Dynamic Model for Determining Technological and Economic Parameters for Precision Pigs Farming

Belma Gaazi, Plamen Daskalov, Tsvetelina Georgieva, and Eleonora Kirilova

Abstract— **Dynamic model for determining technological and economic parameters for precision pigs farming is proposed in the paper. The model includes equations describing the temperature-humidity processes, growth, feed consumption and heating in the building, depending on the controlling inputs and the measurable disturbances movements on the building's microclimate. A cost-effective temperature is determined to maximize growth and minimize feed and energy consumption by using the Direct Search optimization procedure in Matlab. A cost effective temperature for 9 climatic zones of Bulgaria in winter season for fattening pigs 45 and 90 kg has been found. The economically efficient temperature for 45 kg pigs is determined between 20,86 ℃ - 18,58 ℃ for different climatic zones of Bulgaria. For 90 kg pigs the economically efficient temperature is calculated and the results show that the temperature is the same for all climatic zones – 17.81 ℃..**

Index Terms—**Dynamic model, fattening pigs, cost-effective temperature, microclimate.**

I. INTRODUCTION

The increase in electricity prices and increased technological requirements and the need to reduce production costs require the deployment of models and building systems to maintain optimum microclimate parameters in livestock buildings [4, 13, 17]. The microclimate in livestock breeding must provide an optimum animal environment, which in turn influences the growth, consumption of feed, which determines the economic efficiency of the production. One of the key components that increase productivity in agriculture is the choice of appropriate technology to manage, and it is related to the effective and economical use of energy resources with an opportunity to reduce costs in the production [9, 10, 11, 12, 15, 16]. Creation on model is useful instrument appled in a software program which facilitates further study of the variables that affect the environmental conditions inside a pig barn [20]. The main task in developing a model for controlling technological parameters is the choice of a suitable room temperature in which the obtain maximum growth and minimum

feed consumption. The purpose is not to choose the biologically optimal temperature by a ordinance [1], but to calculate the cost-effective internal temperature in relation to the other factors influencing it [14].

II. STRUCTURE OF THE MODEL

The purpose of our study is a building for fattening pigs from 45 to 90 kg. The building is equipped with contours for controlling natural ventilation and underfloor heating. The microclimate is considered as a dynamic system, which is formed from inputs divided into three distinct groups: biological and inter-climatic factors (Np, m, Gb), external natural factors (ta, da, Vw) and economical factors (PriceF, PriceQf, PriceM) (Figure 1). The outputs of the microclimatic dynamic system are Profit, Costs (RazhQf, RazhF) and the estimated cost-effective temperature (tb) that needs to be maintained in the room.

The overall dynamic model is a set of several models - a model for heating and humidification from animals, a heating model, a growth model, and a feed consumption model. The models have inputs that can be set by an operator. After starting the optimization in the model, the calculations are generated in search of an effective internal temperature for which maximum profit is obtained. Once the procedure has found the best temperature value, the optimization is terminated and the calculated cost, profit and economic optimum temperature are displayed.

- The model for heat and humidity from animals depends on the number of animals in the building, the mass of the animals and the temperature in the room;
- The influence factors of the heating model are outdoor temperature, outdoor humidity, wind speed, air exchange in the building, heating and humidity, and room temperature;
- The growth model depends on the temperature in the room and the number of animals;
- The feed consumption model also depends on the temperature in the room and the number of animals.

III. ANALYTICAL DESCRIPTION OF THE MODEL

A. A model for Total Heat and Humidity from Animals

A equation describing the heating of an animal according to kilograms (2-100 kg) expressed in kW derived from Strom [2] is as follow:

$$Q_{at} = (29 (m + 2)^{0,5} - 40 / 1000. \qquad (1)$$

where Q_{at} - latent heat from one animal, m - the mass of the animals in the building.
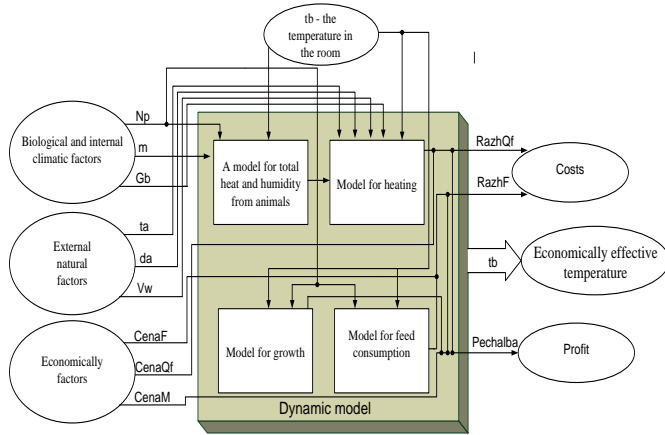

Fig. 1. Structure diagram of the dynamic model for calculating economical optimal temperature and economic parameters

The total heat emitted by all animals consists of latent and sensitive heat, the ratio of which depends on the temperature in the building. Equation 2 describes the total heat of all animals in the building in kW [2]:

$$Q_p = N_p * Q_{at} (0,8 - 1,85 * 10^{-7} (tb + 10)^4). \quad (2)$$

where Q_p - the total heat of all animals in the building, N_p - number of animals in the building, tb - the temperature in the room.

Equation 3, describes the total humidity of all animals in the building [18]:

$$D_p = N_p * 0,001 * (0,26 * tb^2 - 6,46 * tb + 81,6). (3)$$

where D_p - the total humidity of all animals in the building, kg / h.

B. Model for Growth and Feed Consumption

Data from [5], where graphically show the influence of room air temperature on the growth and feed consumption for 45 and 90 kg, were used to obtain the desired models for fattening pigs.

- After the approximation of the data with least squares for growth of 45 kg fattening pigs (Fig. 2) it was obtained that the most appropriate equation describing the model for 45 kg pigs is a fourth degree polynomial with a correlation
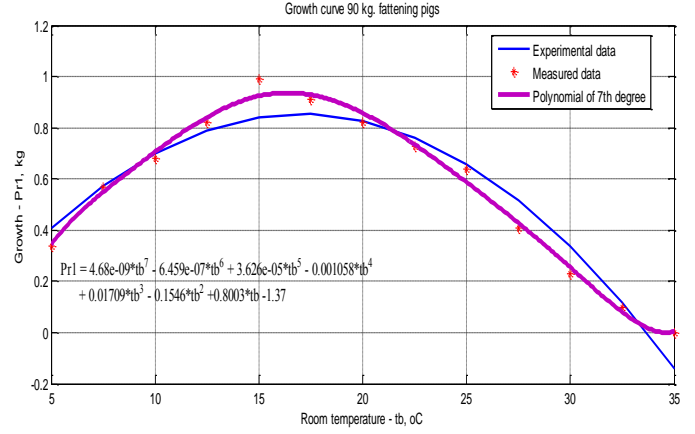
coefficient $R^2 = 0.9955$ (4).

Figure 2. Influence of the room air temperature on the growth to 45 kg fattening pigs

$$Pr1 = 4,545e^{-6} * tb^4 - 0,000403 * tb^3 + 0,009959 * tb^2 - 0,06175 * tb + 0,6843. \qquad (4)$$

where Pr1 - growth of 45 kg for fattening pig per day, kg.

- After the approximation on the data by least squares for 90 kg for fattening pigs is choice seventh degree polynomial with correlation coefficient $R^2 = 0.9901$, which most accurately describes the measured data (5).

Figure 3. Influence of the room air temperature on the growth to 90 kg fattening pigs

$$Pr1 = 4,68e^{-9} * tb^7 - 6,459e^{-7} * tb^6 + 3,626e^{-5} * tb^5 - 0,001058 * tb^4 + 0,01709 * tb^3 - 0,1546 * tb^2 + 0,8003 * tb - 1,37. \qquad (5)$$

- The feed consumption model is obtained by approximating the measured data using the least squares method. For 45 kg fattening pigs is a quadratic equation with correlation coefficient $R^2 = 0.99$ - (Fig. 4), which best describes the built curve (6).

Figure 4. Influence of the room air temperature on the feed consumption for 45 kg fattening pigs
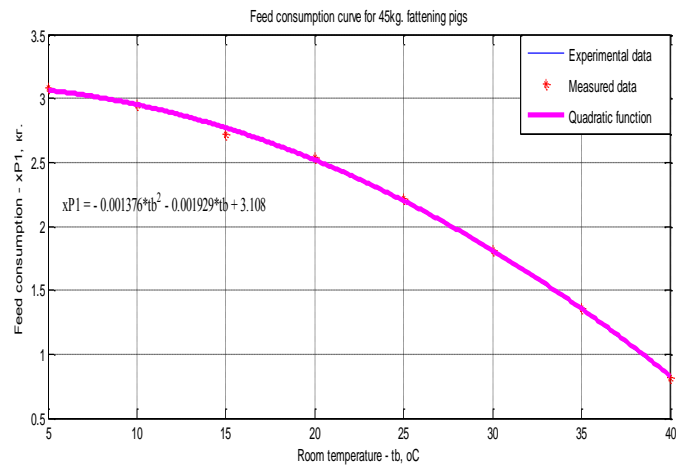
$$xP1 = - 0,0013762 * tb2 - 0,0019286 * tb + 3,1082. \quad (6)$$

where xP1 - the amount of feed needed for 1 pig, kg.
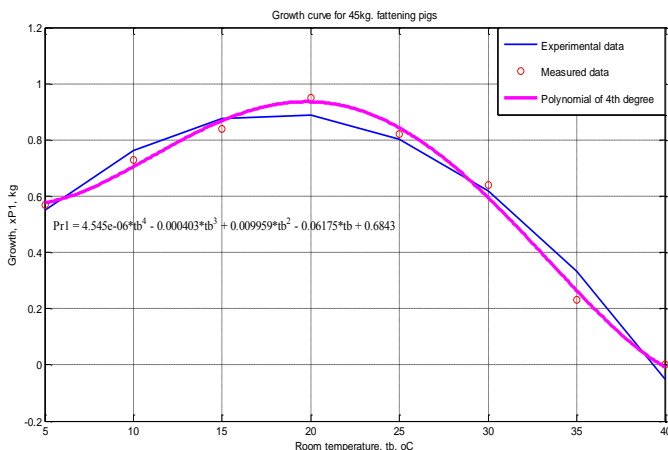
- The feed consumption model for 90kg fattening pigs is a cubic equation with correlation coefficient $R^2 = 0.99$ - (Fig.5) with (7).

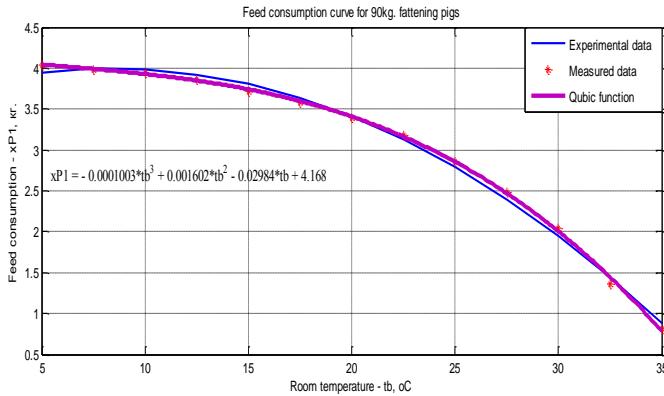$$xP1 = -0,0001003 * tb^3 + 0,001602 * tb^2 - 0,02984 * tb + 4,168. \qquad (7)$$

Fig.5. Influence of the room air temperature on the feed consumption for 90 kg fattening pigs

C. Model for heating a pig farm

The heating model is derived from [3], the parameter Q_f representing the heat emitted by the underfloor heating in the building in kilowatts (kW):

$$Q_f = [tb - (b_{g1}*t_a + b_{g2}*d_a + b_{g3}*V_w + b_{g4}*G_b + b_{g6}(D_c + D_p))]/b_{g5} - Q_p. \qquad (8)$$

$b_{g1 ... } b_{g6}$, are coefficients representing the steady-state transfer on the building;

t_a - outside temperature, ℃; d_a - external moisture content, g/kg; V_w - wind speed, m/s; G_b - measured amount of ventilated air through the building envelope, m³/h; D_c - pulsated water flow rate for cooling air, kg/h; D_p - the production of water vapor from pigs, kg/h; Q_p - Sensitive heat from pigs, kW.

The use of (8) allows the amount of heat to be determined in winter. For this purpose it is assumed that the additional moisture for humidifying the building air is $D_c = 0$ in the winter heating period and the variables t_a, d_a and V_w are taken on the average for the season. The air exchange in the building G_b is based on minimal ventilation rate to the humidity balance in the building.

Equation (8) allows the amount of heat to be determined in winter heating season. For this purpose it is assumed that the additional moisture for humidifying the air in the building in the winter heating period, and the variables are taken in the average for the season. The air exchange in the building is based on minimal ventilation rate to the humidity balance of the building.

D. Output economic parameters of the model

- Cost equations

The economic parameters include the cost of electricity for heating and the costs associated with the amount of feed

consumptions. Based on the average prices of the feed, we can assume that the price is 300 BGN per ton, whose value is input and can be changed. The electricity price for business clients currently operating on average is around 0,20 BGN / kWh [6]. Cost equations are:

$$RazhQ_f = Qf * CenaQf * 24. \qquad (9)$$

$$RazhF = J * CenaF. \qquad (10)$$

where $RazhQ_f$ - heating costs for 24 hours in BGN; CenaQf - average electricity price for business customers, BGN / kWh; RazhF - cost of feed, BGN; J - required amount of feed for all animals in the building, kg; CenaF - price of feed, BGN / kg.

- Equation for profit

Profit is calculated from all growth in BGN subtracting the cost of heating and feed:

$$Pechalba = -(Pr\_Lv - (RazhQ_f + RazhF)). \qquad (11)$$

where Pechalba - profit, lv; Pr_Lv - total growth, BGN.

IV. OPTIMIZATION PROCEDURE AND CALCULATION OF THE COST EFFECTIVE ROOM TEMPERATURE

To find the cost-effective temperature 'tb' we use the optimization procedure "pattern search". This procedure uses the Direct Search method that solves optimization tasks, which do not require information about the target function's gradient. Therefore, it can also be applied in the optimization of undifferentiated and discontinued functions. In this case, the direct search has a larger field of application in comparison with the gradient method and their inferior in fast response [7]. The function, which must be minimized / maximized, accepts the vector tb and returns as a solution to the scalar function evaluated by 'tb':

[tb,fval]=
patternsearch(fun,x0,A,b,Aeq,beq,lb,ub,nonlcon,options)

- tb – Solution;
- fval - Objective function value at the solution;
- patternsearch – optimization procedure;
- fun - Objective function;
- x0 - Initial point, specified as a real vector, patternsearch uses the number of elements in x0 to determine the number of variables that fun accepts;
- A - Linear inequality constraints, specified as a real matrix.;
- b - Linear inequality constraints, specified as a real vector;
- Aeq - Matrix for linear equality constraints;
- beq - Vector for linear equality constraints;
- lb - Lower bound for 'tb';
- ub - Upper bound for 'tb';
- nonlcon - Nonlinear constraint function;
- The "patternsearch" procedure of each iteration performs the following basic operations:
1) Generate multiple points of the so-called mesh - network;
2) Selecting from the network a point for which the target function has a value lower than the current polling. This point becomes current;

3) Correcting network size;

4) Check the criteria for terminating the calculation.

V. ALGORITHM OF THE MODEL FOR CALCULATION AND OPTIMIZATION:

1. Operator level - the required operator data required for the computation procedures is entered.

2. Software level - model parameters are cleared based on the patternsearch optimization procedure.

After starting the optimization procedure, which cyclically calculates the output values of the model at different temperatures and finds the above-described economically most effective temperature 'tb' inside the room at which obtained maximum profit based on the other factors introduced by an operator, affecting the building's microclimate – Fig. 6.

3. Control level - after receiving the cost effective temperature, the received information is visualized with the ability to control the microclimate in the room.
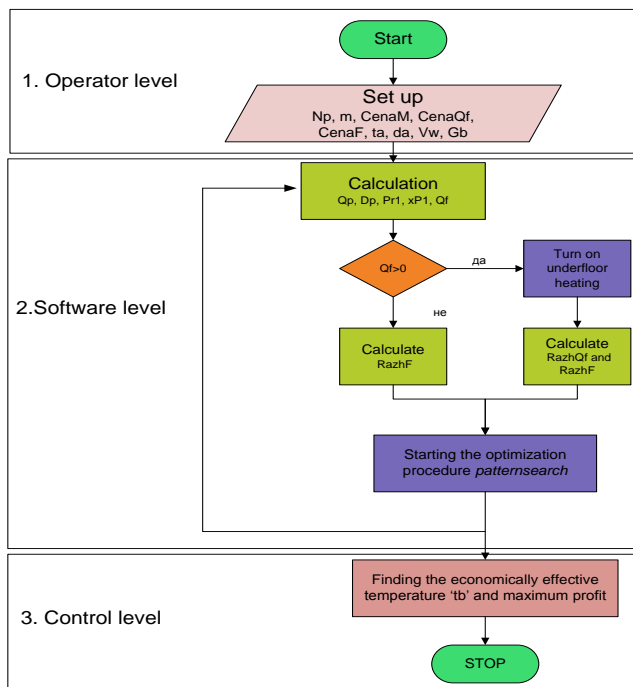

Figure 6. Algorithm for finding the cost-effective temperature in a pig farm
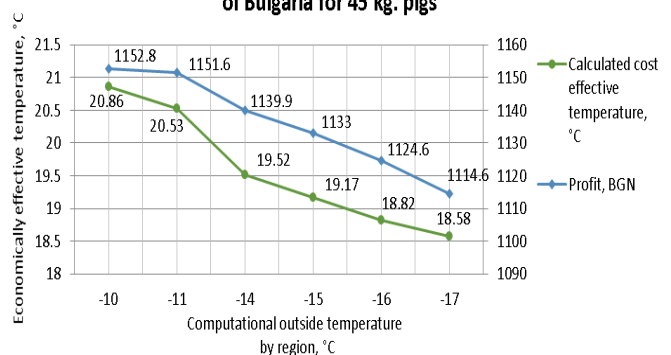
VI. SIMULATION RESULTS

Simulation tests were conducted in the Matlab environment, and the influence of outdoor temperature during the winter heating season on the internal temperature in the pig farm was assessed. In Bulgaria the heater winter season is relatively long and most important, in terms of costs. There are 9 climate zones [8] (Table 1), where the external computing temperature varies, and necessary to define in which areas which temperature in pig buildings should be maintained to obtain maximum production with minimum costs.

TABLE I. COMPUTATIONAL OUTSIDE TEMPERATURE FOR THE WINTER HEATING SEASON FOR THE CLIMATIC ZONES OF BULGARIA [8]

№	Climate zone	Calculated outside temperature
1	Northern Black Sea coast	-11℃
2	Dobrudja	-15℃
3	Northern Bulgaria - the valley of the Danube River	-17℃
4	Northern Bulgaria - central part	-17℃
5	Southern Black Sea Coast	-10℃
6	Southern Bulgaria - central part	-15℃
7	Sofia and the sub-Balkan valley	-16℃
8	Southern Bulgaria	-14℃
9	Southwest Bulgaria	-10℃

Have been research with simulation tests for 45 and 90 kg for fattening pigs and the external computational temperature for different climatic zones of Bulgaria was changed. Figure 7 presents the graphically calculated cost-effective temperature and the profit obtained for the nine climatic zones of Bulgaria for 45 kg for fattening pigs.

Figure 7. Graphical data for calculated internal economic efficiency temperature and profit for 9 climatic zones of Bulgaria for 45 kg fattening pigs

Research carried out for 90 kg fattening pigs with change in the external computational temperature for different climatic zones of Bulgaria have found a cost-effective temperature of 17.81 ℃ for all climatic zones, giving the fact that older pigs can tolerate lower temperatures without affecting their health [19]. The larger the pig, the lower the LCT (Low Critical Temperature).

VII. CONCLUSION

Simulation experiments were performed for 45 and 90 kg fattening pigs in the Matlab environment with a dynamic optimization model for determining the cost effective temperature for the winter heating season for 9 climatic zones of Bulgaria. The results show that for 45 kg pigs economic efficiency temperature is between 20.86 °C and 18.58 °C for different climate zones of Bulgaria. For 90 kg pigs the temperature is 17.81 ℃ for all climatic zones due to the fact that older pigs can adapt and tolerate the lower temperatures [19]. According to the results obtained from an economic point of

view, it is advisable to grow younger pigs in the warmer climatic zones of Bulgaria.

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