}$$

Results and discussion. By means of the developed equations (8, 10, 11) the analysis of the air regime in the barn for 50 cows has been made. The ventilation system of the barn is mechanized. The intensity of the CO_2 flow from cattle to the internal room space makes 110 l/h. The animals' outdoor run is carried out for 2 hours from 9 to 11 a. m. Maximum permissible CO_2 concentration in the internal barn space is 2.5 l/m^3. The CO_2 concentration in the outer supply air makes 0.4 l/m^3. The barn building space is 10,000 m^3. The estimated air exchange according to the equation (1) makes 2620 m^3/h. Fig. 2 – 4 show the results of calculations with different air exchange intensity.

Fig. 5 shows the comparison of the CO_2 concentration time change averaged as to the barn space, in the mode of permanent and periodic ventilation. According to the equation (1), under the conditions of permanent ventilation, the estimated air exchange to reduce CO_2 will make 2620 m^3/h. At this air exchange intensity, the CO_2 concentration in the internal room space will grow from k_{out}, g/m^3, to the maximum permissible value within 87 hours since the moment of the herd entering the barn. At this, the active phase of the CO_2 concentration growth will be observed during the first 20 hours (Fig. 2).

At the same time, the cattle's outdoor run and the absence of CO_2 flow from them to the barn space in the period from 9 to 11 a. m. permits to reduce the intensity of air exchange between 0 and 9 a.m. from 2620 to 2283 m^3/h in the conditions of periodic ventilation, and thus, to achieve the increase of the k_{int}, g/m^3, concentration to the maximum permissible level (2.5 l/m^3) for the moment of the cows' outdoor run. Saving the air exchange intensity at the level of 2283 m^3/h during the outdoor run, reduces the CO_2 concentration from 2.5 l/m^3 to 1.73 l /m^3.

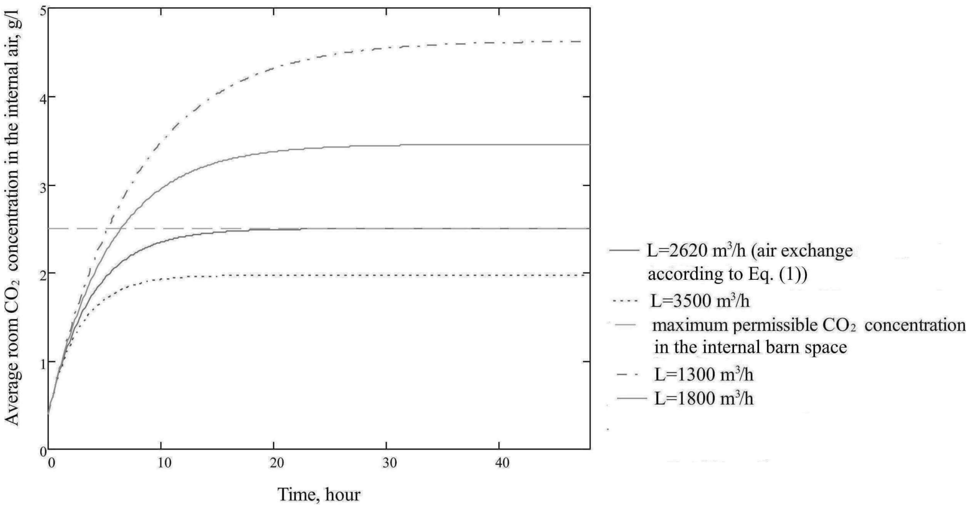

Fig. 2. The time change of the CO_2 concentration, averaged as to the room space at different air exchange intensity in the system general air exchange permanent ventilation

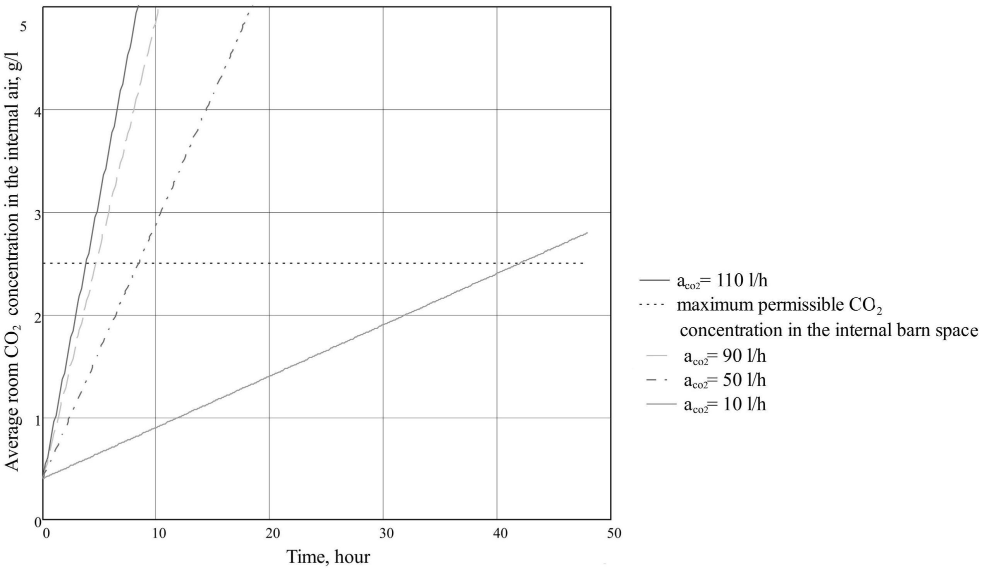

Fig. 3. The time change of the CO_2 concentration, averaged as to the room space at different intensity of carbon dioxide flow from animals a_{CO2} and at the absence of air exchange, i.e., when $L = 0$ m^3/h

When the cattle is staying in barn between the two outdoor runs for 22 hours, and at the permissible CO_2 concentration increase from 1.73 to 2.5 l/m^3, the required air exchange intensity must make 2610 m^3/h according to the suggested mathematical model.

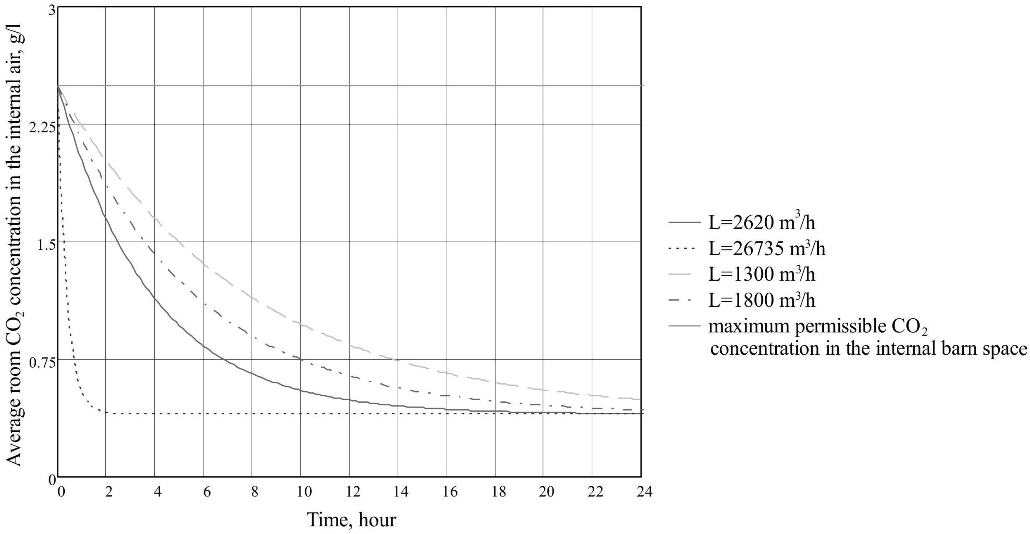

Fig. 4. The time change of the CO_2 concentration averaged as to the room space at different CO_2 intensity of air exchange during the animals' outdoor run, i.e. at a_{CO2}=0

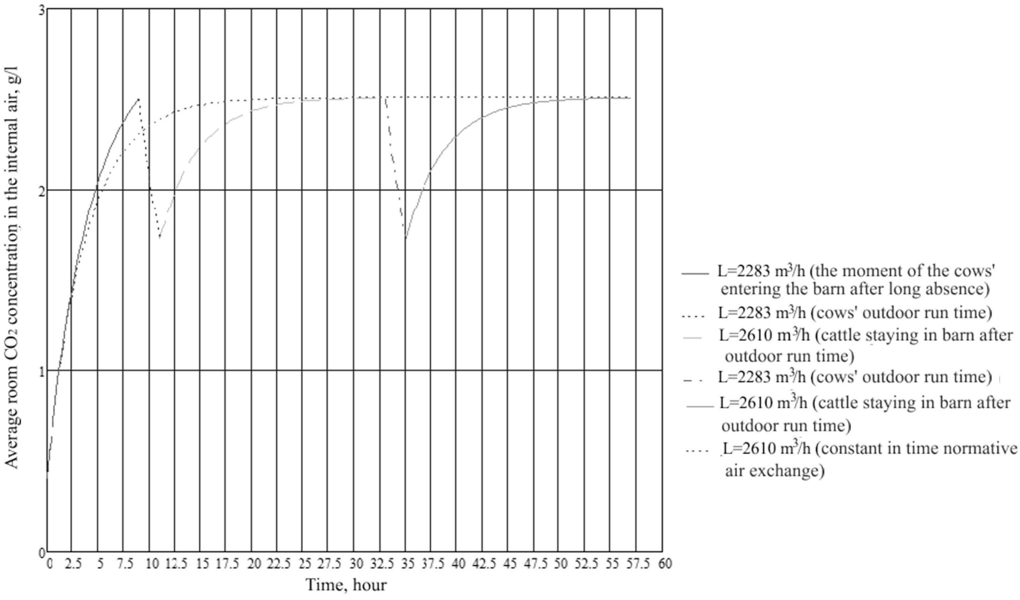

Fig. 5. The time change of the CO_2 concentration averaged as to the room space at the permanent and periodic general air exchange ventilation.

As it can be seen from the above said and from the results presented in Fig. 5, using periodic ventilation permits reducing the amount of air pumped by the air supply units within 48 hours (excluding the period from 0 to 11 a. m.) from 125,760 m^3/year to 123,972 m^3/year, which will reduce the electric power costs to drive the electric air pumps.

Conclusion. As it can be seen from the results presented in Fig. 2 – 5, the suggested mathematical model of air exchange in the premises for keeping cattle, at the stage of designing general air exchange ventilation systems, permits the following: to analyse the time change of the CO_2 concentration averaged as to the room space at different air exchange multiplicity in the room; to determine the air exchange intensity to reduce CO_2 based on obtaining the desired CO_2 concentration for a certain period of time; to analyse the energy efficiency of the periodic ventilation to reduce CO_2 in the premises for keeping cattle with time-variable air exchange intensity compared to the permanent ventilation system.

References

1. Armstrong D. V. “Heat stress interaction with shade and cooling.” *Journal of Dairy Science*, no.77 (7), 1994.
2. Egiazarov A. G., 1981. *Otoplenie I ventilyaciazdaniy I sooruzheniy selskohoziaistvennogocomplexa*/ A.G. Egiazarov. Stroyizdat, 1981.
3. Marucci A., Monarca D., Cecchini M., Colantoni A., Giacinto D. S., Cappuccini A. “The heat stress for workers employed in a dairy farm”*J. Agricultural Engineering*, no. XLIV, 2013.
4. Pedersen S., Takai H., Johnsen J. O., Metz J. H. M., Groot Koerkamp P. W. G., Uenk G. H., Phillips V. R., Holden M. R., Sneath R. W., Short J. L., White R. P., Hartung J., Seedorf J., Schroder M., Linkert K. H., Wathes C. M. “A comparison of three balance methods for calculating ventilation ratesin livestock buildings.” *J. Agric. Engng*, no. 70, 1998.
5. Robertson J. *Better Cattle Housing Design.* EBLEX, 2013.
6. Sharp G. M. *Ventilation of cattle and sheep buildings. Technical Note.* SAC, 2008.
7. Stroi A.F. *Teplosnabzhenie i ventilyaciasel’skohoziaistvennychzdaniy i sooruzheniy.* Energy, 1983.
8. Guzyk D. V. “Metod raschota teplopoter v construccii pola v svinovodcheskih pomescheniyah.” *Komunalnoye hoziaystvo gorodov*, no. 30, 2001.
9. Fediai B. M. “Povitroobmin v tvarynnickih primyschennyah z gumovym pidlogovym pokryttiam.” *Energetyka ta avtomatyka,* no. 4, 2014.

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Розрахунок повітрообміну для зниження концентрації CO_2 при періодичному провітрюванні приміщень утримання великої рогатої худоби

Б.М. Федяй[1], Д.В. Гузик[2]

[1]к.т.н, доцент, Полтавський національний технічний університет імені Юрія Кондратюка, м. Полтава, Україна, fed_bn@ukr.net

[2]к.т.н, доцент, Полтавський національний технічний університет імені Юрія Кондратюка, м. Полтава, Україна, guzikd@rambler.ru

Вигульне утримання тварин дозволяє змінювати інтенсивність повітрообміну для боротьби зі шкідливостями протягом доби. При цьому важливо за час вигулу худоби організувати такий повітрообмін, який забезпечить потрібну якість повітря, зокрема концентрацію CO_2 у внутрішньому об'ємі приміщення, на момент повернення великої рогатої худоби до стійла. В статті розглянуто питання аналітичного вирішення задачі щодо визначення зміни середньої в об'ємі приміщення концентрації CO_2 за визначений проміжок часу при наперед заданій інтенсивності повітрообміну.

Ключові слова: періодична вентиляція; внутрішнє повітря; концентрація CO_2; повітрообмін.

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Расчёт воздухообмена для снижения концентрации CO_2 при периодическом проветривании помещений содержания крупного рогатого скота

Б.Н. Федяй[1], Д.В. Гузик[2]
[1]к.т.н, доцент, Полтавский национальный технический университет имени Юрия Кондратюка, г. Полтава, Украина, fed_bn@ukr.net
[2]к.т.н, доцент, Полтавский национальный технический университет имени Юрия Кондратюка, г. Полтава, Украина, guzikd@rambler.ru

Выгульное содержание животных позволяет изменять интенсивность воздухообмена для борьбы с вредностями на протяжении суток. При этом важно за период выгула скота организовать такой воздухообмен, который обеспечит необходимое качество воздуха, в частности концентрацию CO_2 во внутреннем объёме помещения, на момент возвращения крупного рогатого скота в стойло. В статье рассмотрен вопрос аналитического решения задачи по определению изменения средней по объёму помещения концентрации CO_2 за определённый промежуток времени при заданной интенсивности воздухообмена.

Ключевые слова: периодическая вентиляция; внутренний воздух; концентрация CO_2; воздухообмен.

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