Bulgarian Journal of Agricultural Science, 25 (Suppl. 2) 2019
Agricultural Academy

Technical equipment of farms for comfortable cow keeping in winter conditions

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Abstract

Chernoivanov, V., Katkov, A., Gabitov, I., Yukhin, G., Martynov, V., Khasanov, E., Mudarisov, S., Baltikov, D., Khammatov, R., & Kovalev, P. (2019). Technical equipment of farms for comfortable cow keeping in winter conditions. *Bulgarian Journal of Agricultural Science, 25*(Suppl. 2), 45–53

The aim of the study is the reduction of energy consumption in the livestock house through the development and justification of microclimate and watering parameters, creating comfortable conditions for a cow in winter. The proposed air supply and recirculation unit saves energy by reducing the need for air exchange as a result of drying the air inside the building, as well as the released heat during the condensation of water vapors. For the theoretical description of the technological process of providing the microclimate parameters in the barn it is proposed to use the laws of thermodynamics taking into account the phase transformation of moisture. The circulation system of water supply to the auto-drinkers excluding liquid freezing, is proposed. The water supply system is provided with a device for information transmission about water consumption to a computer for remote data analysis and organizational decision-making. The method of determining the parameters of the microclimate in the barn is proposed. As a result of using the proposed system, energy savings during the heating season in the amount of 133 thousand kW per hour is achieved.

Keywords: cows watering; ventilation; microclimate; water vapor; dew point

Introduction

The productivity of cows with high-quality and regular feeding depends largely on the comfortable conditions of the animals. Illumination, heating, and ventilation become particularly energy-intensive in winter. Reduced day light means an increase in the illumination expenditures, besides the optimal microclimate maintenance in winter is associated with significant energy costs for heating the ventilated air. Also, significant energy consumption requires heating of tap water, which is necessary to supply cows with drinking water at the comfort temperature and to avoid freezing water. In an integrated approach, this problem can be solved via alternative energy sources, such as solar energy and bioenergy. Presently, there are approaches that make it possible to easily adapt a source of solar energy to the conditions of an agricultural enterprise or any other object that is remote from the urban infrastructure (Kovshov et al., 2018). There are also future-proof approaches to energy generation from animal waste. This practice is especially essential step in providing a microclimate in the barn (Kovshov & Skamyin, 2017a; 2017b; Kovshov et al., 2017).

In this regard, the issue of saving energy resources without worsening the conditions of comfortable keeping of cows is still open. The purpose of this research is to close it.

The concept of microclimate includes: temperature and humidity, speed of its movement, the content of harmful gases, dust, ionization, illumination and noise level.

Air temperature is the most important factor of the environment that affects the heat exchange of the body. The surrounding temperature at which the heat production is minimal, and the physiological functions of the organs and systems of the animal are not tense is called a zone of thermal indifference or temperature comfort. The lower and upper points of thermal indifference are called critical temperatures. At temperatures below the lower critical point metabolism and heat production in the animal increases, so cows with good fatness need to be fed about 1% more for each degree of temperature reduction, and cows with low fatness – 2% more. Moreover, the value of the lower critical temperature for cows with good fatness is minus 7°C, and with low fatness is minus 1°C. At a surrounding temperature above +15°C the heat output from the animal's body slows down. At the same time, animals consume less feed, their productivity and resistance to diseases also decreases (Mader et al., 2010).

The increased speed of air movement at high temperatures protects animals from overheating and at low temperatures is the cause of hypothermia. The air velocity inside the barn should not exceed 0.5 m/s in winter and 1.0 m/s in summer (Norms of technological design of cattle farms).

Limit concentrations of harmful gases in the barn are: for CO_2 – 0.25%, for NH_3 – 20 mg/м^3, for H_2S – 10 mg/м^3 (Hazanov et al., 2016).

Increased humidity in the room helps to reduce productivity. Cows' milk yield is reduced by 1% for each percentage of air humidity increase over 85%. In addition, humid air adversely affects the life of process equipment and building structures. However, excessively low relative humidity (below 40%) leads to increased sweating in animals, dry mucous membranes, decreased appetite, productivity and disease resistance (The microclimate of livestock buildings, 2015).

The main importance in the fight against excessive humidity is effective ventilation with air heating, as well as the maximum limitation of water vapor sources in the barn.

When calculating the ventilation and heating systems (Martynov & Gabidullin, 2016; Yukhin et al., 2016), an analytical dependence of the partial pressure of saturated water vapor in the air mixture on the temperature and total pressure, the dependence of the partial pressure of saturated water vapor on its temperature, as well as the dependence of the dew point temperature on the pressure of saturated water vapor is required. It is difficult to use standard tabular data when designing heat and mass transfer devices (Filnei, 1966).

Currently, analytical dependences of the form (Filnei, 1966; Guidelines for the design of heating and ventilation systems for pig farms and complexes, 2009) are used in the calculations:

$$p_s = a_1 \exp[a_2 t/(a_3 + t)], \qquad (1)$$

where *ps* is the partial pressure of saturated water vapor, Pa; a_1, a_2, a_3 – coefficients; t – temperature, °C, which reflect the nature of the curve and generally approximate experimental data well in the temperature ranges from -50 to 0°C and from 0 to +100°C, but the error at individual points is 100 or more Pa, and even reaches several thousand Pa. More accurate formulas (Filnei, 1966) have a complex form, contain up to seven regression coefficients, are inconvenient to use and it is impossible to express the temperature and determine the dew point temperature.

Water plays a key role in milk production, regulates body temperature and many other body functions in dairy cattle. While forage and rations, as a rule, are controlled consumption of water, its availability and quality is often overlooked. Cows consume about 4-4.5 l of water per kg of milk produced (Drinking behavior in dairy cows, 2009). Typically, cows drink 7-12 times a day and consume a total of 10 to 20 l of water at a time. In particular, cows prefer to drink after milking and during feeding (Drinking behavior in dairy cows, 2009). Water consumption largely depends on the ambient temperature, productivity and live weight of animals (Axegärd, 2017).

At loose maintenance it is recommended to use open group drinkers with heating. Recommended length of the watering edge for cows at the I-II stage of lactation is 10 cm/head; for cows at the III stage of lactation is 6 cm/head; for dry cows is 4 cm/head. Water pipe and drinker must ensure the water flow 12-18 l/min. The volume of the troughs should be at least 150 l of water. Troughs must be easy to clean from contamination. The maximum distance to the drinker is 20 m. The minimum distance between the drinker and the enclosing structures is 2.7 m. The maximum height from the floor level to the edge of the drinker is 800 mm. The water depth should be at least 70 mm, so that the animal can dip the muzzle into the water by 30-50 millimeters (Basics of modern milk production: Practical guide, 2014; Hazanov et al., 2016).

The loss of water from the body is due to milk production (about 34%), urinary excretion (17%), fecal excretion (31%), perspiration and loss of steam from the lungs (18%) (Adams & Sharpe, 1995).

Water for drinking cows must meet the requirements for drinking water (SanPiN, 2001) except for the total hardness up to 18 mg eq/l, chlorides up to 600 mg/l and sulfates up to 800 mg/l (Norms of technological design of cattle farms).

The water temperature for drinking cattle older than 20 days should not be below 8-12°C (Norms of technological design of cattle farms). However, animals are reluctant to use water with a temperature above 27°C (Looper & Waldner, 2002).

The purpose of this research is to reduce energy costs in livestock houses premises by developing and substantiating the parameters of microclimate and watering systems that create comfortable conditions for keeping cows in winter.

Material and Methods

Experimental studies were conducted on the dairy farm LLC "Plemzavod imeni Lenina", Dyurtyuli district, Republic of Bashkortostan.

Two barns with the size of 27×100 m are interlocked with each other by a wide gallery, in which the milking unit is located. Each barn is designed for 350 cattle. In one case animals are kept on a leash, the second barn is reconstructed under loose keeping of animals (Figure 1). The loose barn is divided into four technological groups. Each group of animals has access to three group auto drinkers. In total 12 group water dispensers are installed in the barn (Figure 2). Currently, there is a gradual filling in of the buildings of the animals.

It is planned to reconstruct the second barn with tethered animals. For this purpose, theoretically and experimentally sound technological and technical solutions will be used, as well as the experience gained in the operation of the first building.

Fig. 1. The reconstructed barn for loose keeping of animals

Fig. 2. Area drinkers and slickers in the technology group of the barn

Justification of rational parameters of the ventilation unit was carried out with the help of theoretical research methods. For this purpose, a method of calculating the ventilation system of the barn depending on the specified technological parameters was developed. It was necessary to establish the dependence of the experimental data (Filnei, 1966) of the saturated water vapor pressure on the temperature with the lowest possible error and to express the dew point temperature from this dependence.

The condition of the best approximation is to achieve the minimum sum of the squares of deviations of table (experimental) and calculated values under the following restrictions:

- deviation of table and calculated values of saturated water vapor pressure should not exceed 1.5-2 PA for the temperature range from -50 to +100°C;
- the relative error of the calculated pressure values for the specified temperature range shall not exceed 0.05%.

Justification of rational parameters of the cow watering system was carried out with the help of experimental research methods. To determine the intensity of water consumption in the water supply system metering device water mark VCM-25M is mounted (Figure 4 and Figure 5). The device is equipped with a special designed electronic unit that provides every second transmission of the readings to the computer during the day.

Results and Discussion

In the developed ventilation system of the barn, significant energy savings are achieved by reducing the need for air exchange as a result of drying the air inside the house, as

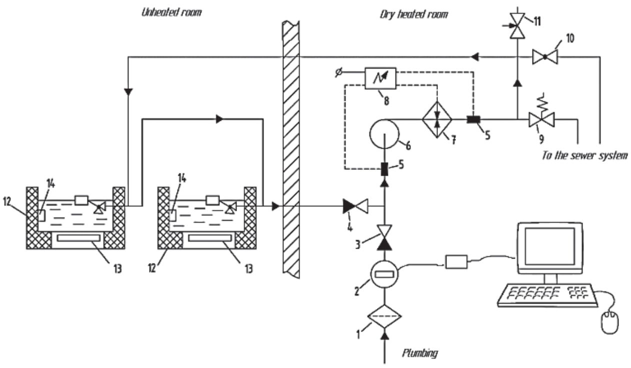

Fig. 4. Schematic diagram of the circulating heating installation of water in the auto drinkers

Fig. 5. Installation of the circulating heating water in drinking bowls

well as the released heat during the condensation of water vapors.

The proposed circulation system for watering cows with a flowing electric heater eliminates the freezing of water in winter conditions providing round-the-clock water supply to the auto drinkers.

The air supply and recirculation unit (Figure 3) is used to organize air exchange and ensure the moisture balance in houses with significant water vapor emissions, namely in livestock buildings and the milking parlor. The installation is located in the house 1 and contains an adjustable inlet louver grating 2, a receiving chamber 3 with adjustable louver grilles 4, a single-pass heat exchanger in the form of a tube grating 5 and 6, tube bundle 7, an outlet chamber 8 with adjustable louver grilles 9, one or more fans 10 installed in the exhaust chamber 8. Below the coil is a pan 11 provided with a system 12 for the condensate. If the air supply and recirculation unit is located in the lower part of the room, pallet 11 is combined with the floor. In the pipe grids 5 and 6, holes 13 and 14 are respectively made, and in the grid 5 of the receiving chamber 3 they are made with the possibility of regulating the passage section. Pipes and tube grids of the heat exchanger are made of polymer material.

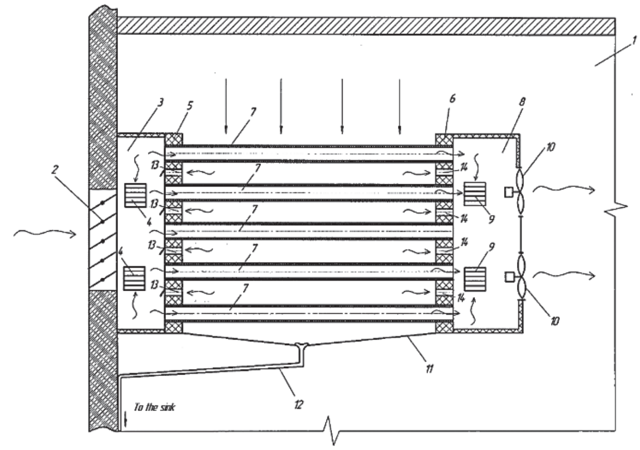

Fig. 3. Scheme of air supply and recirculation unit

The installation works as follows. At the work of the fans 10 due to the vacuum created by them through an adjustable louver grille 2, the outside air enters the receiving chamber 3 and moves through the pipes 7. In cold periods, the pipes 7 inside the house 1 are washed with recycled warm and moist air outside as a result of natural convection and air suction through the holes 13 and 14 that leads to its cooling below the dew point and condensation on the surface of the pipes 7. In this case, the latent heat of vaporization is released. This heat is perceived by flows of air moving inside and outside the pipes 7 that helps to preserve the thermal balance of the house 1. The heated supply air comes from the bundle of pipes 7 to the exhaust chamber 8, where it is mixed through the holes 14 and adjustable louvered grates 9 by the recirculated air of the house due to the vacuum available in this chamber. As a result, the temperature of the air injected into the house 1 by fans 10 is close to the temperature of the air in the room. The placement of several fans 10 in the exhaust chamber 8 contributes to a more uniform vacuum pressure throughout its volume. The condensate formed on the surface of the tube bundle 7 is collected in the pallet 11 and discharged through the system 12 into the sewer.

At an outside temperature below minus 10-15°C to avoid icing of the surface of the pipes 7 and reduce air exchange, the Louvre grilles 4 are slightly opened. This leads to a decrease in the supply of fresh air and mixing it with warm air from room 1. With a stronger cooling, it is possible to further reduce the supply of supply air by covering the Louvre grate 2.

At an outside temperature above -5°C, adjustable openings 13 and louvered grilles 4 and 9 are covered that leads to an increase in air exchange and due to a decrease in the temperature of the air passing through the tube bundle 7, contributes to the loss of condensate on the outer surface of these pipes and the drying of air inside the house 1.

In the warm period, adjustable openings 13 and louver grilles 4 and 9 are completely closed. The device operates with maximum supply of supply air without internal air recirculation and drying.

Thus, the supply and recirculation unit ensures efficient operation due to the fact that it carries out air drying with the release of heat of phase transformation, controlled forced inflow of supply and recirculated air and their mixing in different proportions depending on the time of year with adjustable air exchange from the minimum in the cold period to the maximum in the warm period, thereby eliminating the icing of the heat exchanger tube bundle and the blowing of air into the house by cold jets.

Ensuring the inflow and recirculation of air with just one or more parallel fans simplicity and compactness of the installation is achieved, as well as its reliability. The production of pipes 7 and pipe grids 5 and 6 of the heat exchanger made of polymer material ensures their durability and increase of the reliability of the device.

This supply and recirculation unit in most cases allows reducing the required air exchange V_w (m³/h) to remove excess moisture to the level of air exchange V_{CO_2} designed to remove carbon dioxide:

$$V_w = (G - G_d)/[(d_2 - d_1)p] = V_{CO_2} = P(P_2 - P_1), \quad (2)$$

where G is the total moisture in the room, kg/h; G_d is the performance of the air dryer, kg/h; d_2 is moisture content of the room air, kg/kg of dry air; d_1 is moisture content of the outside air, kg/kg of dry air; P is air density at room temperature, kg/m³; P is the amount of carbon dioxide emitted in the room, l/h; P_2 is the maximum permissible content of CO_2 according to standards, $P_2 = 2.5$ l/m³; P_1 is CO_2 content in fresh air, $P_1 = 0.3$ l / m³.

The condensate falling out during the operation of the supply and recirculation unit in the amount allows not only to reduce the required air exchange and thereby reduce the heat losses associated with the ventilation of the house, but also to ensure the allocation of additional heat flow:

$$Q_d = r.G_d, \quad (3)$$

where r is the latent heat of vaporization (condensation) of water, J/kg.

The calculations should take this amount G_d which will ensure the heat balance of the house without the use of heating devices taking into account heat gain from animals and heat loss from ventilation over the fence and on the evaporation of moisture from exposed wetted surfaces. All components of the heat balance are calculated according to the generally accepted method (Recommendations for the calculation, design and application of electric heating systems of livestock farms and complexes, 1983; Guidelines for the calculation and design of microclimate systems in the construction of new and reconstruction of existing livestock buildings, 1988; Recommendations for the calculation and design of systems to ensure the microclimate of livestock buildings with the utilization of the heat of the exhaust air, 2004).

For theoretical studies of the ventilation system it was required to establish the dependence of the experimental data (Filnei, 1966) of the saturated water vapor pressure on its temperature. To do this the analytical dependence of the form is applied:

$$p_s = a_1 \exp[a_2 t/(a_3 + t + a_4 t^2)], \quad (4)$$

which differs from (1) entry additive $a_4 t^2$.

The solution to the optimization problem is done using the add-in “Finding solutions” in MS Excel and a specially developed algorithm in the Excel macro that implements the method of cyclic alternating-variable descent method. Taking into account the low convergence of the obtained objective function with the noted constraints, these methods were applied sequentially and alternated with each other.

In general the pressure of saturated water vapors in a multicomponent system (in atmospheric air) can be calculated by the formula (Filnei, 1966):

$$p_{sa} = p_s.k, \quad (5)$$

where k is a correction parameter depending on the composition of the dry part of the vapor-gas mixture, its total pressure, temperature and the aggregate state of water.

Usually in the calculation of the parameter k is neglected. The relative error in determining the pressure of saturated water vapor mixed with air and, consequently, the partial pressure of water vapor in the air due to the neglect of the coefficient k is systematic and reaches 0.79% (in the temperature range from minus 40 to plus 90°C and pressure 0.5-1.1 MPa). For example, at an atmospheric pressure of 0.1 MPa and a temperature of +20°C, the saturated water vapor pressure in a single component system is 2337.08 Pa, and in air is 2347.48 Pa (relative error is 0.445%). To eliminate this error, using tabular data (Filnei, 1966) for the temperature range from minus 40 to plus 90°C and pressure from 0.09 to 0.11 MPa and for the case of equilibrium of water vapor over water, the following regression dependence was obtained:

$$k = 1.00042827 + 0.0000000392857.P_a - 0.000002138.t + $$
$$+ 0.000000599.t^2 - 0.0000000020345.t^3, \quad (6)$$

where P_a is atmospheric pressure, Pa.

Table 1.Values of regression coefficients

Temperature *t*, ºC	Partial pressure of saturated water vapor			
	In a single-component system		In the air	
	Over ice	Over water	Over ice	Over water
Negative, from *–50* to 0	$a_1 = 610.64$ $a_2 = 22.42689$ $a_3 = 272.247$ $a_4 = 0$	$a_1 = 610.64$ $a_2 = 17.82$ $a_3 = 245.1427$ $a_4 = 0$	$a_1 = 613.08$ $a_2 = 22.194$ $a_3 = 269.664$ $a_4 = 0.00015$	$a_1 = 613.36$ $a_2 = 17.8518$ $a_3 = 245.57$ $a_4 = 0$
Positive, from 0 to +100		$a_1 = 610.64$ $a_2 = 17.46458$ $a_3 = 240.0989$ $a_4 = 0.0001569$		$a_1 = 613.08$ $a_2 = 17.49$ $a_3 = 240.392$ $a_4 = 0.00015$
$z = sign\ (t)$	$z = sign\ (p - 610.7)$		$z = sign\ (p - 613.36)$	

As a result of solving the optimization problem, the coefficients a_1, a_2, a_3, a_4 are determined, the numerical values of which are presented in Table 1.

If calculations are required for the entire temperature range from -50 to +100°C, the formulas obtained for positive and negative temperatures can be combined using the sign *z* (Table 1). In this case, the partial pressure of saturated water vapor in a single-component system in thermodynamic equilibrium with the liquid and solid phase of water for the considered temperature range is calculated by the formula:

$$p_s = 610.64\exp\left[\frac{(19.945735 - 2.481155z)t}{256.17295 - 16.07405z + t + 0.00007845(1+z)t^2}\right], \quad (7)$$

i.e. $a_1 = 610.64$; $a_2 = 19.945735 - 2.481155z$; $a_3 = 256.17295 + 16.07405z$; $a_4 = 0.00007845(1 + z)$.

When a single-component system is in thermodynamic equilibrium with the liquid phase of water, the partial pressure of saturated water vapor for the considered temperature range is defined as:

$$p_s = 610.64\exp\left[\frac{(17.64229 - 0.17771z)t}{242.6208 - 2.519z + t + 0.00007845(1+z)t^2}\right], \quad (8)$$

i.e. $a_1 = 610.64$; $a_2 = 17.64229 - 0.17771z$; $a_3 = 242.6208 - 2.5219z$; $a_4 = 0.00007845(1 + z)$.

When using formulas (7) and (8), the absolute error does not exceed 1.65 Pa, and the relative error does not exceed 0.05%.

The pressure of saturated water vapor in the air above the ice surface (for negative temperatures) and pure water (for positive temperatures) is calculated by the formula:

$$p_s = 613.08\exp\left[\frac{(19.842 - 2.352z)t}{255.028 - 14.636z + t + 0.00015(1+z)t^2}\right], \quad (9)$$

i.e. $a_1 = 613.08$; $a_2 = 19.842 - 2.352z$; $a_3 = 255.028 - 14.636z$; $a_4 = 0.00015$.

The absolute error of the formula (79) does not exceed 1.45 Pa, and the relative error is less than 0.046%.

The partial pressure of saturated water vapor p_{sa} calculated by the formula (4) taking into account the obtained coefficients a_i ($i = 1, \ldots, 4$) allows to calculate the moisture content of air in kg/kg of dry air by the formula (Guidelines for the design of heating and ventilation systems for pig farms and complexes, 2009):

$$d = 0.622\varphi.p_{sa}/(P_a - \varphi.p_{sa}), \quad (10)$$

where φ is the relative humidity in fractions.

The enthalpy of moist air in kJ / kg sv can be determined by the formula (Guidelines for the design of heating and ventilation systems for pig farms and complexes, 2009):

$$i = 1.005t + (2501 + 1.8t)d. \quad (11)$$

The convenience of formulas (7) – (9) is that at a known saturation pressure:

$$p_{s1} = \frac{d.P_a}{0.622 + d}, \quad (12)$$

of these you can express the temperature which is the dew point t_p. This requires solving the equation:

$$a_4 t_p^2 + [1 - a_2/\ln(p_{H1}/a_1)]t_p + a_3 = 0, \quad (13)$$

for $a_4 > 0$ the solution to this equation is:

$$t_p = \left(b - \text{sign}(b)\sqrt{b^2 - 4a_3a_4}\right)/(2a_4), \quad (14)$$

where $b = a_2/\ln(p_{H1}/a_1) - 1$

as in the case when $a_4 = 0$

$$t_p = a_3/b. \quad (15)$$

For a single-component system in thermodynamic equilibrium with liquid and solid phases, the absolute error of the dew point temperature is in average 0.0023°C and does not exceed 0.007°C, and the relative error is less than 0.06% (except for the range from -5 to +5°C).

For a single-component system in thermodynamic equilibrium with the liquid phase in the considered temperature range, the absolute error of the dew point is on average 0.00255°C and does not exceed 0.0072°C, and the relative error is also less than 0.06%.

For humid air in thermodynamic equilibrium with liquid and solid phases, the absolute error of the dew point temperature is on average 0.0020°C and does not exceed 0.006°C, and the relative error is less than 0.033% (except for the range from -5 to +5°C).

For humid air in thermodynamic equilibrium with the liquid phase for the specified temperature range, the average absolute error of the dew point temperature is 0.0022°C and does not exceed 0.006°C, and the relative error is less than 0.032%.

The barn is equipped with a circulation watering system with a direct flow electric water heater (Figure 4 and Figure 5).

The device includes a filter 1, a direct flow water meter 2, back-pressure valves 3 and 4 for directional water movement. The temperature sensors 5, the circulation pump 6, the direct flow water heater 7 and the control box 8 provide the water supply of the required temperature. The overpressure relief valve 9, the ball valve 10 and the air removal valve 11 protect the watering system from overpressure and the formation of air plugs. The automatic drinkers 12 are located in an unheated room and are equipped with autonomous electric heaters 13 and temperature sensors 14.

The device for circulating of the heated water in the water dispenser works as follows.

The cold water coming from the water pipe passes through the filter 1, the water flow meter 2 and is fed to the circulation pump 6 which directs the heated water to the auto drinkers 12. The water flow meter 2 has an electronic data transmission unit to a computer with an interval of one second.

At night with low water consumption from the drinkers 12, the direct flow water heater 7 and the electric heaters 13 are periodically switched on and with the help of temperature sensors 5 and 14, the water temperature is reduced and the minimum energy consumption at this time. The circulation pump 6 excludes freezing of water in the water supply system located in the unheated room. The overpressure relief valve 9, the ball valve 10 and the air removal valve 11 protect the device for watering cows with heated water from overpressure and the formation of air jams.

During the day, the temperature sensors 5 and 14 increase the temperature of the water in the auto drinkers 12 for watering cows with water at the optimum temperature.

There were 160 cows during the experiments in the building. Water consumption per day was 14 m^3, i.e. 87.5 l per one animal (Figure 6). The most intensive consumption of water occurred during milking and distribution of feed (Figure 7) in the time intervals of 6-9, 14-15^{30} and 18-21 hours. Increasing the intensity of water consumption after milking and feeding is associated with the physiology of cows. Reduction of water consumption below the average for the body may be connected to the quantity and quality of feed and water quality. In this case it is necessary to identify the causes and eliminate them. The minimum intensity of water consumption in the building was 1 liter per min, and the maximum was 32 l/min.

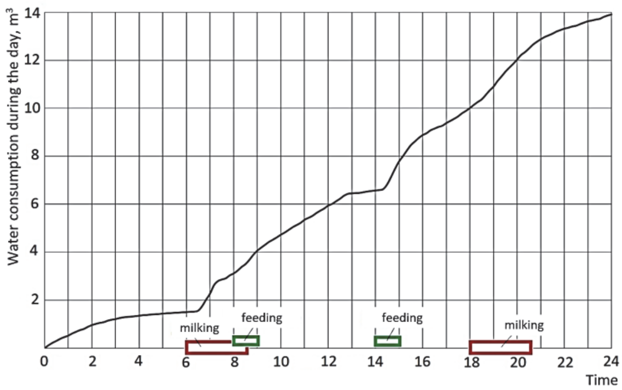

Fig. 6. Water consumption in the barn during the day

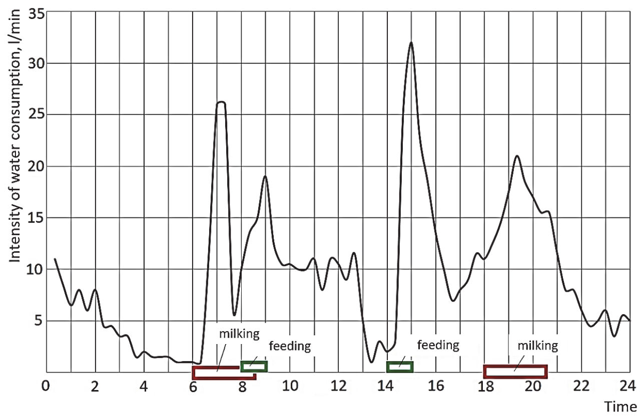

Fig. 7. Intensity of water consumption in the barn

Calculations carried out in accordance with the recommended methods (Recommendations for the calculation, design and application of electric heating systems of livestock farms and complexes, 1983; Guidelines for the calculation and design of microclimate systems in the construction of new and reconstruction of existing livestock buildings, 1988; Recommendations for the calculation and design of systems to ensure the microclimate of livestock buildings with the utilization of the heat of the exhaust air, 2004), as well as taking into account the above formulas, allowed determining the energy savings from the use of the supply and recirculation unit in one house for 350 cows during the heating season. It is established that to ensure the thermal balance in this room using a traditional ventilation system with heaters, the required power of the heating system is 160 kW, at an external temperature of minus 25°C and 60 kW at an external temperature of minus 15°C. Due to the fact that the air supply and recirculation unit is able to maintain the heat balance in the barn without additional heating costs, the annual energy savings taking into account the variability of average daily temperatures in the heating period for the conditions of Ufa city surroundings (Martynov et al., 2017) is more than 133 thousand kWh per year.

Studies of Axegärd (2017) found that water consumption during the day depends on the breed of animals, their productivity, social rank of animals, and lactation period. The data obtained in these studies allow us to judge a significant daily unevenness in water consumption, which corresponds to the results of our experiment (Figure 7). Study of Le Riche et al. (2017) revealed the interrelation of water consumption in the group with the performed technological operations (milking, movement of animals, etc.), which is consistent with the results obtained (Figure 6 and Figure 7), when intensive water consumption occurred during milking and distribution of feed in the time intervals of 6-9, 14-15^{30} and 18-21 hours. Increasing the intensity of water consumption after milking and feeding is associated with physiological processes occurring in the body of cows.

Conclusions

The proposed method of calculating the pressure of saturated water vapors using the formulas (5)-(8) allows us to calculate the ventilation and heating system of the barn with a minimum error and to justify the design parameters of the supply and recirculation unit. The air supply and recirculation unit is able to maintain the heat balance in the barn without additional heating costs. Annual energy savings, compared to the traditional forced heating and ventilation system of the barn, taking into account the variability of average daily temperatures in the heating period for the conditions of the Ufa city surroundings is more than 133 thousand kWh per year.

The circulation system of cows' watering with a flowing electric heater eliminates freezing of water in winter conditions, providing round-the-clock water supply to the auto drinkers. Installed remote metering devices of the consumed water amount of water allow estimating the consumption of water in the barn during the day, which is necessary for timely management decisions and also allows including a device for heating water in the circulation system by using the heat of cooled milk. The obtained analytical dependences to determine the partial pressure of saturated water vapor and the dew point temperature have a simple form and provide high accuracy of calculation, which allows them to be used in the calculation and optimization of heat and mass transfer processes and equipment.

The design of the supply and recirculation unit made it possible to provide optimal air parameters in the livestock premises in the winter and transition periods of the year and reduce the cost of ventilation and heating. The water circulation system eliminates freezing of water supply in winter and allows remote monitoring of water consumption ensuring the adoption of the correct management decisions.

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