The Influence of Litter on Thermal Conditions inside a Broiler House

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Abstract

The paper presents an analysis of the following measurements: litter temperature (Θ_L), indoor air temperature (Θ_i) and ground temperature during the winter and summer broiler production cycles in real operating conditions of a mass scale broiler farm. The assessment of thermal conditions in the broiler living zone is widened by the parameter of operative temperature (Θ_o), taking into consideration not only Θ_i but also Θ_L – the only partition that comes in direct contact with the birds.

The paper also presents the percentage division of the researched area depending on the difference between optimal air temperature (Θ_{opt}) and litter temperature (Θ_L) in the winter and summer production cycle. This is considered for three variations: $\Theta_L < \Theta_{opt}$ – 10-14-day period at the beginning of the production cycle characterized by the feeling of cold; $\Theta_L = \Theta_{opt}$ – middle and short period of thermal comfort and $\Theta_L > \Theta_{opt}$ – the longest, approx. 4-week period with the feeling of heat surplus. Daily fluctuation of Θ_L =5-11 K in the winter season is much larger than in the summer season Θ_L =1-3 K. Higher daily amplitude of Θ_L favorably influences physical activity of birds and their thermal comfort.

Moreover, the work describes the character of heat exchange between the litter and the ground, which from week 3 of the production cycle is favorable for thermal conditions by limiting the increase of Θ_L to 33-34^{o}C.

It is the authors' opinion that taking into consideration Θ_L, the only partition that comes in direct contact with the birds, in the development of thermal conditions within the broiler living zone will inevitably lead to the improvement of breeding technology, which would answer to birds' thermal preferences at various stages of the production cycle.

Keywords: Broiler house, Thermal conditions, Litter temperature, Operative temperature

1. Introduction

In poultry breeding, thermal conditions in the broiler living zone on a given day of the production cycle are most frequently evaluated by comparing air temperature inside the production hall (Θ_i) with air temperature recommended by standards or producers' instructions (Θ_{opt}).

Specialist literature which enumerates significant microclimate parameters of broiler houses does not always mention thermal radiation of partition walls coming in direct contact with the birds. Therefore, it is not surprising that the influence of litter on thermal conditions in the broiler living zone is often disregarded. The authors of this work first studied how litter dominates thermal conditions inside a broiler house in the years 2002-2004 during experimental research on heat exchange between a broiler house and surrounding ground. The research revealed that, irrespective of time of year, at the beginning of the broiler production cycle, litter temperature (Θ_L) is definitely lower than Θ_i, even by 6.5-13.5 K; afterwards, a short period of thermal comfort $\Theta_i = \Theta_L$ ensues; whilst in the last three weeks of the cycle, Θ_L is much higher than Θ_i, even by 13-16 K (Nawalany et al., 2004).

In EN ISO 7730 standards on indoor thermal comfort of people (2005), the temperature of radiation of inside surface partitions is given the same significance as air temperature Θ_i. These temperatures make it possible to establish the so-called operative temperature (Θ_o), calculated as an arithmetic medium of Θ_i and Θ_L. Consequently, it is Θ_o that most reliably determines indoor thermal conditions. The temperature of radiation of inside surface partitions affects Θ_o in such a way that partitions colder than Θ_i cause the feeling of cold, for example the floor colder than Θ_i by 4°C yields operative temperature of $\Theta_o = \Theta_i - 2$°C; while partitions warmer than Θ_i give the feeling of warmth. Considering the fact that analogical principles will apply to thermal conditions inside broiler houses, only radiation temperature of floor, that is litter Θ_L, will be of practical significance here. Radiation temperature of side walls in broiler houses can be disregarded as the broiler living zone encompasses solely the bottom layer of air which measures only 10-30 cm for birds in movement and even less for those remaining still. Dawkins and co-authors (2004) as well as Bieda and Nawalany (2006) agreed that broiler population exerts less influence on broiler house thermal conditions than litter temperature and humidity. Therefore, it can be assumed that Θ_L, bird population and Θ_i are most important parameters shaping thermal conditions in the broiler living zone. ΘWith ventilation and air-conditioning systems working properly, air movement in the litter zone does not usually exceed admissible values (0.1 $m \cdot s^{-1}$) so its influence on indoor thermal conditions can be disregarded. On the other hand, it is the concrete floor and ground beneath that exert a very significant influence on thermal conditions inside broiler living zone (Radoń et al., 2004; Radoń, 2004).

The aim of this paper is to analyze the influence of litter on thermal conditions in the broiler living zone on the basis of continuous measurements of Θ_L and ground temperature against the required Θ_{opt} and calculated Θ_o, occurring in real operating conditions of a winter and summer production cycle. Moreover, the paper characterizes heat exchange from litter to the ground beneath the broiler house.

2. Materials and Methods

The research was conducted in a broiler house belonging to a broiler farm at Ujazd, in the south of Poland (fig. 1). The broiler house, with a production hall of 1000 m^2, was bred with Ross chickens. The hall was equipped with heating, ventilation and fogging systems controlled automatically. The measurements were conducted until the 35th day of the winter production cycle (11.02- 18.03.2003) and until the 35th day of the summer production cycle (26.06- 01.07.2003). 6. The 6th week of the production cycle was omitted due to population reduction, which significantly disturbed indoor thermal conditions. Moreover, the breed was under daily monitoring (deaths) and weekly check of chicken weight gain (table 1.).

The temperature of litter surface was measured with the help of ten PT-100 sensors, with the accuracy of ± 0.1ºC, placed across the researched area (fig. 1c). Θ_L should be understood as the set of litter temperatures across the researched area ($\Theta_{L\,1}$; Θ_{L2}; Θ_{L3}……Θ_{L10}) measured at 10 measurement points at 6.00 pm, which is when the birds were normally active. It was assumed that the isofield of optimal litter temperature exists only when $\Theta_L = \Theta_{opt}$ +/- 1°C. Air temperature was recorded every hour and results were registered by a multichannel data logger produced by HP.

Before the production space was housed with birds, the non-insulated concrete floor was covered with a 10-centimetre layer of long straw (barley and wheat).

The researched broiler house, which fulfilled higher requirements with respect to ventilation, veterinary control, etc., allowed maximum population density admissible in Poland equaling 42.0 kg per 1 m^2. The start-up weight of the winter cycle population was 4.10 $kg \cdot m^{-2}$ and increased to 41.13 $kg \cdot m^{-2}$ on day 35. In the summer production cycle, the population weighed 3.51 and 38.13 $kg \cdot m^{-2}$, respectively.

Until week 3, the chickens were fed with DKA starter birdseed; in the weeks 4 and 5 – DKA grower; and from week 6 – DKA finisher. Throughout the entire breeding cycle, the birds had free access to water bowls. No bacterial or viral diseases which would significantly affect the production process and its results were observed during the researched production cycles.

3. Results

3.1 Litter temperature distribution

The results of Θ_L measurement were presented in a graphic form by means of isofields for selected production days, which made it possible to recognize thermal differences across the researched area (fig. 2 and 3). Based on delineated isofields, for each of the 35 days of the winter and summer production cycle, the proportion of litter area with Θ_L was defined compared to operative air temperature: $\Theta_L < \Theta_{opt}$ (the feeling of cold); $\Theta_L = \Theta_{opt}$ (thermal comfort) and $\Theta_L > \Theta_{opt}$ (the feeling of warmth), which were presented in figures 4a and 4b.

3.2 Winter production cycle

During the first 4 days of the production cycle, 100% of the researched area is characterized by $\Theta_L < \Theta_{opt}$; in the subsequent days, this proportion decreases until it reaches 0% in the 17th day of the cycle. A small isofield of thermal comfort $\Theta_L = \Theta_{opt}$ appears in day 5 and in such a scope maintains until the 20th day of the production cycle. The isofield of temperature $\Theta_L > \Theta_{opt}$ already appears in day 6 of the production cycle and maintains until the end. In the course of time, the isofield starts to develop towards the outside wall. On the 19th and 20th days of the production cycle, the isofield $\Theta_L > \Theta_{opt}$ divides the small isofield $\Theta_L = \Theta_{opt}$. From day 21 onwards, the whole researched area is characterized by temperature $\Theta_L > \Theta_{opt}$. At the beginning of the winter production cycle, Θ_L remains in the range of 22-24^{o}C, whilst on day 35 in the range of 30-34^{o}C. Temperature variation across the researched area was most conspicuous between the 5th and 6th day of the production cycle and equaled as much as 10-11 K. It decreased with time to reach 5 K.

3.3 Summer production cycle

The summer cycle is characteristic for a short, only 11-day, period of $\Theta_L < \Theta_{opt}$, including 5 days with 100% coverage. The period of thermal comfort $\Theta_L = \Theta_{opt}$ is even shorter and lasts 10 days. The $\Theta_L > \Theta_{opt}$ period begins on the 8th day of the production cycle, whilst on day 16 it already covers the entire research area, which maintains till the end of the production cycle. In the summer production cycle, the isofield $\Theta_L = \Theta_{opt}$ appears in the centre of the researched area on day 7; the following day, the other isofield, $\Theta_L = \Theta_{opt}$, appears in the near-wall zone. The isofield $\Theta_L > \Theta_{opt}$ appears on day 9 and until day 13 it is surrounded by the isofield $\Theta_L = \Theta_{opt}$. From day 15 onwards, the whole researched area is characterized by temperature $\Theta_L > \Theta_{opt}$. On the 1st day of the production cycle Θ_L equals 25-27^{o}C, and on the 35th day 33-34^{o}C. Compared to the winter season, Θ_L diversity across the researched are during the 35 days of the production cycle is insignificant and does not exceed 2-5 K.

On day 1, of both winter and summer production cycle, Θ_L was lower by approx. 6 K and 9 K respectively from recommended for that day temperature (Θ_{opt}=33^{o}C). However, on the 35th day of both production cycles, the maximum Θ_L equaled 34^{o}C and was higher from the temperature required for that day of the cycle (Θ_{opt}=20^{o}C) by 14 K.

3.4 Heat exchange to the ground

Thermal relationship between litter temperature and non-insulated floor temperature draw the authors' attention to the question of heat exchange between these agents. Conducted measurements of temperature distribution in the concrete floor and ground beneath during the winter and summer production cycle revealed temperature differences between the start and end of the given cycle and made it possible to determine isofield distribution as well as the directions of heat flux in the ground (fig. 5).

Established temperature distributions in the ground point towards a significant role of ground in broiler house thermal management (Radoń et al., 2004). At the beginning of the production cycle and also prior to that when the production hall is heated for breeding, a large portion of heat produced by heating devices transfers through the litter to the ground, to the detriment of local thermal management (fig. 5a and 5c). From the moment when $\Theta_L > \Theta_{opt}$, which coincides with the increasing surplus of heat in litter, the flow of heat flux from litter to the ground continues. This phenomenon gradually starts to determine thermal conditions inside the broiler house, as the ground receives heat surplus from the broiler living zone (fig. 5b and 5d). The average increase of ground temperature, only to the depth of 1 m, during the 35 days of the breeding cycle equals approx. 7 K in winter and approx. 6 K in summer. During technological breaks, the heat accumulated in the ground, particularly in colder seasons of the year, is mostly transferred to the air and only an insignificant part is retained until the next production cycle. The character of heat exchange between the broiler house and the ground described above occurs both during the winter and the summer production cycle.

4. Discussion

4.1 Evaluation of litter temperature influence on thermal conditions

From the day of housing till the 35th day of the production cycle, the distribution of Θ_L significantly differs from Θ_{opt} determined by zoohygienic standards. Therefore, it seems reasonable to describe thermal conditions in the broiler living zone with the help of Θ_o. The development of isofields in litter is a dynamic and complex phenomenon affected by the following parameters changeable in time: population size, periods of broiler activity and rest, humidity and biothermal processes occurring inside the litter, as well as heat flux from the litter to the ground, that is to the concrete floor and the ground beneath.

Population affects Θ_L in the first place by moistening the litter with chicken droppings which leads to litter fermentation. This is accompanied by heat production and heat transfer to the litter by birds remaining at rest. The authors' own research revealed that birds resting on the litter heat it relatively quickly with their own bodies and as a result of the fermentation process (Nawalany et al., 2004; Radoń, 2004). Broiler rest is divided into a number of periods, whose length depends on the difference between Θ_L of the place selected for rest and a certain limit value of Θ_L at which the chickens leave the place of rest. Results of other authors' studies point out that towards the end of the production cycle, the frequency of rest periods increases with the simultaneous decrease of their length. For example, 5-week birds begin their rest period at the temperature Θ_L = 34^{o}C and finish after approximately 10 minutes when Θ_L reaches 38^{o}C. In the case of 6-week chickens, limit temperature of litter, which makes the birds leave their place of rest, is Θ_L = 40^{o}C. The differentiation of thermal conditions in litter is conducive to birds' physical activity, which is favorable to the development of their bone structure and muscles (Reiter, 2006; Reiter and Bessei, 2009). However, it is a matter of discussion whether longer rest periods in the case of birds up to 3 weeks of age and shorter rest periods, lasting only a few minutes, in the case of birds older than 3 weeks are recommendable from the point of view of behaviorism and bird welfare.

From day 5 of the winter production cycle, significant daily fluctuation of Θ_L across a given area, which equals 5-11 K, provides a wider choice of place of rest, according to thermal needs of broiler chickens. The summer period is less favorable in that respect, as daily Θ_L variation across a given area equals, as already mentioned, only 1-3 K, which does answer chicken thermal preferences. Based on Sosnówka-Czajka and Herbut's findings (2001), chickens prefer lower temperatures as they grew older.

Taking into consideration the functioning of heating and air conditioning systems which maintain appropriate Θ_{opt} inside the broiler house for a given day of the production cycle, the only agent whose temperature varies during the day is litter. Only litter then can realize chicken's thermal preferences. Taking into consideration different thermal preferences of broiler chickens (Sosnówka-Czajka and Herbut, 2001), maintaining the daily isofield variation in the litter may turn out favorable for two reasons. Firstly, it will enable the birds to freely choose most suitable operative temperature Θ_o. Secondly, it will increase their physical activity (Reiter and Bessei, 2009). However, the value of preferred Θ_o generally depends on the age of chickens (Alsam and Wathes, 1991): the older they are the more willing to move towards areas of operative temperature Θ_o of approx. 20^{o}C. Moreover, previous research confirmed that temperature preferences change regularly during the day depending on bird activity (Sosnówka-Czajka and Herbut, 2001).

4.2 The role of ground in the development of thermal conditions

Considering the distribution of Θ_L in relation to temperature distribution in the concrete floor and ground beneath, it can be concluded that the role of ground in the development of thermal conditions inside a broiler house undergoes a radical change during the production cycle. Initially, the floor and ground beneath accumulate heat radiating from the production hall, which generates much larger energy losses than only heating the broiler house and maintaining Θ_{opt}. Yet from week 3 of the production cycle, when the thermal role of litter begins to dominate in the broiler house, the ground starts to receive the surplus of heat from the litter, thus limiting the increase of temperature of litter not occupied by birds to Θ_L = 33-34^{o}C. It needs to be clearly emphasized here that if the ground did not accumulate the surplus of heat emitted by the litter, we could expect that already in week 4 of the production cycle, Θ_L would reach its limit value for bird thermal stress.

4.3 A proposal to include operative temperature in the evaluation of thermal conditions

It is the authors' opinion that taking into consideration Θ_L in the development of thermal conditions within the broiler living zone and applying the new parameter to evaluate these conditions will inevitably lead to the improvement of breeding technology, which would answer to birds' thermal preferences at various stages of the production cycle. The proposal to include Θ_L, which according to research (Dawkins et al., 2004; Bessei, 2006; Meluzzi and Sirri, 2009) plays a significant role in the development of thermal conditions in the broiler living zone, into the scope of microclimate parameters to be monitored can be joined with other postulates stipulating the need to conduct further research on the improvement of thermal conditions for various breeds and genetic lines of broiler chickens at particular stages of the production cycle.

Systematic achievements in genetic research have led to increased nourishment and zoohygiene requirements and high broiler productivity. According to the authors, both chicken welfare and productivity may be still increased by introducing continuous monitoring of Θ_L, evaluation of thermal conditions based on Θ_o, and most of all new technologies for the regulation of litter temperature, for example, with the help of a hydronic radiant floor installation heating litter at the beginning of the production cycle and cooling it particularly from week 3 of the production cycle (Nawalany et al., 2010).

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Table 1. Production in the winter (11.02. -18.03.2003) and summer (26.06 -01.07.2003) production cycle

Cycle/ Day of cycle		Number of chicken	Weight (kg)	Stock density	
				(birds per·m^{-2})	(kg·m^{-2})
Winter	1	19720	-	-	-
	7	19506	4096	19.51	4.10
	14	19371	10266	19.37	10.27
	21	19277	15614	19.28	15.61
	28	19199	26878	19.20	26.88
	35	19132	41133	19.13	41.13
Summer	1	18700	-	-	-
	7	18465	3508	18.47	3.51
	14	18364	9365	18.36	9.37
	21	18286	15543	18.27	15.54
	28	18208	26401	18.21	26.40
	35	18156	38127	18.16	38.13

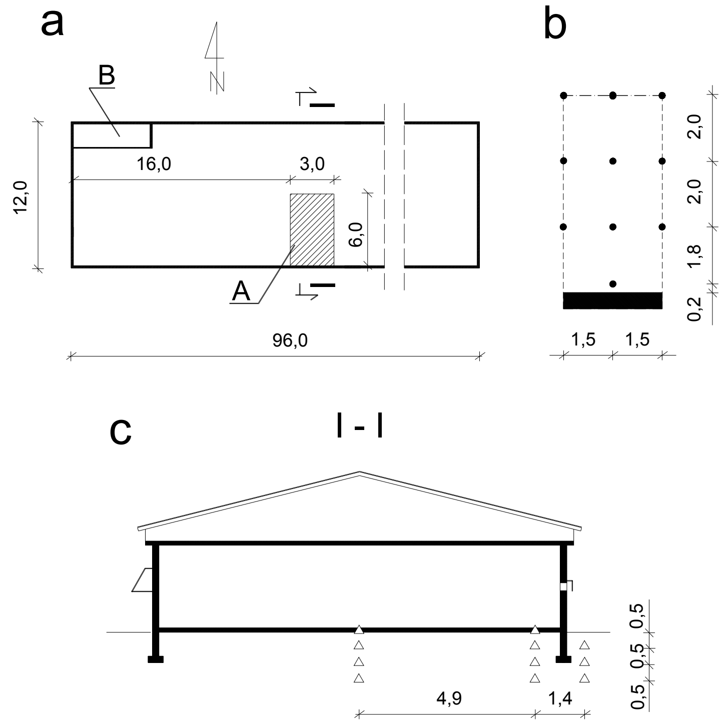

Figure 1. Orientation plan of the broiler house and the distribution of measurement points: a – projection, b – distribution of measurement points in the litter, c – cross-section; A – research area, B – broiler control room; ● – measurement points in the litter, Δ – measurement points in the ground.

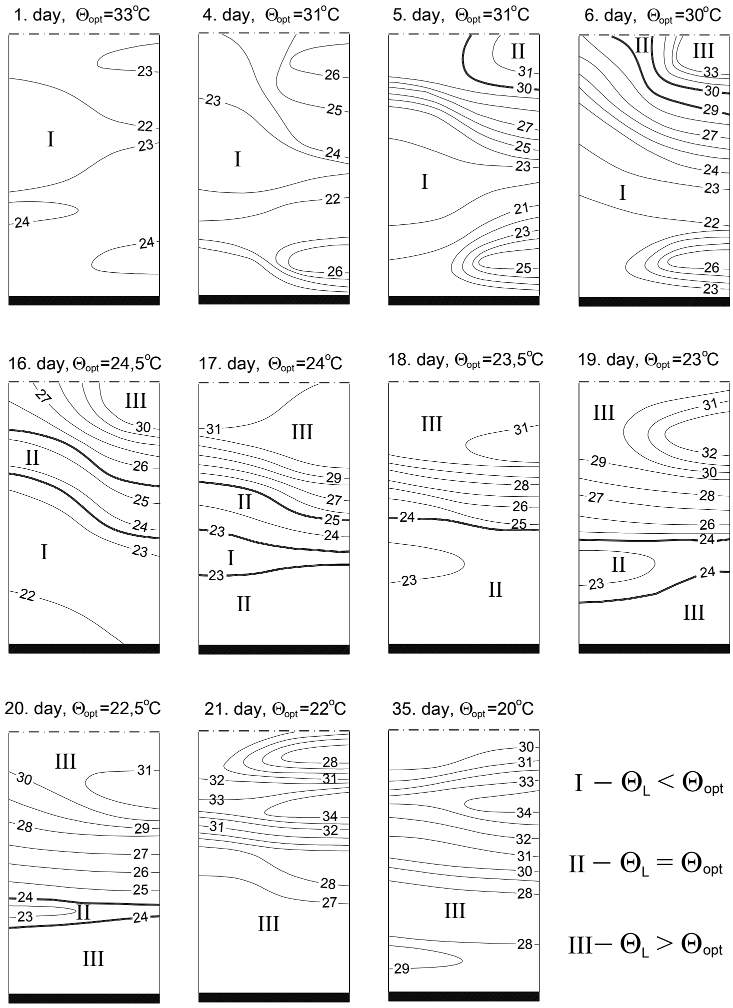

Figure. 2. Temperature distribution in litter Θ_L, winter production cycle (11.02. -18.03.2003) for selected days of the cycle with optimal air temperature Θ_{opt}

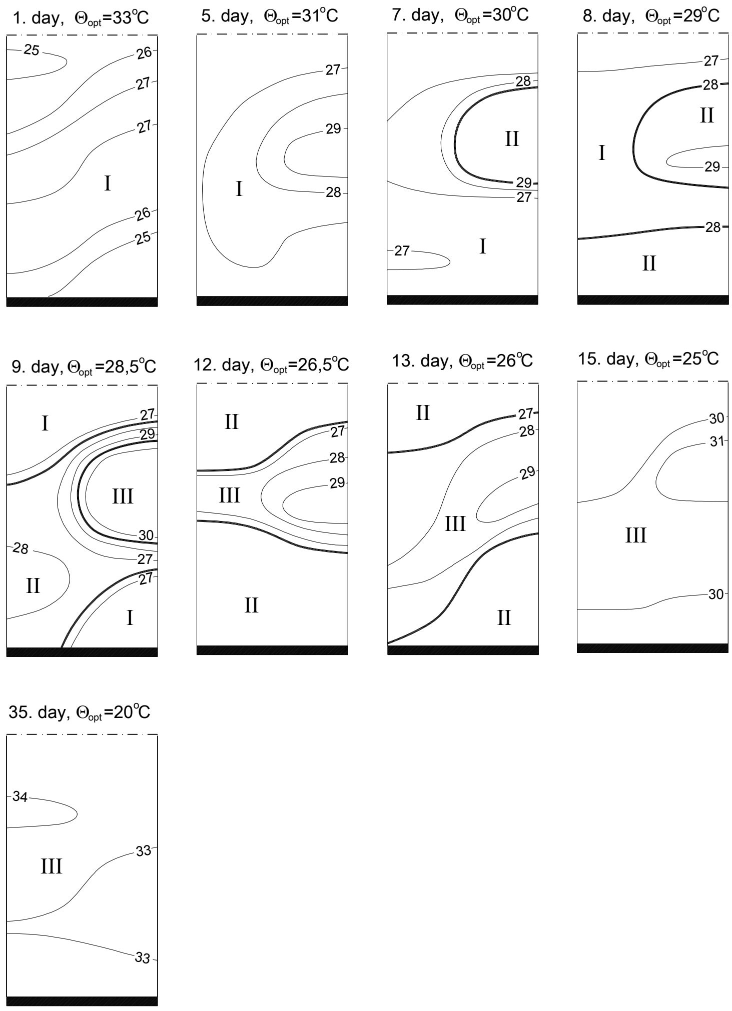

Figure 3. Temperature distribution in litter Θ_L, summer production cycle (26.06. -1.07.2003) for selected days of the cycle with optimal air temperature Θ_{opt}

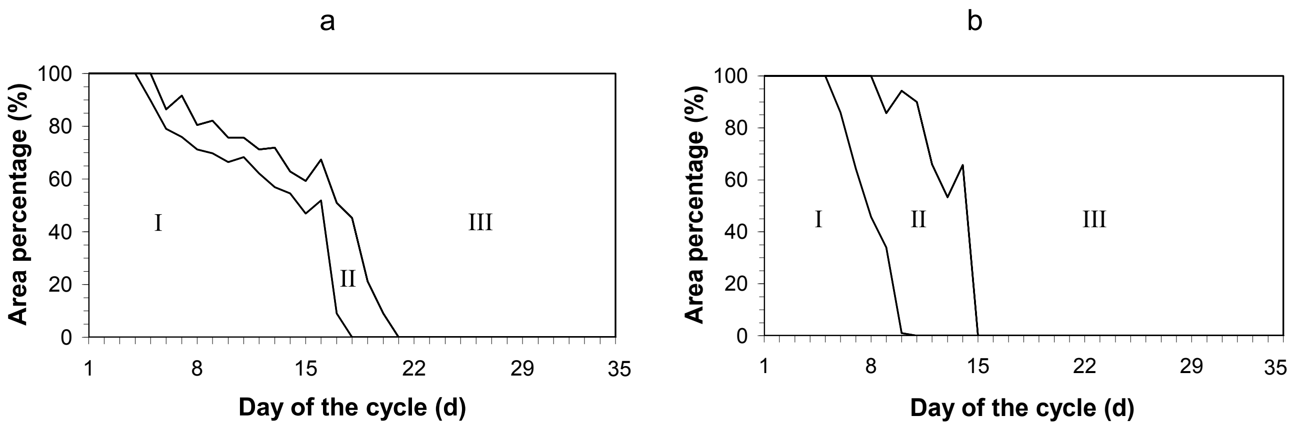

Figure 4. Percentage division of researched litter area with temperatures

I – $\Theta_L < \Theta_{opt}$, II – $\Theta_L = \Theta_{opt} \pm 1$ K, III – $\Theta_L > \Theta_{opt}$,

a – winter production cycle (11.02. -18.03.2003), b – summer production cycle (26.06 – 1.07.2003).

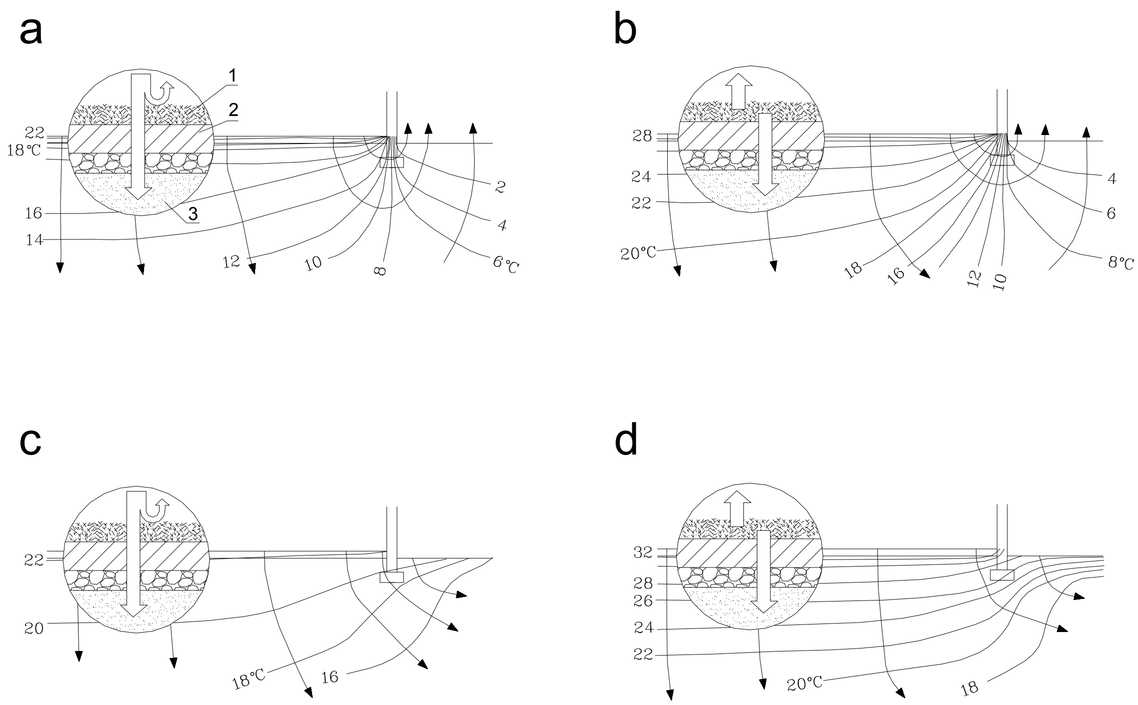

Figure 5. Temperature distribution and heat flux directions in the ground as well as outline of heat exchange between the litter, air and the ground; a – day 1 of the winter production cycle (11.02.2003), b – day 35 of the winter production cycle (18.03.2003), c – day 1 of the summer production cycle (26.06.2003), d – day 35 of the summer production cycle (1.07.2003), 1 – litter, 2 – concrete floor, 3 – ground