A New Approach to Controlled Natural Ventilation of Livestock Buildings

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An alternative is considered for substitution of the present mechanically ventilated air-conditioning systems in standard livestock building structures on commercial pig-growing farms in Bulgaria. On the basis of a proposed method of controlled natural ventilation and air conditioning in a stock breeding building, some pig-breeding buildings for piglets and fattened pigs have been restructured. Seasonal studies of temperature and humidity have been conducted. Average statistical values for the air temperature and humidity in the restructured buildings and in the existing building with mechanical ventilation, which is regarded as reference, are presented. In the naturally ventilated building, a more favourable humid environment is maintained, the temperatures being comparable to those in the reference house. The regained heat flows of the heat exchange system have been calculated. A 28-25% degree of heat recovery of the ventilation heat loss can be obtained. The favourable results with the naturally ventilated systems show that this system is a realistic alternative for ventilation in pig-breeding buildings in Bulgaria and its application must be promoted.

1. Introduction

Pig breeding in Bulgaria is a commercial activity and pig building structures are mainly ventilated. Bulgaria has a moderate climate with the following distribution of temperatures throughout the year: 0-5% between -15 and -25°C; 2-5% between -7 and -14°C; 8% between -1 and -6°C; 18% between 0 and 5°C; 19% between 6 and 11°C; 22% between 12 and 17°C; 17-5% between 18 and 23°C; 10% between 24 and 29°C; 2-5% between 30 and 36°C (Climate Reference Book of Bulgaria, 1983). For these conditions, the finishing pig housing can do without additional heating. The consumption of energy for building ventilation is still rather high, though, and may thus create difficulties for pig producers when economic margins are small and when electricity costs are high as in Bulgaria. These circumstances demand new, effective and energy-saving methods of air conditioning. The object of research is the standard building structures for pig growing, which have a share of about 60% in the whole of pig-producing farm structures in this country (Beremsky, 1978). Special attention in elaborating the method of ventilation was given to natural ventilation systems because of the possibility of considerable reduction of electrical energy consumption.

The research results in this field are rather scanty (Foster & Down, 1987). It is generally believed that the natural ventilation systems are not able to ensure the required indoor climate throughout the year. The underlying recent intensive research shows that the controlled natural ventilation systems can be successful in comparison with the mechanical ventilation systems (Berckmans & Goedseels, 1986). Natural ventilation systems have a much lower sound level than mechanical ventilation systems and reduce the risk for the animals to suffer from respiratory diseases (Brockett & Albright, 1987).

2. Air conditioning with automatically controlled natural ventilation

The research studies on controlled natural ventilation systems refer mainly to ventilation by means of openings situated in the side walls and the ridge of buildings (Brockett & Albright, 1987; Bruce, 1978), where the air flows directly into the animal living area, thus raising the
risk of respiratory diseases. In winter, the waste heat recovery is limited. During the summer, the buildings are not ensured against overheating.

The drawbacks mentioned are not encountered in the ventilation scheme shown in Fig. 1 (Andonov et al., 1989). Basic elements of the ventilation system are movable side-wall valves (1), inlet (2) and outlet air ducts (3) and ridge vent (4). The air inlet and outlet ducts are manufactured from reinforced polyethylene foil. Ducts (3) are double-bottomed, constituting an air cushion (8). In this way, no condensate is formed on the outer duct surface. Inlet air ducts (2) are connected with windows (10), which are acting as valves. Vents (4) are placed on ridge (6) and are connected with outlet air ducts (3). Ridge vents (4) contain a control valve (5), and ridge vents bottom valve (7) can be opened for summer ventilation.

The building roof (6) is made of thin weather-proof plates from an artificial material. Air inlet ducts (2) and outlet ducts (3) compose the underroof insulation. They serve as a heat exchanger as well.

The longitudinal building walls contain movable valves (1) of stagger disposition with adjacent spray nozzles (9), the latter serving for water cooling of incoming air during hot summer days when outdoor relative humidity is rather low.

The system functions in two major modes—summer and winter modes.

2.1. Winter mode

In winter, valves (7) and (1) are closed [Fig. 1(b) and (c)]. Fresh air enters through inlet channels (2) to the upper middle part of the building. Running through channels (2), the air is being partially recuperatively heated with waste heat from outlet channels (3) and indoor air, which is in contact with the inlet channels. Leaving the inlet channels, the inlet air is uniformly distributed to the animal housing area. Thus, the air is additionally heated by the heat emanated by the pigs. In the animal area, the air is taken up by the outlet channels (3) and is exhausted from the building through ridge vents (4). The air exchange is controlled by valve (5). The inlet and outlet air channels are of a successive arrangement for a better distribution of temperature and velocity fields of air in the building. Inlet channels (2) are situated next to the roof and occupy the lower
half of the roof area. Nevertheless, the air running through them is partially heated, however its temperature stays near to the outdoor temperature. This is an important physical pre-condition for reduction of thermal losses through building roof.

2.2. Summer mode

In hot weather, valves (5), (7) and (1) are open [Fig. 1(d) and (e)] and ventilation is carried out mainly by means of circulation of atmospheric air entering through side-wall valves (1). Air is partially taken in by channels (2) as well. Air moves through animal area and further flows out into the atmosphere through outlet vents (4). Waste air is taken in by channels (3). When the temperature in the building $t_a$ is comparatively high ($t_a > 25^\circ C$), spray nozzles (9) are set into operation. The water spray is directed to the animal area, where it wets pig bodies and locally cools the building structure.

Fig. 1. Layout of a controlled natural ventilation system, installed in an experimental standard building for 1800 finishing pigs. The building is divided in two zones: zone A, equipped with evaporative cooling (with spray nozzles) and zone B without nozzles: (a) general layout of the building; (b) and (c) winter operational mode; (d) and (e) summer operational mode; (1) side-wall valve; (2) air inlet duct (channel); (3) air outlet duct (channel); (4) ridge vent; (5) air damper; (6) roof; (7) bottom valve; (8) air cushion; (9) water spray nozzles; (10) knee-joint window; (11) inlet opening; (12) outlet opening; (C) controller; (D) temperature sensor.
Another refined variant of a natural ventilation system with improved possibilities for utilization of waste heat is shown in Fig. 2(a)–(c) (Andonov, 1994). Novelties are the outside inlet air ducts which are constituted by the external building wall and heat insulation layers (11). Window valves (10) are connected
with these ducts and with inside inlet air ducts (2) within the building. Inside inlet (2) and outlet (3) ducts do not alternate as in comparison with the aeration plan of Fig. 1(a). They are situated one inside the other, as inlet air ducts (2) envelop the outlet air ducts. Thus, a more effective waste ventilation heat exchanger is constituted.

The system functioning in winter and summer modes is illustrated in Fig. 2(a) and (b). An advantage of the proposed ventilation system is the increased utilization of waste heat. This is due to the improved arrangement of the motion of the airflow. Running through the outside inlet air ducts, the fresh air is being partially heated with the heat passing across the wall. This heat is regained heat that was lost through the wall. Entering into inside air ducts (2), the air envelops the whole surface of outlet air channels (3) and deprives their heat as it is being additionally heated. Thus, the waste ventilation heat losses are utilized.

3. Experimental buildings

Three livestock buildings were monitored. Experimental building 1 is a standardized building structure for 1800 growing and finishing pigs, where the air conditioning is accomplished by means of an automatically controlled natural ventilation system (ACNV) (Fig. 1). Experimental building 2 is of the same design standard, with a capacity of 800 weaned piglets with a body weight of 7–30 kg. This building is equipped with the proposed refined ventilation system (Fig. 2).

The building used as a reference was of the same design standard (Fig. 3), had the same animal capacity as experimental building 1 and was ventilated with a mechanical ventilation system.

3.1. Experimental building 1

The area of experimental building 1 was 1600 m², with a volume of 6000 m³, length 100 m, width 16 m and height 6 m. Two zones (A and B) of equal area were established [Fig. 1(a)]. Zone A was furnished with the water spray nozzle system for cooling atmospheric air. There were no such water spray nozzles for cooling in zone B. Inlet air channels (2) were 40 in number with dimensions of 2.4 m by 0.4 m. Outlet channels (3) were 32 in number with the same dimensions. The total area of side valves (1) was 92 m², the total number of valves was 40 (20 valves on each side of the building). Vents (4) were 16 in number with a total area of 16 m². Nine hundred pigs were housed in each zone of the building.

The controller (C) holds the algorithm for the control of air temperature $t_a$ in the building. The air temperature $t_a$ of 18°C is taken to be an optimum temperature. The two-level temperatures of 22°C and of 25°C were preset. Valves (5), regulating the air exchange, closed partially at $t_a \leq 18^\circ C$, and opened completely at $t_a > 18^\circ C$. When valves (5) were partially closed, about 10% of the area of vent openings remained. Thus, the minimum quantity of the necessary air for the animals was ensured. When the value for $t_a$ exceeded the set value of 22°C, bottom valves (7) and side valves (1) were opened. Water spray nozzles (9) were set in operation when the value for $t_a$ exceeded the set value of 25°C. Relative humidity of the outdoor air is 20–60% in the summer in Bulgaria, thus allowing considerable evaporative cooling. Heat stress is decreased this way and specific control functions on indoor humidity are not necessary.

3.2. Experimental building 2

The area of experimental building 2 was 420 m², with a volume of 1575 m³, length of 35 m, width of 12 m and height of 5 m. Six inlet–outlet air channels were situated under the roof [Fig. 2(a)]. They were made from reinforced polyethylene foil with the dimensions shown in Fig. 2(b), section A–A. The control of air temperature

![Fig. 3. Mechanical ventilation system installed in standard reference building: (a) layout of building with fan arrangement; (b) cross-section of building with insulation; (1) fans; (2) roof insulation; (3) knee-joint window; (C) controller; (D) temperature sensor; (4) roof](image-url)
inside the building was equal to the one in experimental building 1.

3.3. Reference building

The area of the reference building was 1600 m², length 100 m, width 16 m and height 6 m (Fig. 3). Sixteen high-speed fans of volume flow rate from 1000 to 2000 m³/min and a total electric capacity of 4-8 kW were mounted on the roof. The roof (4) was made of corrugated artificial material plates. Roof heat insulation consisted of an 80 mm thin glass wool layer. Controller (C) switches the fans into operation with maximum flow rate of 2000 m³/min when temperature of air \( t_a \) is higher than 22°C. The minimum flow rate is used at \( t_a \leq 22°C \). The fans are turned off when \( t_a \leq 18°C \).

4. Thermal and hygroscopic processes

The weekly change in temperature and relative humidity of air was continuously recorded by hygro-thermographs.

The data were recorded in the course of 32 weeks which is the period of two cycles of 4 months each, designated for finishing pigs. The measuring period comprises all seasons—winter, spring, summer and autumn.

All the recorded data were statistically analysed. The thermal and relative humidity processes with air are treated as ergodic random processes with normal distribution (Martinenko et al., 1984). Mathematically proposed values and root-mean-square deviation of processes are calculated and compared for each week of the finishing pig period. The interval of record digitization \( T \) is 1 h. The obtained results are represented in Figs. 4 and 5.

Additional active experiments were carried out for evaluation of aeration rate and waste heat recovery in experimental building 2. The atmospheric temperature \( t_a \), temperature \( t_d \) of the air inside the building, the air temperature \( t_1 \) and \( t_2 \), respectively, inside in the beginning of inlet ducts and inside in the end inlet ducts, the air temperature \( t_3 \) inside in the beginning of outlet ducts and the air temperature inside in the ridge vent \( t_4 \) along with the flow rate \( V \) of ventilation air in the experimental building were synchronously recorded. Measuring locations are given in Fig. 2. Low-inertia platinum thermoresistors were used. Airflow through roof openings was measured by means of a thermo-electrical anemometer with a measuring set of 20 thermocouples (Petkov and Bankov, 1978). The integral value of air velocity was taken into consideration. The accuracy of measurement in the range 0-0.6 m/s⁻¹ is ±0.01 m/s⁻¹, and in the range 0.6-0.9 m/s⁻¹ is ±0.05 m/s⁻¹. Thirty experiments were carried out in
the winter. The duration of each experiment was 240 min. A sampling interval of 10 min was chosen. The heat transferred in the ventilation process $Q_u$ in kW was calculated according to the equation

$$Q_u = \rho c V(t_3 - t_4)$$

where: $\rho$ is the density of the air in kg m$^{-3}$; $c$ is the specific heat of the air in kJ kg$^{-1}$ K$^{-1}$; $V$ is the airflow rate through the ridge vents in m$^3$ s$^{-1}$; $t_3$ is the air temperature inside in the beginning outlet ducts in °C; $t_4$ is the air temperature inside in the ridge vent in °C.

The waste heat (ventilation heat loss) $Q_l$ in kW was calculated according to the equation

$$Q_l = \rho c V(t_a - t_0)$$

where: $t_a$ is the air temperature inside the building in °C; $t_0$ is the temperature of the outdoor air in °C.

The results of one experiment are represented graphically in Fig. 6(a)–(c). The mean values $\overline{Q_u}$ and $\overline{Q_l}$ for the heat transferred and the heat loss, respectively, for each experiment were determined. An efficiency factor for the recovery heat $\varepsilon$ was computed...
5. Technological results for finishing pigs

Finishing pigs with an initial weight of 30 kg and slaughter weight of 100 kg were in the reconstructed experimental building 1. Measurements were done during two production cycles with duration of about 4 months each. The first cycle comprises the period November–February (winter), the second one is from 15 May till September (summer). A special procedure was worked up for the purpose of this research. A limiting factor was the fact that the experiment was carried out under commercial conditions. In the reference building (Fig. 3), the number of pig pens was 78. Experimental building 1 had 80 pens, 40 pens were in zone A, and 40 in zone B. The number of pigs in each pen was 23–25. The pigs were brought into the experimental and reference buildings simultaneously.

The research had two main aspects.

5.1. Total control on pig condition in both buildings

A register was kept for everyday record of the number and weight of the pigs, the expenditure on medicines, etc. Animals were weighed prior to and at the end of the pig finishing period. The results are presented in Table 1. The number of pigs in the experiment was between 1703 and 2004 for each cycle. The daily feed intake was registered.

5.2. Intermediate control

Three controlled boxes exist in each of the investigated buildings, both experimental and reference ones. The aim of the procedure is to obtain a better authenticity of results by means of an extract from the cycle of pig finishing. The period of observation was 4 weeks, the pens in the experiment had similar locations in both buildings. The batch number of pigs brought in was 70, all of them equal in liveweight, age, sex, and health condition. Pigs were weighed once a week at a fixed time. The results are presented in Table 2.

6. Analysis of measured results

The proposed arrangement of the ACNV system (Fig. 1) ensures better conditions for pig growing throughout the whole year, compared with existing mechanical ventilation systems (Fig. 3). For all the seasons, the air temperatures in the experimental and the reference buildings are very close in value (Fig. 4, curves $M_{te1B}$ and $M_{tr}$, respectively). The difference between both temperatures is up to 2°C. The root-mean-square temperature deviation in experimental building 1 is the lowest one (Fig. 4, curve $\sigma_{te1B}$), showing more stable temperature fields were maintained through natural ventilation. Higher values of temperature in the experimental building are recorded in summer when no cooling of air exists (zone B) (Fig. 4, curve $M_{te1B}$ compared to $M_{tr}$). A considerable improvement of this situation is found when cooling nozzles are applied (zone A, Fig. 1) (Fig. 4, curve $M_{te1A}$ compared to $M_{tr}$). This fact should be mentioned as a new quality of the proposed arrangement of aeration, achieved on the basis

as the correlation

$$
\varepsilon = \frac{Q_{in}}{Q_{l}} \times 100
$$

The results are summarized in Fig. 7.
of saved electrical energy for ventilation. In this way, in summer, overheating of the animals and growth suppression are normally prevented.

As far as the humidity of air is concerned, the advantages of the proposed aeration system are to be traced throughout the whole year. The relative humidity of the air in experimental building 1 in winter is 60–70% (Fig. 5, curve MRhe1A). No formation of condensate was observed. In the reference building, the relative humidity was even higher than 80%, where a condensate was traced to form on roof and walls, due to restricted air exchange in the building when the controller turned off the fans. The comparison during transition seasons (spring–autumn) is similar. In summer, the humidity in the experimental building is closer to the optimum one. The operation of humidification nozzles maintains the humidity in the recommended range of 55–75% (Fig. 5, curve MRhe1A). The humidity variation was lower in the experimental building, as expressed by the root-mean-square deviation (Fig. 5, curve sRhe1A). The energy saving is considerable, up to 30% of waste heat is recovered [Fig. 6(c), curve Qu and Fig. 7]. The mean value from all experiments of the degree of utilized heat is 28–25%. Entering atmospheric air increases its temperature up to 5°C (Fig. 6(a), curve t2 compared to t0). In winter, the mean energy saving in experimental building 2 is 126 kWh day\(^{-1}\).

Better results in pig growing during the research period were recorded in experimental building 1 compared to the reference one: dead pigs were less, 0.7–1.35%, those slaughtered of necessity were less with 0.33–1.3%. The daily liveweight gain was higher with 4.3–6.6%, and fodder consumption was less, 1.9–9.4% (Table 1). The results of the check observation are higher too (Table 2). The differences in total are not very considerable, but they show the micro-environment in the experimental building to be of a more favourable nature for pig growing compared to the reference one.

### 7. Conclusions

(1) The experimental research proved the efficiency of the concerned air-conditioning systems. The comparison between experimental building structure 1
with an automatically controlled natural ventilation system and the reference building structure with a mechanical ventilation system demonstrated the better temperature and humidity parameters of air and improved animal health conditions in the case of the former. The heat recovery is essential in experimental building structure 2.

(2) The concerned arrangements of automatically controlled natural ventilation system can serve as a basis for the construction of a model of energy saving in livestock building structures. Such structures would be a successful alternative of the existing pig-growing building infrastructure.

References


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