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Mathematical Modelling and Energy Accounting of Heaters for Growing Stock

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Abstract

The article analyzes and summarizes research on the theory of local heating of young stock. The main provisions of the analytical assessment of the temperature felt by animals during their artificial heating are considered. The modes of heat transfer for a standing and lying animal under external heat exposure are considered. The heat balance calculation scheme is presented using the example of a piglet. One of the main indicators of the thermal state of animals is sufficiently strictly defined — the temperature of its surface. This indicator is crucial in the development of methods for choosing the energy parameters of local heating means. The change of external exposure to infrared radiation can influence the thermal state of the animal.

Keywords

Local Heating, Sensible Temperature, Animal Heat Transfer, Thermal State, IR Irradiators.

Introduction

One of the ways to increase the livestock production and simultaneous significant energy saving is, in the general case, the introduction of means of local electrical heating into the energy system of young livestock buildings [1]. This is due to the fact that there are still numerous farms where, despite good feeding, high pedigree qualities of animals and birds, a significant number of young animals die from the unsatisfactory state of the microclimate (and especially the ambient temperature). As a result of death, culling and the underutilization of the genetic potential of young animals, the potential productivity of animals is underutilized.

To date, in-depth studies have been carried out related to the development, comparative evaluation of the effectiveness and implementation of various means of local heating [2-4]. As a result, various calculation methods [5, 6] and equipment for local heating of young animals were proposed, such as infrared electric and gas irradiation plants, heated floors, panels, stoves, rugs, mats, as well as combined heating devices [7–9].

However, these developments do not fully cover the range of livestock needs. Known methods for calculating and selecting energy and structural parameters, as well as substantiating the operating modes of local heating means, are based on various scientific principles, have unequal reliability and accuracy.

The most accurate methods for calculating the heat transfer of a living organism indoors have been developed using a human example [10]. As applied to animals, this approach is rather laborious [11]. A number of researchers have proposed options for calculating the heat transfer of an organism as applied to young animals of some individual species of animals and birds [12-14].

In the 2000s, an automated technology was proposed for centralized local and general heating in poultry farming with control of the heat absorbed by birds [15].

A scientific work [16] considers in general the processes of energy exchange of young livestock during the operation of a set of electrified systems of the local microclimate.

Physical modeling and efficiency assessment showed good results for the combined heating method [17].

At the same time, a generalized methodology for calculating the heat transfer of young animals, which would optimize the means of local heating in full, has not been created.

An analytical calculation of the temperature of the animal's surface is crucial in developing a methodology for choosing the energy parameters of local heating means.

The justification of the laws and features of heat transfer of young livestock with the environment under external artificial heat exposure based on a generalization of the results of known and own research is an urgent task.

Analytical Assessment of the Room Temperature Outside the Locally Heated Zones

In mathematical modeling of heat transfer between the design animal and the environment, it is rational to use a complex parameter — the room temperature t_p — instead of the air temperature t_a and the radiation temperature

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of the internal surfaces of the building envelope τ_R. This allows us to simplify mathematical calculations without compromising the accuracy of calculations [18].

t_p for both animals and humans is usually determined by the equation,

$t_p = At_a + B\tau_R$, (1)

where A and B are the thermal coefficients characterizing the degree of thermal effect of the fences and the ambient air on the animal.

A and B can be obtained from the thermal characteristics of the animal

$A = \alpha_c / (\alpha_r + \alpha_c)$; (2)

$B = \alpha_r / (\alpha_r + \alpha_c)$. (3)

where α_c и α_r are convective and radiant heat transfer coefficients, respectively.

For the purpose of using equations in the mathematical models of design animals, we determine t_p, which characterizes the livestock building with the known t_a and τ_R. For this, we consider the thermal balance of the design animal in two cases.

1. *The animal stands in an idealized climatic chamber* with thermal conditions $t_a^c = \tau_R^c = t_p = t_{s.p}$.

The system of equations describing the heat balance of the body is as follows

$Q_s^c = Q_r^c + Q_c^c$;

$Q_r^c = \alpha_r^c(\tau_{sur}^c - t_p)\varphi_R F_\Sigma$;

$Q_c^c = \alpha_c^c(\tau_{sur}^c - t_p)F_\Sigma$, (4)

where for idealized conditions (climatic chamber) Q_s^c, Q_r^c and Q_c^c are the heat losses of the design animal: total (explicit), radiant, and convective, W; α_r^c and α_c^c - heat transfer coefficients by radiation and convection, W/m^2°C; τ_{sur}^c — heat exchange surface temperature of the design animal, °C; φ_R is the irradiation coefficient from the surface of the animal's body to the building envelope; F_Σ is the heat exchange surface area of the animal, m^2.

2. *The animal stands in a particular room* with t_a and τ_R , while $t_a \neq \tau_R$.

The system of equations describing the heat balance of its body is as follows

$Q_s^p = Q_r^p + Q_c^p$;

$Q_r^p = \alpha_r^p(\tau_{sur}^p - \tau_R)\varphi_R F_\Sigma$;

$Q_c^p = \alpha_c^p(\tau_{sur}^p - t_a)F_\Sigma$, (5)

where Q_s^p, Q_r^p, Q_c^p, α_r^p, α_c^p, τ_{sur}^p are the same dependencies as in the first case, but for the conditions of the real room.

Let us suppose that the thermal state of the animal in both cases is equally valuable and is characterized by the same value $t_{s.p}$ (i.e., $Q_s^c = Q_s^p$; $\tau_{sur}^c = \tau_{sur}^p = \tau_{sur}$) and, therefore, the temperature in the room is equivalent to the temperature in the climate chamber. Then, solving together systems of equations (5) and (6) with respect to t_p, we obtain

$t_p = \alpha_c^p t_a/(\alpha_r^c + \alpha_c^c) + \alpha_r^p \tau_R/(\alpha_r^c + \alpha_c^c) + [1 - (\alpha_r^p + \alpha_c^p)/(\alpha_r^c + \alpha_c^c)]\tau_{sur}$. (6)

In expression (7), considering the reciprocity of radiant fluxes and the specifics of radiant heat transfer in livestock buildings, according to [18], the assumption is $\varphi_R = 1$.

In engineering calculations of heat transfer in livestock buildings [18], especially for a limited range of t_p changes, the following assumptions are often made

$\alpha_c^c = \alpha_c^p = \alpha_c$; (7)

$\alpha_r^c = \alpha_r^p = \alpha_r$; (8)

Given this, we can represent (7) in a simplified form

$t_p = \alpha_c t_a / (\alpha_r + \alpha_c) + \alpha_r \tau_R / (\alpha_r + \alpha_c)$. (9)

Thus, based on a system of equations describing the heat balance of the animal's body, an expression is obtained for determining the room temperature.

2. Analytical assessment of the sensible temperature in locally heated zones

2.1 Calculation for a standing animal.

A common calculation method for infrared heating based on the so-called "temperature balance" [19] involves the use of equations of the type (1), presented as follows

$t_{s.p} = At_a + B\tau_R + CE$, (10)

where C is the thermal coefficient of radiant heating, °Cm^2/W; E - thermal flux from an IR emitter, W/m^2.

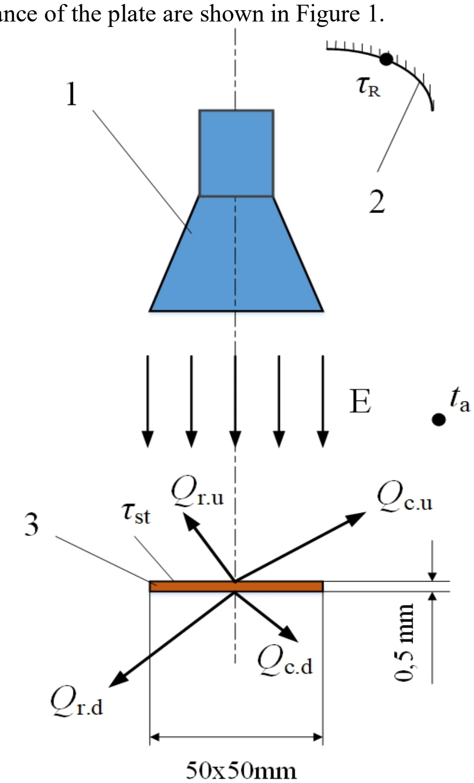
In this case, the following relation is usually used, given [19]

$C = kk_1$, (11)

where $k \approx 1$ is the coefficient of "perception" of infrared radiation by the animal's body; k_1 is the calibration coefficient connecting E with the temperature obtained on the surface of the heated object due to the action of infrared radiation.

k_1 = 0.04 m^2°C/W was obtained experimentally by measuring the heating of a metal plate (thermocouple [19]). However, as calculations show, k_1 is not a constant. The value depends on many parameters (t_a,τ_R, initial temperature and physical properties of the heated object, etc.). Therefore, *C* requires clarification. For this purpose, the analytical definition of k_1 as a function of several variables is of interest.

In [19], to measure *E*, a flat thermocouple was used, which is a copper-constant thermocouple with a diameter of 0.5 mm soldered from below onto blackened copper foil. When measuring *E*, the thermoelement was located in air under an infrared lamp at a level corresponding to the position of the irradiated surface of the animal's body. The components of the heat balance of the plate are shown in Figure 1.



1- Infrared Source; 2- The inner surface of the building envelope (fragment); 3- Heated Plate

Figure 1: Calculation Scheme of the Heat Balance of the Heated Object

We assume that a thermocouple in the form of a flat metal plate with an area of F = 0.025 m^2 and a negligible thickness has a temperature τ_{st}, °C in the steady state same throughout its volume. The heat transfer from the ends of the plate is neglected. The plate is irradiated from one (upper) side, and heat is removed to the environment from two sides (that is, the heat transfer surface is twice as large as the heat transfer surface). The equation of heat balance of the plate equation is as follows

$aEF=Q_{r.u}+Q_{c.u}+Q_{r.d}+Q_{c.d}$, (12)

where a=1 is the coefficient of perception of infrared radiation by a blackened plate; $Q_{r.u}$, $Q_{c.u}$, $Q_{r.d}$, $Q_{c.d}$ are the radiant and convective heat transfer from the upper and lower surfaces of the considered plate, respectively, W.

$Q_{r.d}=Q_{r.u}=\varepsilon_{pl}C_o[0,81+0,005(\tau_{st}+\tau_R)]\times(\tau_{st}-\tau_R)F$;

$Q_{c.u}=2,17(\tau_{st}-t_a+60V_a^2/l_{pl})^{1/3}(\tau_{st}-t_a)F$;

$Q_{c.d}=1,16(\tau_{st}-t_a+60V_a^2/l_{pl})^{1/3}(\tau_{st}-t_a)F$; (13)

where $\varepsilon_{pl} \approx 1$ is the reduced emissivity of the surface of the irradiated body and the internal surfaces of the building envelope in the room; l_{pl}= 0.05 m is the characteristic size of the plate surface.

Let us define as follows

$\Delta\tau_1=ak_1E$,

(14)

where $\Delta\tau_1$ is the increment of the plate temperature under the action of infrared radiation, °C.

To simplify the calculations in accordance with the foregoing, we take as follows

$\tau_R = t_a$. (15)
Then
$\tau_{st} - \tau_R = \tau_{st} - t_a = \Delta\tau_1$. (16)
Solving together (13) ... (15) given (16), we obtain the following expression
$k_1 = [2\varepsilon_{pl} C_o (0{,}81+0{,}005\Delta\tau_1)+3{,}33(\Delta\tau_1+60V_a^2/l_{pl})^{1/3}]^{-1}$. (17)
Figure 2 shows the relationship $k_1 = f(\Delta\tau_1;\ V_a)$, obtained as a result of calculations according to (17).

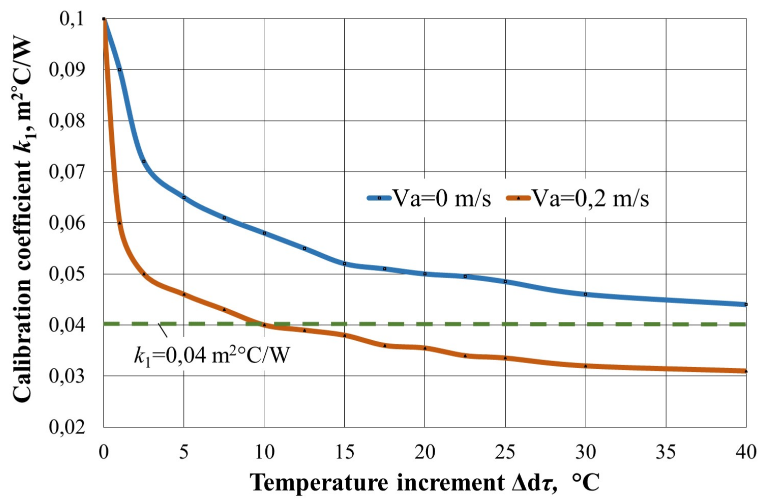


Figure 2: Relationship of the Calibration Coefficient k_1 to the Temperature Increment of the Heated Object Δτ:

For the realistically possible values of $\Delta\tau_1$ and $V_в$ in the young livestock and poultry settings, the region between the curves corresponding to V_a=0 and V_a=0.2 m/s was obtained. The straight line corresponding to k_1 = 0.04 m²°C/W is also given here (averaged experimental data [19]).
As can be seen from Figure 2, the approximation of the experimental data k_1 of the straight line k_1=0.04 m²°C/W agrees quite well with the calculated data at V_a=0.2 m/s and 15°C>$\Delta\tau_1$>8°C. At lower values of V_a and $\Delta\tau_1$, the use of k_1=0.04 m²°C/W in the calculations can lead to errors.
More strictly, the values of the components of equation (11) can be determined from the first comfort condition [18].
For this, by analogy with the system of equations (5), we compare the heat balance of the design animal for two cases.
a). The animal stands in a climatic chamber $t_a^c = \tau_R^c = t_p = t_{s.p}$.
The system of equations describing the heat balance of the design animal's body is as follows:
$Q_s^c = Q_r^c + Q_c^c$;
$Q_r^c = \alpha_r^c(\tau_{sur}^c - t_p)(F_{sh}+F_{cr})\varphi_R$;
$Q_c^c = \alpha_c^c(\tau_{sur}^c - t_p)(F_{sh}+F_{cr})$. (18)
where, according to [18], $F_\Sigma = F_{sh}+F_{cr}$; F_{sh} is the surface area of the lower non-irradiated part of the animal, m² and F_{cr} is the surface area of the upper irradiated part of the animal, m².
b). *The animal stands in a room* with t_a and τ_R , while $t_a \neq \tau_R$.
Local heating is carried out from above by an infrared irradiator pviding energy exposure E. From the infrared irradiator, the animal perceives an additional amount of heat ΔQ_{RAD}. For this case, the system of equations describing the heat balance of the body of the design animal will be as follows
$Q_s^p = Q_r^p + Q_c^p + Q_{r.sh}^p + Q_{c.sh}^p - \Delta Q_{RAD}$;
$Q_r^p = \alpha_r^p(\tau_{sur}^p - \tau_R)F_{cr}\varphi_R$;
$Q_c^p = \alpha_c^p(\tau_{sur}^p - t_a)F_{cr}$;
$Q_{r.sh}^p = \alpha_{r.sh}^p(\tau_{sur.sh}^p - \tau_R)F_{sh}\varphi_R$;
$Q_{c.sh}^p = \alpha_{c.sh}^p(\tau_{sur.sh}^п - t_a)F_{sh}$;
$\Delta Q_{RAD} = F_{ps} a_{sur} E$, (19)

where for the conditions of the considered room, Q_s^p is the apparent (total) heat emission of the design animal, W; Q_r^p and Q_c^p are radiant and convective heat transfer from the irradiated surface F_{cr}, W; $Q_{r.sh}^p$ and $Q_{c.sh}^p$ are the same with the non-irradiated surface F_{sh}, W; α_r^p and α_c^p are the coefficients of radiant and convective heat transfer from the irradiated surface F_{cr}, W/m^2°C; $\alpha_{r.sh}^p$ and $Q_{c.sh}^p$ are the same from the non-irradiated surface F_{sh}, W/m^2°C; τ_{sur}^p is the temperature in the steady state of the surface of the design animal for F_{cr}, °C; $\tau_{sur.sh}^p$ is the same for F_{sh}, °C; F_{ps} is the surface area of the animal, the sensible heat flux from the IR emitter; a_{sur} - infrared absorption coefficient of the surface of the animal.

If the means of local heating (in this case, an infrared irradiator) provide the design animal in the considered room with the same thermal conditions as in the climate chamber (with the same $t_{s.p}$), then

$$Q_s^c=Q_s^p \text{ .} \tag{20}$$

Solving together (18) ... (20) with respect to $t_p=t_{s.p}$, at $\varphi_R = 1$ we obtain

$$t_{s.p}=(\alpha_c^pF_{cr}+\alpha_{c.sh}^pF_{sh})t_a/(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})+(\alpha_r^pF_{cr}+\alpha_{r.sh}^pF_{sh})\tau_R/(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})+ a_{sur}F_{ps}E/(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})+[\tau_{sur}^c-(\alpha_r^p+\alpha_c^p)F_{cr}\tau_{sur}^p/(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh}) - -(\alpha_{r.sh}^p+\alpha_{c.sh}^p)F_{sh}\tau_{sur.sh}^p/(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})]. \tag{21}$$

If we suppose by analogy with (7) and (8) that

$$\alpha_r^p=\alpha_{r.sh}^p=\alpha_r^c=\alpha_r \text{ ;} \tag{22}$$

$$\alpha_c^p=\alpha_{c.sh}^p=\alpha_c^c=\alpha_c \text{ ,} \tag{23}$$

and the infrared irradiator heats the animal's body uniformly from all sides (an idealized case, possible, for example, with a certain combination of several irradiators, when $F_\Sigma=F_{cr}+F_{sh}=F_{ps}$) and, therefore,

$$\tau_{sur.sh}^p=\tau_{sur}^p=\tau_{sur}^c, \tag{24}$$

then (21) takes a simplified form similar to (10):

$$t_{s.p}=\alpha_ct_a/(\alpha_r+\alpha_c)+\alpha_r\tau_R/(\alpha_r+\alpha_c)+a_{sur}E/(\alpha_r+\alpha_c). \tag{25}$$

Let us note that in this case, the values A and B, according to (1) and (10), correspond to (2) and (3), and

$$C=a_{sur}(\alpha_r+\alpha_c)^{-1}. \tag{26}$$

For calculations up to (10), it is convenient to define

$$1/(\alpha_r+\alpha_c)=\xi \tag{27}$$

and represent (26) as follows

$$C=\xi a_{sur}. \tag{28}$$

In the general case, ξ is a function of many variables and is different for each animal species. However, in evaluative engineering calculations, one can approximately determine ξ as a constant value from the thermal characteristic of the design animal $Q_s=f(t_{s.p})$. To do this, we first approximate the thermal characteristic of the design animal with sloping straight lines that correspond to its apparent (total) convective and radiant heat transfer (Figure 3).

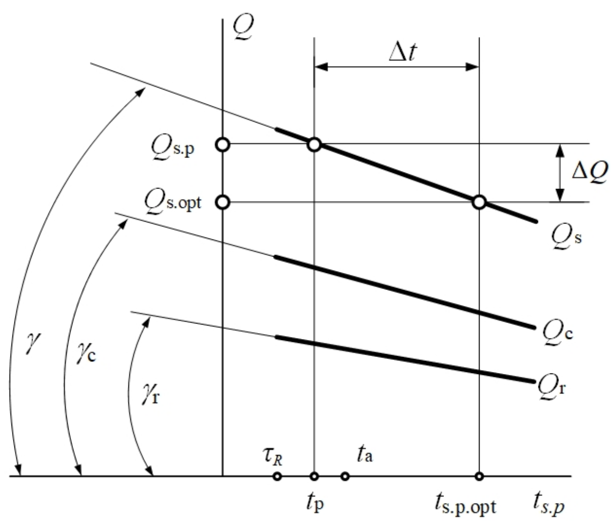


Figure 3: Calculation Scheme for Coefficient ξ .

Equations [18, 19] showed that

$$\mathrm{tg}\gamma_r=\alpha_r \text{ ;} \qquad \mathrm{tg}\gamma_c=\alpha_c \text{ .} \tag{29}$$

From Figure 3 and equation (30) it follows that

$$\mathrm{tg}\gamma= \mathrm{tg}\gamma_r + \mathrm{tg}\gamma_c = \alpha_r + \alpha_c. \tag{30}$$

We consider the line Q_s (Figure 3). The animal is in a room with some t_p, which can be determined according to (1) based on the known t_a and τ_R. In this case, the animal emits a certain amount of apparent heat $Q_{s.p}$. Let us suppose that under these conditions, optimal thermal condition are required for the animal with $t_{s.p.opt}$, which, according to the first comfort condition, corresponds to $Q_{s.opt}$. From Figure 3 it follows that an increase in $t_{s.p}$ by a certain value Δt (from t_p to $t_{s.p.opt}$) corresponds to a decrease in Q_s by ΔQ (from $Q_{s.p}$ to $Q_{s.opt}$):

$\Delta t = \xi_1 \Delta Q$, (31)

where ξ_1 is the compliance coefficient, °C/W.

A decrease in Q_s by ΔQ and a corresponding increase in $t_{s.p}$ by Δt can be result from an additional heat influx from an external heat source. In the general case, $\xi_1 \neq$const. It's a function of many variables, including the physiological characteristics of the organism, the specifics of its heat exchange with the environment, behavioral reactions, etc. However, for engineering calculations, according to (31) and Figure 3, it can be written that

$\xi_1 = \Delta t / \Delta Q = \mathrm{ctg}\gamma$. (32)

Solving together (30) and (32), we find

$\xi_1 = 1/(\alpha_r + \alpha_c)$. (33)

We prove the correctness of the calculations made by comparing their results with [19], for which, comparing (27) and (33), we obtain $\xi = \xi_1 = \mathrm{ctg}\, \gamma$.

When heated by an infrared irradiator, when $F_\Sigma \neq F_{ps}$, equations (10) and (25) take the form as follows

$t_{s.p} = At_a + B\tau_R + CEF_{ps}/F_\Sigma$; (34)

$t_{s.p} = \alpha_c t_a/(\alpha_r + \alpha_c) + \alpha_r \tau_R/(\alpha_r + \alpha_c) + \xi a_{sur} EF_{cr}/F_\Sigma$. (35)

These equations help approximately determine the sensible room temperature for a standing animal $t_{s.p}$ with the known t_a and τ_R under infrared heating.

The required value of the heat flux density E to reach a given $t_{s.p}$ in a room with known t_a and τ_R can be found for a standing design animal from (34) or (35) as follows

$E = (t_{s.p} - At_a - B\tau_R) / (\xi a_{sur} F_{cr}/F_\Sigma)$. (36)

2.2 Calculation for a lying animal.

By analogy with the calculation of $t_{s.p}$ for a standing animal, we compare its heat balance for two cases:

a). The animal stands in a climatic chamber $t_a^c = \tau_R^c = t_p = t_{s.p}$. Its heat balance can be described by the system of equations (18).

b). *The animal lies in a room* with τ_f, t_a и τ_R, while $\tau_f \neq t_a \neq \tau_R$. Let us suppose that local heating is carried out from above by an infrared irradiator providing illumination E (the presence of a contact heater can be considered by changing the value τ_f). The animal perceives a certain amount of heat ΔQ_{RAD} from the infrared irradiator. The surface temperature of the animal at the point of contact with the ground in the steady is τ_{af} (Figure 4). The system of equations describing the heat balance of the body of the design animal is as follows

$Q_s^p = Q_r^p + Q_c^p + Q_t^p - \Delta Q_{RAD}$,

$Q_r^p = \alpha_r^p (\tau_p^p - \tau_R) F_{cr} \varphi_R$,

$Q_c^p = \alpha_c^p (\tau_{sur}^p - t_a) F_{cr}$,

$Q_t^p = (\tau_{af} - \tau_f) F_{sh} / R_f$,

$\Delta Q_{RAD} = F_{ps} a_{sur} E$, (37)

where R_f is the conditional equivalent resistance to heat transfer of the floor in the room, m^2°C/W.

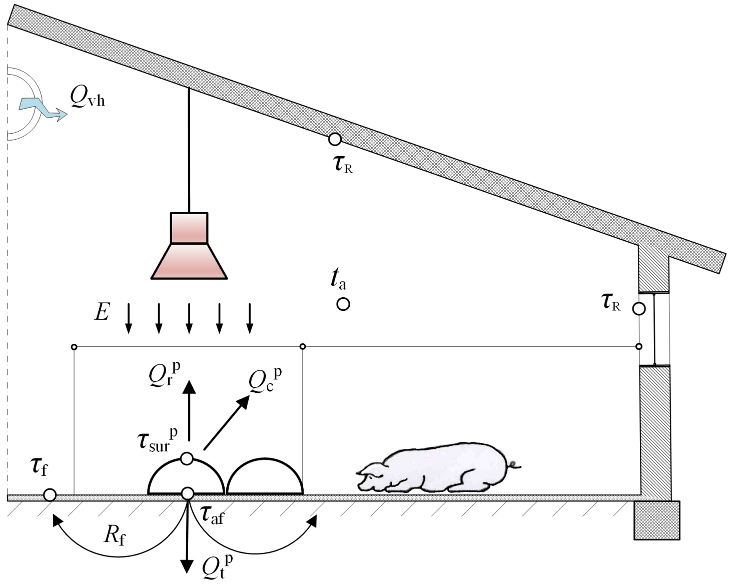


Figure 4: Calculation Scheme of the Heat Balance for determining $t_{s.p}$ of a Lying Animal

If the means of local heating (in this case, an infrared irradiator) provide the lying design animal in the considered room with the same thermal conditions as the standing animal in the climate chamber (with the same $t_{s.p}$), then condition (20) is fulfilled. Then, solving together (18), (20), (37) with respect to $t_p=t_{s.p}$, at $\varphi_R=1$ we obtain

$$t_{s.p}=\alpha_c^p F_{cr} t_a /(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})+\alpha_r^p F_{cr}\tau_R /(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})+$$
$$+a_{sur}F_{ps}E /(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})+F_{sh}\tau_f /R_f(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})+$$
$$+[\tau_{sur}^c-(\alpha_r^p+\alpha_c^p)F_{cr}\tau_{sur}^p/(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})-F_{sh}\tau_{af}/R_f(\alpha_r^c+\alpha_c^c)(F_{cr}+F_{sh})]. \quad (38)$$

Comparing (21) and (38), it is easy to verify that, if in the calculations of $t_{s.p}$ it is required to switch from a lying animal to a standing one, then, taking $F_{sh}=0$ in (38) and also making assumptions (22) ... (24) based on the notes to them, and taking $\tau_{af}\approx\tau_{sur}^c\approx\tau_{sur}^p$, $\alpha_r+\alpha_c\approx(R_f)^{-1}$, we obtain expression (25).

For a lying animal (when $F_{sh}\neq0$) it is possible, having accepted the above assumptions, considering (34) and (35), to simplify (25) as follows

$$t_{s.p}=AF_{cr}t_a/(F_{cr}+F_{sh})+BF_{cr}\tau_R/(F_{cr}+F_{sh})+CF_{cr}E/(F_{cr}+F_{sh})+DF_{sh}\tau_f/(F_{cr}+F_{sh}). \quad (39)$$

Here A and B can be determined according to (3), (4). We find C from (28), and $D=(R_f)^{-1}\xi$.

Thus, equations (6), (21), (38) and (39) were obtained on the basis of solving systems of equations describing the heat balance of the animal during its heat exchange with the environment under external heat exposure, and therefore are a rather rigorous expression of the sensible temperature $t_{s.p}$.

Monitoring of this parameter by probing [20-21] and using a feedback sensor for IR heaters [22] allows developing an energy-saving intelligent control system for local heaters of young animals.

Conclusion

The relationships of the main thermal characteristics of young animals (primarily the temperature of their surface of apparent heat transfer) as functions of room temperature have been analytically substantiated. Based on mathematical modeling of heat transfer of a “design animal” using the heat balance equation of a homeothermic organism, a simple case of this method is justified and a simplified method for selecting the energy parameters of local heaters of various types using the concept of “perceived temperature” has been developed. This technique also allows determining the actual thermal conditions in both the heated and unheated areas of the room in the form of a single numerical value in degrees of “sensible temperature”.

One of the main indicators of the thermal state of animals is sufficiently strictly defined — the temperature of its surface. This indicator is crucial in the development of methods for choosing the energy parameters of local heating means. The change of external exposure to infrared radiation can influence the thermal state of the animal.

References

1. Tikhomirov D., Vasiliev A. and S. Dudin, 2019. Energy-saving electrical installations for heat supply of agricultural objects. Advanced Agro-Engineering Technologies for Rural Business Development Hershey, PA, USA, 96-122.

2. Kuzmichev A.V., Tikhomirov D.A. Thermal conditions in the areas for piglets // Electrotechnology and electrical equipment in the agricultural sector. 2019.No 3 (36). P. 17-22.
3. Spodyniuk, N., Zhelykh, V. and Ol. Dzeryn, 2018. Combined Heating Systems of Premises For Breeding of Young Pigs And Poultry. FME transactions, 46(4): 651-657
4. Bystritskii D.N., Kozhevnikova N.F., Liamtsov A.K., Murugov V.P. Electrical infrared devices in animal husbandry / - M.: Energoizdat, 1981. - 152 p.
5. Boenue E., Roy St. and M. Jakob, 1989. Analysis of radiation intensity by infrared heaters for piglets with different housing systems. Proc. 4th int. Conf: Phys. Properties Aqr. Mate and Influence Technol, Process, Rostock, Sept. 4-8.
6. Damasceno, Flavio A., Oliveira, Carlos E. A., Saraz, Jairo A. O., et al. 2018. Validation of a heating system in the farrowing house using a CFD approach, Engenharia Agricola, 38(4): 471-477.
7. Akhramovich A.P., Gerasimovich L.S., Dashkov V.N., Koloss V.P. The infrared irradiation system for animals for the intensification of production processes // Energy supply and energy saving in agriculture. - M.: State National Institution, All-Russian Research Institute of Electrification of Agriculture, 2014. - Part 3. - P. 224-227.
8. Barros, Juliana de S. G., Rossi, Luiz A. and Karina Sartor, 2015. Use of PID controller as efficient technology in heating system of swine nursery, Revista brasileira de engenharia agricola e ambiental, 19(5): 476-480.
9. Pedersen, L. J., Larsen, M. L. V. and J. Malmkvist, 2016. The ability of different thermal aids to reduce hypothermia in neonatal piglets, Journal of animal science, 94(5): 2151-2159.
10. Webb P. Thermal properties of the environment and temperature stress. Fundamentals of space biology and medicine. - M. Nauka, 1975, v. 2, vol. 1, p. 105-141.
11. Kozhevnikova N.F., Alferova L.K., Liamtsov A.K. The use of optical radiation in animal husbandry.- M .: Rosselkhozizdat, 1987.-87 p.
12. Heating of rural residential and livestock buildings with infrared sources / Ia.A. Kungs, A.G. Lapitskii, V.D. Nikitin, N.V. Loam; under the general. ed. N.V. Tsuglenka. - Krasnoyarsk: Publishing house of Krasnodar State Agrarian University, 2008. - 144 p.
13. S.A. Rastimeshin, V.N. Rasstrigin, A.K. Liamtsov. Calculation of the necessary energy illumination created by an infrared emitter in a combined heating unit for lambs // Electrothermics. - 1983, No. 11 (249). - P. 13–14.
14. Zarecky, M. and J. Hajek, 1992. Temperature conditions and ethology of suckling piglets kept in pens with installed infrared heaters, Zivocisna vyroba. 37(1): 39-46.
15. Dubrovin A.V., 2004. Automated electrical technology for centralized local and general heating in poultry farming, theses, All-Russian Institute for Electrification of Agriculture, Moscow, Russia.
16. Baroev T.R., Zarutskii V.M. Combined infrared and ultraviolet radiation unit // Bulletin of Gorsky State Agrarian University. 2014. V. 51. No. 3. P. 174-178.
17. Ziemelis, I, Iljins, U. and A. Skele, 1999. Combined local heating for piglets. Conference: International Conference on Trends in Agricultural Engineering Location: Prague, Czech republic Date: Sep. 15-17.-1999 // Trends in agricultural engineering. P. 441-445.
18. Rastimeshin S.A., 1995. Justification of the parameters of local electric heaters of young livestock, theses, All-Russian Institute of Electrification of Agriculture, Moscow, Russia.
19. Liamtsov A.K., 1991. System of technical means for lighting, infrared heating and irradiation in animal husbandry. Theses, All-Russian Institute of Electrification of Agriculture, Moscow, Russia.
20. Hoff, S.J. 2003. Infrared radiant sensing for controlling IR-based heaters // Conference: 2nd International Symposium on Swine Housing Location: Raleigh, NC Date: OCT 12-15, 2003. Swine housing ii, proceedings Book Series: ASAE PUBLICATION Pages: 56-63.
21. Hoff, S. J. 2009. Feedback sensor development for IR-based heaters used in animal housing micro-climate control, Applied engineering in agriculture, 25(3): 403-415.
22. Kuzmichev A.V., Liamtsov A.K., Tikhomirov D.A. Thermal energy indicators of IR irradiators for young livestock // Lighting engineering. 2015. No. 3. P. 57-58.

