Improved Energy Management in an Intermittently Heated Building Using a Large Broiler House in Central Europe as an Example

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Abstract: This paper deals with the problem of rational energy management in an intermittently heated broiler house. The aim was to evaluate the energy amount necessary to heat up the building floor for the production cycle, preceded by a technological interruption of varying length. The scope of studies included the indoor and outdoor air temperature measurements and the soil temperature measurements under the building floor. The results of field tests allowed computer simulations to be carried out in the WUFIplus software (Fraunhofer Institute for Building Physics, Holzkirchen Branch, Germany). The variant analysis was preceded by the validation of the calculation model whose results showed a strong correlation of theoretical data with actual results. The winter breeding cycle was analyzed in detail. The detailed soil and air temperature curves are presented graphically. The results allow a conclusion that the length of the technological interruption has a significant impact on the amount of energy in the first days of the broiler breeding. The extension of the technological interruption by seven days increases the amount of heating energy in the first day of the cycle by 24%. The extension of the technological interruption causes also the need for a longer floor heating in the first day of the cycle.

Keywords: building energy management; broiler house; heat exchange with soil; floor temperature; conditions in the broiler living zone

1. Introduction

The breeding of broiler chickens takes place in strictly defined thermal conditions. One-day-old baby chickens that are brought to the building require the temperature of 30–33 °C, and at the end of the cycle, six-month-old chickens should stay at 18–20 °C. A technological interruption is used between the breeding cycles for cleaning and disinfection. The building heating is off during such an interruption. A broiler house is an example of a cyclically heated building, so the length of the technological interruption is very important for the energy demand of the building. The most important factors influencing the thermal conditions in the broiler living zone are indoor air temperature (Θi), stocking density, and the bedding temperature (ΘL). The thermal phenomena occurring in the bedding which covers the thermally uninsulated floor are influenced by the contact with the chickens’ bodies and the heat exchange with soil.

The studies on the heat exchange with soil have been conducted mainly in residential buildings. A lot of publications present methods and calculation tools, and some of them also show the results of experimental measurements [1–7]. Therefore, the thesis that the technological interruption length has a significant impact on the thermal conditions in the chicken living zone and heat exchange with soil is justified. Consequently, it can be expected that an appropriate use of the heat capacity of soil under the
broiler house and in its vicinity can help create favorable thermal conditions inside the broiler house in accordance with the breeding technology.

The studies conducted in the real conditions of a large broiler house showed the dominating impact of the bedding on the thermal conditions indoors. It was determined that, in the first five days of the winter breeding cycle, the $\Theta_L$ was even $14^\circ C$ lower than the temperature required in that breeding phase ($\Theta_{opt}$), and the $\Theta_L$ in the last 20–25 days of the summer cycle was even $15^\circ C$ higher than $\Theta_{opt}$ [8]. A large difference between $\Theta_{opt}$ and $\Theta_L$ means that the sensible temperature ($\Theta_0$) on the broiler living zone was unfavorable, for the most part, for the breeding [9]. The results of many studies [10–13] clearly show the need for correct thermal and moisture parameters of the bedding—the only part of the building envelope in direct contact with birds. Microclimatic conditions in poultry rooms depend on the temperature and humidity of the air, lighting, ventilation, and concentration of harmful gases, as well as temperature and humidity of the litter. Due to the species of bred poultry (broiler chickens), it should be noted that the most important partition having almost direct contact with animals is the floor. In the rearing of chicks, its temperature is particularly important, as it directly determines their thermal comfort. Cold litter causes the chicks to chill quickly. At the time of placing broiler chicks in the chicken coop, the temperature of litter and air should be 30–33 $^\circ C$. Along with the altitude, the air temperature requirements decrease, and so, at a height of 1.5 m from the ground, 22–24 $^\circ C$ should be provided. The birds’ perception of thermal comfort is influenced by the floor temperature and speed of air movement. The results of many studies clearly indicate the need to shape the right temperature and humidity parameters of the floor—the only partition with which the birds have direct contact [1,14].

A lot of attention has been given in the literature to the bedding quality optimization and its microbiological and physical and chemical properties [15,16], and the broiler chickens’ welfare improvement [1,17,18], but the impact of the soil under the broiler house on the thermal conditions in the bedding is still under-researched.

The broiler breeding technology requires a technological interruption to prepare the building for the next breeding cycle. Most poultry breeders in Poland use two- or even three-week interruptions between the breeding cycles. Such a long time during which the building is not heated causes the cooling of the building itself and the soil in its vicinity. In order to provide optimum conditions in the next breeding cycle, the broiler houses are heated for a few days before the start of the new cycle. However, shortening the time between the cycles, even to one day, allows for the saving of a certain amount energy to heat the building in the initial breeding phase. The shortening of the technological interruption will allow the use of the heat accumulated in the soil under the building in the next breeding cycle.

The detailed knowledge on the temperatures in the soil adjacent to the broiler house in a sufficient temporal and spatial scale will allow for the evaluation of the role of soil on the thermal conditions and will help determine the actual boundary conditions necessary to calculate the heat exchange between the broiler house and the soil. The results of these calculations will contribute to the determination of the impact of the technological interruption length on the broiler-house energy demand.

2. Materials and Method

2.1. Studied Facility

The studies were conducted in a 1000 m$^2$ broiler house whose longitudinal axis was in the East–West direction (Figure 1). A straw layer about 3 cm thick was spread on the uninsulated concrete floor before the start of each breeding cycle. The broiler house had air heating, transversal mechanical ventilation, and misting. All systems were automatically controlled. During the studies, the Ross chickens did not have any bacterial or viral diseases that could significantly affect the breeding and its results. The entire building volume is heated, so no spot heating is used.
The outer walls were insulated with 0.12 m thick Styrofoam. The ceiling above the production part of the hall is of steel construction, filled with mineral wool between the main structures. From below, the roof is secured with a vapour barrier film and galvanized steel sheet. Above the structure, there is an unheated space, separated from the external environment by a wooden rafter roof. The roof is covered with concrete tile sheets.

2.2. Temperature Measurement Points and Instruments

The studies were conducted in an 18 m² area located in the central part of the broiler house, between the longitudinal axis and the outside wall (Figure 1a). The soil temperature measurement points were situated in 3 lines (Figure 1b,c). The measuring instruments included an HP multichannel recorder and 13 PT-100 sensors with 0.1 °C resolution and ± 0.1 °C measuring error used to measure the soil temperature and the indoor and outdoor temperature.

The measuring frequency was 1 h. This frequency value was based on previous studies on the heat exchange between the building and the soil. The measurements covered 7 breeding cycles and 6 technological interruptions and were conducted between 4-06-2016 and 22-08-2017.

The building was founded on 0.24 m thick concrete foundations, on 1.0 m deep below the surface. The building walls are made of used aerated concrete type “600”, with a thickness of 0.12 m. The outer walls were insulated with 0.12 m thick Styrofoam. The ceiling above the production part of the hall is of steel construction, filled with mineral wool between the main structures. From below, the roof is secured with a vapour barrier film and galvanized steel sheet. Above the structure, there is an unheated space, separated from the external environment by a wooden rafter roof. The roof is covered with concrete tile sheets.

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**Figure 1.** Placement of soil temperature sensors (measuring line A, B, and Z) and indoor (Θᵢ) and outdoor (Θₑ) air temperature sensors; (a) projection; (b) cross-section.
2.3. Calculations

Considering the operation of the heating and ventilation system in broiler houses, which maintain optimal temperature suitable for a given day of rearing, the only center with a different temperature on a given day remains the floor, which alone can meet the thermal preferences of broiler chickens. The roof mainly affects the energy balance of the building, while it has no direct impact on the thermal comfort of animals. At work, the authors have dealt only with the impact of the length of the technological break on energy demand and the time necessary to heat the floor to the recommended temperature. During the technological break, the building’s interior is cleaned and disinfected. During this time, the heating system is turned off or is running very weakly. The floor is cleaned with high-pressure water. Fluctuations in floor, soil, and indoor air temperature were monitored continuously. Therefore, the effect of floor cooling by water or energy necessary to dry the floor was taken into account in the calculations, although providing a specific value of energy necessary only for drying the floor at the moment would require additional analyzes and calculations, and this phenomenon was not the subject of this work. The calculation used the equation of energy balance method for elemental volume. The software validation was performed before the calculations and included the following:

- Choosing the correct thermal conductivity coefficient for the soil and outside envelopes;
- Determining the length of the period preceding the proper calculation period in order to eliminate the initial error;
- Determining the appropriate values of the air ventilation and infiltration streams;
- Simulation of cases where, at 10 m below the ground surface, the constant soil temperature or adiabatic plane was used, and then comparing with the measurement results;
- Determining the initial soil temperature.

The calculations were made by assuming the technological interruptions for the winter and summer breeding cycles lasting 1, 2, 3, 4, 5, 6, 7, 14, and 21 days. During the examined period, in real conditions, the technological break was 21–24 days, depending on the production cycle. The measurement points in the model reflected their actual location in the broiler house (Figure 2). The calculations assume a 180-day period of adaptation of the calculation tool, taking into account the initial conditions to real conditions. It was only after this time that the results for further analysis were taken into account.

![Figure 2. Broiler house model (a) and the grid of soil temperature measurement points (b).](image-url)
The physical parameters of the construction materials and soil used in the calculation model for validation are presented in Table 1.

| Specification          | Bulk Density (kg·m$^{-3}$) | Heat Capacity (J·kg$^{-1}$·K$^{-1}$) | Thermal Conductivity (W·m$^{-1}$·K$^{-1}$) |
|------------------------|-----------------------------|-------------------------------------|-----------------------------------------------|
| Sandy loam             | 1800                        | 840                                 | 0.70                                          |
| Loam                   | 1800                        | 840                                 | 0.85                                          |
| Sand                   | 1650                        | 840                                 | 0.40                                          |
| Concrete               | 2300                        | 1000                                | 2.30                                          |
| Aerated concrete       | 600                         | 840                                 | 0.21                                          |
| Styrofoam              | 20                          | 1500                                | 0.04                                          |
| Mineral wool           | 40                          | 800                                 | 0.05                                          |

Source: PN-EN:6946-2008.

The minimum indoor air temperature used in calculations was $\Theta_{i,min} = 10°C$, and the maximum indoor temperature was $\Theta_{i,max} = 40°C$ in the production cycles period. There was free-floating air between cycles, without heating. The model assumes air exchange under the condition of not exceeding a flow velocity of 1.0 m/s. Heat gains from birds’ bodies were also assumed at 180 W/m$^2$. With regard to the ground temperature, and in this case, the floor, the indoor air temperature is a third type of boundary condition (Fourier condition). It is taken when there is a free, unhindered flow of heat through the edge surface of the body. It is based on the balance of the intensity of heat streams flowing through the edge surface, which is the floor in this case. The ground temperature of 8.8 °C, corresponding to the average annual outdoor air temperature for Krakow (Southern Poland), was assumed to be at a depth of 10 m.

3. Results

3.1. Experimental Studies

The selected results of the floor, soil, and indoor and outdoor temperature measurements are presented graphically (Figure 3). The sinusoidal shape of $\Theta_i$ during the year and a specific shape of $\Theta_e$ significantly influence the $\Theta_C$ under the broiler house and in its vicinity. Thermal conditions in the soil under the broiler house (lines A and B) are determined first by $\Theta_i$, then by $\Theta_l$ and the stocking, and the thermal conditions in the soil in the broiler house vicinity (line Z) are determined by the outdoor climate and the materials and structure of the floor and foundation walls.

![Figure 3. Cont.](image-url)
The floor temperature plays an important role in ensuring the correct thermal conditions in the living zone of broiler chickens. The floor is the building envelope with which the birds stay in direct contact. A correct floor temperature in the first days of breeding affects the health of baby chickens.

The analysis of the results of internal air temperature tests $\Theta_i$ showed a high compliance of their values with the recommended values. On the first day of rearing, $\Theta_i$ ranged from 33 to 38 °C. During the production cycle, $\Theta_i$ was close to optimal, reaching a value of 15–18 °C at the end of the cycle. Due to the precise control of the indoor microclimate, there was no significant effect of the outside air temperature, $\Theta_e$, on the $\Theta_i$ (Figure 3a). The analysis of the temperature distribution in the ground showed that, in winter, the thermal conditions in the broiler house affect the strip of land adjacent to it from the outside. At that time, it was also observed that the external climate affected the floor temperature in the boundary zone, while in the summer, this effect disappeared (Figure 3b–d).

3.2. Calculations

The calculation model was validated based on the measured temperature inside and outside the broiler house. In relation to the soil temperature, this temperature is the boundary condition of the third kind. The initial soil temperature was assumed to be 8.8 °C, which corresponds to the average annual outdoor air temperature in Krakow, Poland. The validation calculations’ results for selected measurement points are shown in Figure 4. Not all results are presented, because there were...
restrictions on the volume of the text. It should be noted that, in other cases, the calculations were also highly consistent with the results of real measurements.

The analysis of valuation results using the Spearman’s (the distribution checked by Kolmogorov–Smirnov) correlation rank test for the calculation model showed a strong convergence of theoretical and actual data (0.91–0.96). Figure 5 presents soil temperature boxplots for selected measurement points. Statistically significant differences (α = 0.05) were determined for points A1–A4, B1–B4, and Z2–Z4. In the winter and summer periods, the significant differences between measurement and calculated data are not noticeable (α = 0.05).

Figure 4. Measured and calculated temperatures in points: (a) A1; (b) B2; (c) Z3.

Figure 5. Soil temperatures in measurement points located in the soil surrounding the building: (a) winter and (b) summer.
The detailed analysis of the impact of the technological interruption duration on the broiler house energy management was made for the winter cycle 19-12-2016 to 8-02-2017 and the summer cycle 28-07-2016 to 12-09-2016. The analysis covered the zone near the wall and in the floor center (Figure 6). The floor temperature in point A1, after one day of the technological interruption, was 18.5 °C. After 21 days of the technological interruption, the temperature at the start of the next breeding cycle was much lower and equaled 11.7 °C. The impact of the technological interruption duration on the floor temperature’s decrease in the zone near the wall was found to be less (B1). After one day of the technological interruption, the temperature in point B1 was 16.5 °C, and after 21 days, it was 10.5 °C. The differences are lower by 10% in comparison with the central zone of the building.

Figure 6. Floor and soil temperatures for technological interruption lasting 1, 2, 3, 4, 5, 6, 7, 14, and 21 days: (a) A1–A4, winter period; (b) B1–B4, winter period; (c) Z2–Z4, winter period; (d) A1–A4, summer period; (e) B1–B4, summer period; and (f) Z2–Z4, summer period.
The energy demand for providing the required floor temperature in the broiler house for the various technological interruption lengths is presented in Figure 7. The impact of length of the technological break is particularly significant during the winter. In summer, the effect of shortening the break is less noticeable and does not significantly affect the energy management of the building ($\alpha = 0.05$).

![Figure 7. Energy demand for heating 1 m$^2$ of the building floor for the technological interruptions of 1, 2, 3, 4, 5, 6, 7, 14, and 21 days in the winter and summer periods.](image)

Ensuring the appropriate floor temperature is extremely important from the point of view of actual breeding conditions. The concrete cooled during the technological interruption causes vapour condensation in the first days of breeding. The analysis of individual technological interruption durations showed almost a relationship between the increase of heat demand on the first day of the breeding cycle and the technological interruption duration. After one day of interruption, the energy demand to heat up 1 m$^2$ of concrete floor to 30 $^\circ$C is 1.84 kW. After three days, this value increases by 9%, and after seven days, by 24%. After 21 days of interruption, the higher energy demand for floor heating is expected to be 37% in relation to the variant with one-day interruption. The analysis also included the impact of the technological interruption duration on the time necessary to heat up the floor to 30 $^\circ$C. In the summer, the technological interruption duration has a significantly lesser impact on the heating energy demand. In comparison with the winter period, the heating of the building requires 1.5–16% of the winter demand. The constant boiler heating power of 50 kW was used in order to obtain reliable results. By "reliable results", the authors understand the adoption of such solutions in simulations that reflect real-world conditions as accurately as possible. Among other things, the power of the heating boiler was adopted on this basis, after prior consultation with the owner of the poultry farm where the field tests were conducted. One-day technological interruption makes the floor temperature drop by 5.5 $^\circ$C. In order to obtain the required temperature on the first day of the breeding cycle, the floor should be heated for about 10 h and 13 min. In case of a seven-day technological interruption, this time increases to 13 h and 26 min. For a 14-day and a 21-day technological interruption, the times are 15 h and 4 min and 16 h and 12 min, respectively.

4. Discussion

The buildings used for intensive breeding of animals can offer many possibilities to optimize the energy consumption [19]. Depending on the breed species, the correct inner climate control can be a significant portion of the total energy consumption. Average heating and ventilation energy demand in large European breeding facilities is from 34 to 37 kWh/m$^2$/year [20], corresponding to about 48% of
energy required during the entire breeding process [19]. In large broiler houses and at high stocking density, there is a large energy gain from the heat emission from the animal bodies, amounting to about 180 W/m² on the last days of the breeding cycle. The experiments by Dawkins et al. [17], conducted at large farms with various bird species, showed that the bedding quality, temperature and moisture control was very important from the point of view of providing the optimum living conditions for broilers. The results of tests by Bessei [1] indicated that the high chicken stocking density limits the heat outflow from the bedding to the air and makes the floor warmer. The results of many years of studies by other authors confirm the rule that an increase of the chicken stocking density causes the floor temperature to increase. On the first days of breeding, the soil under the broiler house cooled during the technological interruption, to about 10 °C in the winter cycle and caused vapour condensation on the concrete floor. The condensate was absorbed by the bedding, causing a reduction of its thermal and insulation properties and consequently a deterioration of thermal conditions in the chickens’ living zone. In the second half of the breeding, on the other hand, the soil became the main, and most frequently the only, receiver of the heat from the bedding, significantly limiting the temperature rise in the bedding and, hence, in the chickens’ living zone. Thus, the soil, as a result of its large thermal capacity, helped prevent discomfort and thermal stress for the birds at the end of the breeding cycle. The breeding cycle at large broiler houses is usually 40 to 50 days long. The cycle length depends on the time necessary to reach the slaughter weight. The sanitation, mostly disinfection of the breeding hall, takes place after the breeding cycle. Taking into account technological interruptions lasting 7–14 days on average, there can be eight full production cycles in one year [21–23]. Shortening the technological interruption is beneficial for thermal conditions in the initial period of breeding, because more heat accumulated in the soil during the previous cycle can be used to obtain appropriate thermal conditions in the birds’ living zone. The studies of the authors have shown that shortening the technological interruption to three days reduces the heating energy demand by 15% in comparison with a seven-day technological interruption. In addition, the extended technological interruption in the winter period extends the period necessary to heat the building and the floor. These relationships are important only when outdoor temperatures are low, particularly in winter. In Poland, technological interruptions can last even 21 days. With such long technological interruptions in the winter, the heating energy demand increases by 28% in comparison with a three-day technological interruption.

5. Conclusions

The studies proved the significant impact of the technological interruption duration on the heating energy demand in the winter period. In the summer period, the impact of the technological interruption duration is not noticeable compared to the impact in the winter. The analysis of validation results showed a strong correlation between the actual and theoretical data. Shortening the technological interruption limits the impact of the outdoor climate on the soil under the floor. The analysis of thermal conditions in the central part of the building showed that the floor temperature after one day of technological interruption was 18.5 °C. When the technological interruption was extended to 21 days, the floor temperature significantly dropped and was 11.7 °C in the middle of the building. The impact of the technological interruption duration is weaker in the zone near the wall, where the impact of outdoor climate is significant. After one day of technological interruption, the floor temperature in that zone was 16.5 °C, and after 21 days, it was 10.5 °C. The differences are lower by about 10% in comparison with the thermal conditions in the central zone of the building. The analysis of the energy amount necessary to heat the broiler-house floor showed that, after three days of technological interruption, the energy demand is 9% higher than after a one-day technological interruption. Each successive day of technological interruption means more energy for heating. In the extreme case of a 21-day technological interruption, the energy demand for floor heating is 37% higher than for a one-day technological interruption. The obtained results are for the winter breeding cycle when the thermal conditions in the soil surrounding the broiler house are the most unfavorable. The authors believe that, in that period, the
poultry breeders should minimize the interruptions between cycles. The results can be considered reliable for that season; in the transitional periods (spring and autumn), and in the summer, the broiler house is also heated, but the energy amount is definitely lower. The validated model can also be used in the analyses for various boundary conditions representing other climate zones.

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