**ABSTRACT** Thermal comfort is of great importance in chickens to preserve body temperature homeostasis during the growth period and during environmental thermal challenges. Because surface temperatures contribute much to thermal comfort, this research is aimed at studying spatial distribution of surface temperatures of broiler chickens. For this purpose, temperatures of 26 different parts on the chicken body surface were measured using thermography during the growth period of 6 wk. It was observed that there were significant differences in spatial distribution of broiler surface temperatures. The greatest temperatures were measured at the positions with little or no feathering (i.e., cheek, skull, and inner thigh). The least temperatures were observed on the places with thickest feather cover (i.e., wing and breast). The surface temperatures decreased as a function of age from approximately 36 to 28°C. The spatial temperature range on the surface of the bird varied from 6°C in wk 1 to 15°C on wk 6. Temperature differences between the surface of the chicken and its surroundings were also studied, and it was found that in the range of 1 to 6 wk the age of the bird had significant effects on temperature difference ($P < 0.0001$). The temperature difference between the surface of the chicken and environment was at a maximum on wk 4 during the growth period of 6 wk.

**Key words:** temperature difference, temperature gradient, thermoregulation, broiler

**INTRODUCTION**

Quantifying an animal’s surface temperatures and its relation with the thermal environment is of prime importance in thermal biology. The difference between the temperatures of animal surface and the thermal environment is the driving force of sensible heat transfer (convection and radiation). Heat flow from and to the environment is a function of the temperature of the exposed surface (Prosser and Heath, 1991; Yahav et al., 2004). The contribution to heat exchange of surfaces whose temperature is close to the environmental temperature is small, whereas the surface whose temperature is constantly greater or lesser than the environmental temperature contributes significantly to heat exchange. Thus, in calculations of sensible heat transfer of different surface parts (of a bird) surface temperature measurement is a key element (Yahav et al., 2005).

It has been found that the temperatures of the core and feathered skin of a broiler chicken varied by not more than 5°C when exposed to a range of ambient temperature from 20 to 40°C. However, the surface body parts such as comb, shank, and toe varied by up to 20°C and exhibited wide fluctuations in constant environmental conditions (Richards, 1971). Skin temperature variation in time was observed during the course of the day as well as a function of age (Tessier et al., 2003).

Physiologically, control over the rate of heat transfer is exercised by altering the flow of blood to the body surface or by altering the rate of evaporation of water from the skin (perspiration) or respiratory tract (evaporation). Birds possess a thick, highly insulating coat of feathers over most of the body surface and lack sweat glands. Surface temperature changes according to the age of the animal (Richards, 1970). Change in time is dependent on number and quality of the feathers in different places, which act like an insulation layer. At greater temperatures evaporative cooling becomes increasingly important, and when environmental temperature equals the temperature of the body surface it finally represents the only way for loss of heat (Kleiber, 1961).

In their study with naked neck chickens, Yahav et al. (1998) proved the ability of the naked neck chickens, on the one hand, to thermoregulate at low ambient temperatures and, on the other hand, their slightly better
capacity to maintain body temperature at high ambient temperatures. Regulation of body temperature in dehydrated chickens was studied by Zhou et al. (1999). They suggested that dehydration leads to a lesser blood volume, which results in a decrease in blood flow to heat exchange organs and surfaces in broilers. This induces less sensible heat loss from extremities, less evaporative heat loss, and a greater sensible heat loss from trunk, subsequent to regulating their body temperature at a greater level of deep body temperature.

Thermography can be useful to study temporal skin temperature variations related to cellulitis lesions. Therefore skin temperature measurement using thermography in broiler chickens was studied by Tessier et al. (2003). Effects of potential confounding factors, such as bird’s handling duration, abdominal size, age, and time of day, were also estimated. Mean skin temperature was estimated from thermogram pictures by computer image analysis of a predetermined abdominal area.

Spatial gradients of surface temperatures in chickens were also studied by other researchers. Richards (1971) measured surface temperatures on 7 places by a surgical implantation of thermocouples. Using a similar thermography method, Yahav et al. (1998) quantified the surface temperatures, but the research did not consider the effect of the bird’s age on the results. Making use of thermography as well, Tessier et al. (2003) determined only the distribution at the abdominal area and only 3 discrete times during the rearing period.

The objective of this study was to quantify the spatial temperature distribution of 26 different points on the surface of broiler chickens using thermography. Although it was not aimed to calculate the exact heat losses from the birds, differences in surface temperature and the environmental air temperature were also studied to have an idea on the driving force in heat loss from the broiler chicken through its commercial growth period of 6 wk. In addition to that age-associated variation in temperature was studied to evaluate age-related changes in body temperature. Thus, in the light of past research, this study proposes a further detailed analysis on the spatial gradient of surface temperatures on 26 different places on the bird body surface continuously during the rearing period.

MATERIALS AND METHODS

Birds and Housing

The measurements described here were conducted during larger growth control experiments (Aerts et al., 2003a,b). The ethical commission of the Katholieke Universiteit Leuven approved the performed experiments. All the experiments were conducted with Ross 308 broilers, mixed-sex, obtained from a local hatchery.
Female broiler breeders were about 45 wk old. In the hatchery the chicks were vaccinated against Newcastle disease (ND Hitchner G149, Antec International Ltd., Sudbury, UK). The birds were treated at arrival against infectious bronchitis (Nobilis, IB H120, Intervet International, Boxmeer, the Netherlands) followed by a booster vaccination (Nobilis, ND Clone 30, Intervet International) at d 15 against Newcastle disease. Measurements were performed in a compartment with 2,900 birds kept on chopped straw (stocking density of 16 birds per m²). A conventional lighting schedule of 23 h of light and 1 h of darkness was used. Mean air temperature in the room temperature decreased from 29 to 23°C during the 6 wk of growth. Water was freely available to all birds. Five individual broiler chickens were randomly chosen for measurement and analyzed once a week during the rearing period of 42 d. The compartment was equipped with 4 weighing platforms connected to a weighing computer (747 version A1, Fancom B.V., Panningen, the Netherlands) for measuring the average weight of the flock birds every 24 h. Feed consumption was recorded daily. The compartment was equipped with an automatic feeding system (Minimax, Roxell N.V., Maldegem, Belgium). The testing facility was situated in a broiler house of the Agricultural Research Centre Ghent in Belgium.

**Diets**

The broilers were given ad libitum commercial starter feed followed by a grower feed. A starter diet with 211 g/kg of CP and 2,960 kcal of AMEn/kg was given until 10 d of age. From d 11 until d 42, a grower diet with 209 g/kg of CP and 3,060 kcal of AMEn/kg was offered.

**Measurements**

Air temperature ($T_a$) was measured in the ridge and at 2 positions near the side walls (about 1 m above the floor) by means of thermocouples (Techmark Inc., Lansing, MI; 0.5°C accuracy). The mean air temperature of the 3 sensors was used for calculating mean $T_a$. Because the study is more focused on surface temperatures and is not aimed to calculate exact heat losses, air humidity was not measured.

Air velocity ($v$) was measured with a unidirectional air velocity sensor (TSI 8455, accuracy = 2% of reading). Air velocity was measured at 0.3 m above the litter, and the sensor was positioned to measure the airflow along the longitudinal axis of the house. Every measuring day, measurements were made at 5 different positions in the first half of the house, and the average value was calculated once for each week during 6 wk.

The surface temperatures of the broilers ($T_s$) were as determined based on images of an infrared camera (AGEMA Thermovision 570, 0.1°C nominal sensitiv-
ity, 7.5- to 13-μm infrared spectrum, 24° lens, thermal emissivity set to 0.95). Per bird, 3 images were taken (left side view, top view, and bottom view—see Figure 1). The birds were picked up and placed on a wooden plate, and the images were taken as fast as possible to reduce stress effects. The birds were handled by wearing latex gloves to avoid influences of heat and moisture of the hands on the temperature of the feathers.

During the growing period, measurements of $T_c$, $T_e$, and $v$ were performed on d 3, 8, 16, 23, 30, 37, and 42. The values of the air temperature $T_a$ and average weight of the birds were registered daily from the process controllers. For more information about the experimental setup, please refer to Aerts et al. (2003a,b).

To measure the surface spatial temperature distribution, different body parts of the birds were labeled in the images. Temperatures in those parts were recorded weekly during the growth period of 42 d (See Figure 1).

**Data Analysis**

The temperature data were analyzed and observations were categorized in 4 main subjects as follows:

1) Spatial gradients of absolute surface temperatures of broiler chickens measured once a week during 6 wk of growth period. Spatial gradient stands for the difference in temperatures on different areas of the surface of the bird.

2) Change of absolute surface temperatures and the spatial distribution as a function of age.

3) Spatial distribution of temperature differences measured once a week during 6 wk of growth period. Temperature difference ($\Delta T$) represents the difference in temperatures of the certain surface body part and the environmental air temperature.

4) Change of differences between the surface and air temperature as a function of age.

Inequalities between the means were established using Tukey’s honestly significant difference test. An analysis of covariance (ANCOVA) test was applied for testing the effects of 2 main factors, the age (in weeks), and the body part of the chicken, together with continuous variables air temperature and air velocity on $\Delta T$ for 3 different views. Calculations were performed using the SAS Statistics Software release 9.1.3 (SAS Institute Inc., Cary, NC) and Statistics Toolbox of Matlab Software (The Mathworks, Natick, MA).

**RESULTS AND DISCUSSION**

In this study, the temperatures on 26 different points on the surface of 5 individual broiler chickens were measured and analyzed once a week during the rearing period of 42 d.

### Spatial Gradient of Absolute Surface Temperatures of Broiler Chickens at Certain Age

Large spatial gradients were observed on the 3-dimensional surface of the broiler chickens. The gradients ranged up to more than 10°C, depending on the body part and the age of the bird (see Tables 1, 2, and 3). The warmest areas of the bird were the cheek and the inner thigh and were always between 39 and 41°C due to the absence of isolating feathers. Also in the inner thigh, there is an absence of feather growth in this distal band that run dorsally from the vent (Leeson and

**Table 2. The weight (g) and absolute temperatures (°C) on certain parts of the chicken body surface as seen by the top view**

<table>
<thead>
<tr>
<th>Day</th>
<th>Comb</th>
<th>Skull</th>
<th>Neck</th>
<th>Shoulder</th>
<th>Back</th>
<th>Sternum</th>
<th>Upper wing</th>
<th>Wing</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>37.0 ± 1.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.2 ± 1.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.5 ± 1.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.5 ± 1.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35.3 ± 1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.1 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.5 ± 1.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.9 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>37.0 ± 1.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>35.7 ± 2.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>33.0 ± 2.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>36.4 ± 1.4&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>36.3 ± 1.4&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>34.7 ± 2.8&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>37.4 ± 2.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>33.2 ± 2.0&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>36.1 ± 1.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>33.4 ± 1.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>30.2 ± 0.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>33.9 ± 1.8&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>34.1 ± 2.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>31.8 ± 1.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>35.2 ± 3.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>29.3 ± 1.0&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>22</td>
<td>36.5 ± 1.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>35.9 ± 0.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>31.3 ± 1.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>34.8 ± 2.4&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>35.8 ± 3.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>32.1 ± 1.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>36.4 ± 3.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>32.0 ± 1.0&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>30</td>
<td>34.7 ± 2.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>36.1 ± 1.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>31.2 ± 2.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>31.4 ± 3.4&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>32.0 ± 1.6&lt;sup&gt;ab&lt;/sup&gt;</td>
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</tr>
<tr>
<td>37</td>
<td>31.4 ± 2.4&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>27.0 ± 1.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>25.4 ± 1.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>24.8 ± 0.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>26.1 ± 2.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>23.8 ± 0.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>24.6 ± 0.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>24.9 ± 1.0&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Means within a column with no common superscript differ significantly ($P < 0.05$).

<sup>1</sup>The temperatures are measured once a week during the rearing period of 6 wk. Mean ± SD, n = 5.

**Table 3. The weight (g) and absolute temperatures (°C) on certain parts of the chicken body surface as seen by the bottom view**

<table>
<thead>
<tr>
<th>Day</th>
<th>Crop</th>
<th>Upper part of breast</th>
<th>Mid part of the breast</th>
<th>Abdomen</th>
<th>Cloaca</th>
<th>Upper wing</th>
<th>Inner thigh</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>34.8 ± 1.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.1 ± 0.6</td>
<td>36.6 ± 1.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>36.2 ± 1.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.8 ± 1.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>34.5 ± 1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>38.0 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>10</td>
<td>35.9 ± 1.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>38.2 ± 2.0</td>
<td>39.4 ± 1.7&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>38.7 ± 1.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>35.7 ± 3.4&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>36.5 ± 1.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>39.3 ± 1.5&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>15</td>
<td>35.2 ± 1.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>37.7 ± 0.5</td>
<td>38.5 ± 0.8&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>38.1 ± 1.3&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>34.1 ± 1.7&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>34.2 ± 0.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>40.9 ± 1.5&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>22</td>
<td>35.9 ± 1.1&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>38.8 ± 0.3</td>
<td>38.6 ± 1.2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>39.3 ± 1.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>36.1 ± 2&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>35.7 ± 2.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>40.7 ± 1.1&lt;sup&gt;ab&lt;/sup&gt;</td>
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<tr>
<td>30</td>
<td>33.8 ± 3.8&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>39.1 ± 1.2</td>
<td>38.3 ± 1.8&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>36.3 ± 2.5&lt;sup&gt;ab&lt;/sup&gt;</td>
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<td>31.5 ± 1.5&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>40.6 ± 1.4&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
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<td>37.0 ± 1.1</td>
<td>34.7 ± 2.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>32.0 ± 2.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>28.5 ± 3.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27.4 ± 5.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>37.3 ± 5.4&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Means within a column with no common superscript differ significantly ($P < 0.05$).

<sup>1</sup>The temperatures are measured once a week during the rearing period of 6 wk. Mean ± SD, n = 5.
Walsh, 2004). Due to absence of feather growth in these areas, the heat flux was larger to the air. The coldest areas were the neck, wings, and sternum. This is probably due to the strong isolating properties of the feathers on these areas. The least temperature on these areas decreased from 33 to 24°C as the birds grew.

**Change of Absolute Surface Temperatures and the Spatial Gradient as a Function of Age**

As the birds grew, the temperature gradient on the surface of the broilers increased most likely due to less uniform feather cover. At wk 1, the gradient was (maximum – minimum) 6°C, but on wk 6 it reached 15°C on the whole body surface. This increase was observed in all views and occurred almost linearly ($R^2 = 0.94$). When only the absolute surface temperatures were considered, the overall trend was an average (of all chickens and body parts) decrease with time from approximately 33 to 24°C as the birds grew.

**Spatial Distribution of Temperature Differences at Certain Ages**

Temperature differences between the body surface and air temperature ($\Delta T = T_s - T_a$) were also calculated and analyzed. Different body parts had different $\Delta T$. In the top view the comb had the greatest temperature gradient, whereas the wing had the least. It is mentioned in the literature that the head and neck region and perhaps some around the abdomen are poorly feathered; hence, insulation is quite poor in those areas (Leeson and Walsh, 2004). The $\Delta T$ was greatest in the top wing and least in the inner thigh in the bottom view. Cheek had the greatest $\Delta T$. Wing on the other hand had the least $\Delta T$.

**Change of Differences Between the Surface and Air Temperature as a Function of Age**

A 2-way ANCOVA test was applied for testing the effects of 2 main factors, the age (in weeks) and the body part of the chicken, together with the continuous factors of air temperature and air velocity on the mean of the $\Delta T$ for 3 different views. Results can be seen in Table 4. Additionally, $T_a$ (°C) and the air velocity (m/s) during the rearing period of 6 wk can be found in Figure 2. The inside air temperature was controlled by a controller to a desired trajectory dependent on age of birds. Ventilation system helped to maintain the inside temperature to these preset values. Therefore the increase in ventilation and consequently air velocity during the last week of the experiment was due to exceptionally warm outside climate (June 2002).

The main effect age of the chickens revealed a significant result on the temperature difference for all views because the $P$-values were all less than 0.0001 (confidence intervals were set to 95%). Body part, as the second main effect, was significant for side view but insignificant for the top and bottom views ($P = 0.0049, 0.7125, \text{and} 0.6177$, respectively). There was a

| Table 4. Results of analysis of covariance test$^1$ |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Item            | Degrees of freedom | Type III sum of squares | Mean square | $F$-value | $P > F$ |
| Side view       |                  |                     |               |            |        |
| Age             | 1                | 850.4               | 85.4          | 232.5      | <0$^*$ |
| Body part       | 6                | 96.1                | 9.6           | 2.6        | 0      |
| Age × body part | 6                | 104.9               | 10.5          | 2.8        | 0$^*$  |
| Top view        |                  |                     |               |            |        |
| Age             | 1                | 848.6               | 84.8          | 192.7      | <0$^*$ |
| Body part       | 6                | 16.4                | 2.7           | 0.6        | 0.71   |
| Bottom view     |                  |                     |               |            |        |
| Age             | 1                | 718.2               | 71.8          | 128.3      | <0$^*$ |
| Body part       | 6                | 5.4                 | 2.7           | 0.5        | 0.62   |
| Age × body part | 6                | 8.3                 | 4.2           | 0.7        | 0.48   |

$^1$Numbers with an asterisk represent the significant effects, interactions, or both (confidence interval of 95%).
significant interaction between age and body part only in the side view ($P = 0.0022$). That meant that $\Delta T$ changed differently in different body parts of the bird in different ages. Age and body part interactions were not significant in other views. The covariate air velocity did not show any significant effect on $\Delta T$; therefore, it was discarded from the model to make it less complex.

Air temperature, on the other hand, was too much correlated with the main effect age (correlation coefficient = 0.98); therefore, its effect could not be differentiated from the effect of age on $\Delta T$.

Figure 3 showed the differences between the air and the surface temperature of different body parts of broiler chickens as seen by side, top, and bottom views. Figure 4 represented 3 boxplots on the effect of age on $\Delta T$ for each view. The box had lines at the lesser quartile, median, and upper quartile values. Whiskers extended from each end of the box to the adjacent values in the data. Outliers were data with values beyond the ends of the whiskers. Outliers were displayed with a + sign. Both figures showed that the differences ($\Delta T$) tended to increase in the first 4 wk and then decrease again to lesser values than the first week showing a parabolic response.

There could be 3 factors involved in the occurrence of this maximum $\Delta T$ at wk 4. One reason could be the molting of the feathers at that specific age. From the time the bird is hatched until it becomes an adult, feathering passes through several changes of appearance. These changes are due largely to replacement of the feathers. Four generations of feathers grow out of the same follicle. All chicks are covered with a dense coat of down when they hatch. The second molt usually begins at around 4 to 5 wk, and for the modern broiler chickens, this is the only molt of significance (Leeson and Walsh, 2004). Appearing around the same periods, the maximum $\Delta T$ measured by thermogram in all views could be due to this second molting.

The other 2 reasons could be the increase in air velocity or decrease in air temperature in the broiler house during the growth period (see Figure 4). Statistical results from the ANCOVA test proved that increase in air velocity did not have a significant effect on $\Delta T$. Therefore it can be concluded that this factor was not the reason.

On the other hand, it was difficult to conclude the effect of the inside air temperature because it was set to decrease as a function of age (therefore causing a high correlation) as a usual broiler house management practice. Therefore the reason for $\Delta T$ showing a maximum at wk 4 could be 1) physiological: a result of molting the feathers, or 2) management related: decreasing the inside temperature depended on age of birds.

**CONCLUSIONS**

In this study 3-dimensional surface temperatures of broiler chickens were monitored during their rearing period of 6 wk. Temperature measurements were taken once a week from 3 different (camera) views, revealing temperature information on the surface of 26 different body parts. Absolute surface temperatures, spatial gradients, and their change as a function of time were investigated. Additionally, the differences between the absolute surface and air temperatures were calculated to have more insight on the thermal sensations on different body parts of the bird. The absolute differences and their gradients, as well as alteration as a function of age, were studied.

From thermal measurements of the 3-dimensional surface temperatures of broiler chickens, it was observed that there were large gradients in surface temperature (more than 10°C) depending on the area of the body. Areas with little or no feathering showed the greatest temperatures (e.g., cheek and inner thigh were 39 to 41°C). On the other hand, the least surface tempera-
Furures were observed at the places with most developed feather cover (e.g., neck, wing, and sternum were 33 to 24°C). As chickens grew, the absolute temperatures on different body parts decreased from 36 to 28°C. Gradients in temperature on the surface, on the other hand, increased as a function of age and varied 6°C during wk 1 to 15°C until wk 6.

In addition to absolute surface temperatures, the differences between the surface temperatures and the surrounding air temperature were calculated. Age of the bird had a significant effect on ΔT (all $P < 0.0001$). The ΔT were at a maximum from the unfeathered body parts, such as cheek, comb, and shank, and it was at a minimum from the well-covered wing. The ΔT were at a maximum in wk 4 during the growth period of 6 wk. The authors suggest that this could be 1) physiological: a result of molting the feathers, or 2) management related: decreasing of the inside temperature depended on age of birds.

This study proposed not only 3-dimensional temperature distribution on the body of broiler chickens but also provided knowledge on how certain temperatures on certain parts of the body evolved during the growth period of 42 d. The differences between the surface and the surrounding air temperature gave insight into the thermal sensation of the bird.

**REFERENCES**


