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Release of heat, moisture and carbon dioxide in an aviary system for laying hens

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Abstract 1. Production of total heat, divided into sensible and latent heat, together with carbon dioxide and animal activity were determined at different ambient temperatures under full-scale conditions in an aviary system with loose-housed laying hens.

2. Sensible heat production decreased approximately linearly with increasing ambient temperature and was lower during the day than at night. One explanation may be that some sensible heat produced by the hens was converted to latent heat by evaporation of moisture due to increased activity of the hens during the day (scratching in the bedding and drinking/waste water).

3. Latent heat production increased with increasing ambient temperature and was higher during the day than at night. This confirms that the hens, by agitating the bedding during the day and by spilling drinking water, transferred some sensible heat to latent heat by evaporation.

4. Total heat production decreased with increasing temperature because the hens by thermoregulation decreased their metabolism in order to maintain a constant body temperature. The difference between day and night values of total heat production was less pronounced than in the case of sensible and latent heat. In comparison with current guidelines the measurements showed a higher total heat production (22% higher at 20°C).

5. There was a large diurnal variation in carbon dioxide production, closely correlated to measured animal activity; on average carbon dioxide production during the 12-h dark period was only 66% of the production during the day.

INTRODUCTION

Most data on the production of sensible heat, moisture and carbon dioxide by animals are based on experiments carried out in laboratory conditions. Standard equations for estimation of animal heat and moisture production (CIGR, 1984) do not take into consideration the difference between housing systems. Experience from commercial egg production has also shown that the deviation between laboratory studies and real production is high.

There is also a tendency in egg production in several European countries to keep laying hens in systems that enable the hens to move around in the entire system instead of keeping the hens in cages. These systems include more bedding material and manure stored in the systems resulting in different activity patterns which will influence the release of heat, moisture and carbon dioxide. It is therefore important to increase knowledge about the production of heat and carbon dioxide in houses for laying hens in conditions that occur in real alternative loose-housing systems considering the influence of housing and manuring system, activity pattern etc. To obtain these data requires measurements of heat and carbon dioxide balances with high precision under full-scale conditions.

The release of heat, moisture and carbon dioxide in houses for laying hens is influenced by the indoor dry bulb air temperature, but the indoor relative humidity also affects the partition between sensible and latent heat. Air velocity in the surroundings will also affect the release of sensible heat by convection. Air temperature influences the condition of plumage. Cooper and Washburn (1998) found that feather weight was significantly greater at 21°C than at 32°C for chickens. Maghirang *et al.* (1991) found that the concentration of carbon dioxide was significantly lower in hot weather than in cold weather. Food intake and composition are also important, as they make up the source of energy.

Pedersen (1975) showed that an increase in air velocity from 0·2 to 0·5 m/s increased daily gain and food consumption of broilers. However, food conversion was impaired. At high ambient temperatures increased air velocities improves the ability of birds to release sensible heat from their bodies. Investigations (Siegel and Drury, 1968; Drury, 1966; Drury and Siegel, 1966) showed that the body temperature could be kept 1° to 2°C lower at an air velocity of 2·5 m/s rather than 0·1 m/s.

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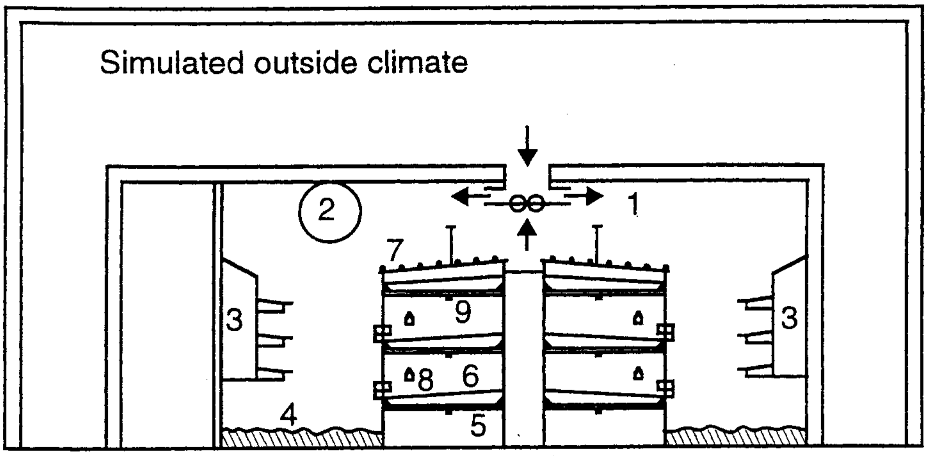


Figure 1. *Climate chamber equipped with an aviary system.*

Heat and moisture production from poultry are also greatly influenced by lighting conditions (Riskowski *et al.*, 1978; Zulowich *et al.*, 1987; Xin *et al.* 1996). About a 25% reduction in moisture, sensible and total heat production can be expected when switching from light to dark conditions for chickens (Xin *et al.* 1996). McQuitty *et al.* (1985) found during measurements in commercial farms with layers in cages that carbon dioxide production was higher during light than during dark periods.

Housing conditions will influence the distribution of total heat production of sensible and latent heat, because evaporation of spilt drinking water and evaporation of water from manure/litter consumes heat. For houses with non-composting bedding, the energy for evaporation can only be taken from the animal sensible heat (or supplemental heat). According to CIGR/ASAE (1999) the release of sensible heat from laying hens in cages accounts for 69% of total heat at 20°C but only 52% for hens in floor housing systems where manure is stored in the house for weeks or months. The basic difference between the 2 systems is that hens kept in cages have no access to the bedding/manure as opposed to the floor housing system where scratching is integral to the system. Housing systems with storage of manure for long periods will also increase the release of carbon dioxide (Gustafsson and Mårtensson, 1990).

The objective of these investigations is to determine the release of sensible, latent and total heat, the influence of ambient dry bulb air temperature on carbon dioxide and the activity pattern under real conditions in an aviary system for laying hens.

MATERIALS AND METHODS

Aviary system

The investigations were carried out in a climate chamber equipped with an aviary system (Marielund) at the research station Alnarp Södergård (Figure 1). The chamber was surrounded by a temperature-controlled air space where the inlet and surrounding air temperatures could be varied over a wide range, thereby making it possible to vary the indoor air temperature. With a constant ventilation flow it was thus possible to vary indoor air temperature.

The chamber had a floor area of 87 m^2. During the investigations 685 Lohmann Selected Leghorn layers were kept in the system. They were 417 to 476 d old with an average weight of 1·8 kg. The aviary system was constructed with 3 horizontal levels with wire mesh (Figure 1). The upper level was equipped with perches. Each level had manure conveyors below the wire mesh. The manure was removed from the conveyors once a day. Part of the floor was covered with a bedding of gravel approximately 40 mm deep. The function and design of the system was intermediate between a cage and a floor system.

The layers were fed *ad libitum* from automatic conveyors on each level. The metabolisable energy content of the food was 11·2 MJ/kg and intake was 1·39 MJ/hen/d during the investigations. The layers had free access to water through water nipples at each level of the system. Spillage water was thereby collected from the manure conveyors. The average water supply was 0·212 l/hen/d and the egg production was 57 g/hen/d.

The period with artificial light and its intensity were automatically controlled. The light period was from 03·30 to 19·30. Maximum light intensity occurred between 08·00 and 13·00 during work operations whereafter the intensity was slightly lowered. The intensity of the light was gradually decreased after 18·00. The maximum intensity varied between 27 and 48 lux in the walking alleys while it was considerably lower, 1 to 4 lux at the different levels of the housing system. Due to unstable conditions in periods with gradually changing light intensity, the night period is defined as 20·00 to 03·00 and the day period as 08·00 to 18·00. Work operations were mainly carried out from 08·00 to 13·00.

Inlet air was sucked into the chamber through 2 inlets at the ceiling which each created 12 horizontal air jets. Outlet air was exhausted at a height of 2·5 m from 1 gable. No extra heat was added to the system except the heat generated from the artificial light during the day period. The maximum effect of the light sources was 845 W.

Measurements

Sensors for measuring dry bulb air temperatures, relative humidities, ventilation rate, carbon dioxide concentration and activity were connected to a computer via an isolated measurement pod: 26 d of measurements were analysed.

Dry bulb air temperatures were measured with thermocouples type T (Cu/Cu-Ni) with 5 sensors in the inlet and 4 in the outlet air, respectively. Dry bulb air temperatures were also measured in 6 other locations in the airspace around the climate chamber for determining heat transmission losses. The air temperatures at different locations inside the climate chamber differed very little from the outlet temperature because of the mixing of the indoor air by the air jets created by the air inlets. The average indoor dry bulb air temperature was therefore defined as the average of the measured outlet dry bulb temperatures. The accuracy of the temperature measurements in individual locations is assumed to be better than 0·4°C (Schlumberger, 1991).

Relative humidities were measured with electronic humidity sensors (Rotronic) in the inlet (2 sensors) and outlet air (2 sensors). The sensors were calibrated against Li-C1 solutions corresponding to 30%, 60% and 90% relative humidities. The accuracy of the humidity sensors is estimated to ±3%.

Ventilation rate was continuously measured with a free-running impeller measuring fan (FANCOM), located in the exhaust air duct. The impeller had been calibrated at the Research Center Bygholm, Denmark, before and after the installation. The accuracy of the impeller was better than 3% of the measured value.

Carbon dioxide concentration in the outlet air was measured with an optical analyser (Riken Keiki). The analyser was calibrated frequently against calibration gases with concentrations of 0 and 1830 ppm respectively. The accuracy of the analyser was better than ±25 ppm. However, there were some drift problems with the analyser during the measuring period. Periods with drift problems have therefore been excluded from the analysis of carbon dioxide production. It has therefore not been possible to analyse the influence of temperature on carbon dioxide production. However, it was possible to analyse night/day relationships. The density of the exhausted air was corrected according to the average outlet air temperature measured with thermocouples.

The activity in the chamber was measured with 4 activity sensors developed at the Research Center Bygholm (Pedersen and Pedersen, 1995) and based on infra red motion detectors, of which 4 were in use. The level of signal from the 4 activity sensors differed considerably depending on the location of the sensors inside the chamber where 2 were placed above the perch area close to the animals and the other 2 above the floor area. The signals were weighted individually and expressed relative to the daily mean, with the ratio:

$$a(t) = \frac{u(t)}{u_{average}} \tag{1}$$

Balance equations and evaluation

The release of sensible heat was calculated from the equation:

$$\begin{aligned} P_s = \frac{q \cdot \rho_a \cdot Cp}{3.6} \cdot (T_{out} - T_{in}) + U_f \cdot A_f \cdot (T_{out} - 7) + \\ U_{w,c} \cdot A_g \cdot (T_{out} - 18) + U_{w,c} \cdot A_{w,c} \cdot (T_{out} - T_{a,s}) \end{aligned} \tag{2}$$

To determine the release of sensible heat, it was necessary to determine the heat transmission losses from the building surfaces of the climate chamber according to the heat balance equation above. These consist of heat loss to the floor, to an adjacent heated room at 1 gable and from the walls and ceiling to the surrounding air space. The ground temperature for the floor was set to 7°C and the temperature in the adjacent room to 18°C. The insulation of the walls and the ceiling was equal so their heat transmission coefficients (*U*-values) are assumed to be identical. The values U_f and $U_{w,c}$ were determined at stationary conditions by heating the air inside the chamber with a 10,000 W electrical heater in 2 trials at low and high temperature levels, when there were no hens inside the chamber. The measurements were carried out both with and without bedding on the walking alleys in order to evaluate the influence of floor insulation on the heat transmission losses. The *U*-values derived from 2 trials with bedding are calculated to U_f=0·70 W/m^2, °C and $U_{w,c}$=1·02 W/m^2, °C respectively. Without bedding the total heat transmission loss was approximately 5% higher than with bedding.

The mass balance of moisture gave the production of moisture as:

$$F = q \cdot \rho_a \cdot (X_{out} - X_{in}) \tag{3}$$

where

$$X = \left(\frac{\phi \cdot 622}{100}\right) \cdot \left(\frac{p}{1013 - \frac{\phi \cdot p}{100}}\right) \tag{4}$$

$$p = 10.0e^{\left(51.9171 - \frac{1350.4}{T} - 4.5453 \ln T\right)} \tag{5}$$

According to CIGR (1992) latent heat production was calculated as:

$$P_l = F \cdot 0{\cdot}680 \tag{6}$$

Total heat production was determined as:

$$P_{tot} = P_s + P_l \tag{7}$$

The balance of carbon dioxide gave the carbon dioxide production as:

$$K = q \cdot \rho_c \cdot (C - 350) \tag{8}$$

Accuracy of determinations

The maximum error of determinations of sensible heat production was estimated from:

$$\frac{/\Delta P_s/}{P_s} = \frac{/\Delta q/}{q} + \frac{/\Delta \rho_a/}{\rho} + \frac{/\Delta (T_{out} - T_{in})/}{T_{out} - T_{in}} + \frac{/\Delta UA/}{UA} \tag{9}$$

The estimated maximum errors were 3% for ventilation rate, 0·003 kg/m^3 for air density, 0·6°C for temperature difference and 5% for total heat transmission loss. According to Equation 9, the maximum error will be dependent on the temperature difference between outlet temperature and inlet/airspace temperatures. At a low temperature difference of 5°C the maximum error of sensible heat may be as high as 20% while it decreases to 11% at a temperature difference of 20°C.

The corresponding maximum error of latent heat production was:

$$\frac{/\Delta P_l/}{P_l} = \frac{/\Delta q/}{q} + \frac{/\Delta \rho_a/}{\rho_a} + \frac{/\Delta (X_{out}\ X_{in})/}{X_{out} - X_{in}} \tag{10}$$

The maximum error in determining the difference in water content between outlet and inlet air was estimated to be 0·26 g/kg. According to Equation 10 the maximum error of latent heat production will be 8%.

The maximum error of carbon dioxide production was:

$$\frac{/\Delta K/}{K} = \frac{/\Delta q/}{q} + \frac{/\Delta \rho_c/}{\rho_c} + \frac{/\Delta C/}{C} + \frac{10}{350} \tag{11}$$

The maximum error in determining outlet carbon dioxide concentration was estimated to be 25 ppm. The maximum error of carbon dioxide production was estimated at 7%, according to Equation 11.

Climate conditions

Because ventilation rate was kept in a relatively narrow range of 0·79 to 1·32 m^3/h and hen, the method of obtaining different indoor temperatures was the selection of different temperatures outside the climate chamber by means of supplemental heating and cooling. At indoor temperatures of approximately 15°C, the outdoor temperature was about 4°C, increased to about 26°C at an indoor temperature of 28°C. The indoor humidity was mainly in the range of 50% to 65%, lowest at high indoor temperatures.

Transmission heat loss decreased from approximately 3·4 to 2·0 W/hen when the indoor temperature increased from 15 to 28°C and ventilation heat loss decreased from 8·2 to 1·5 W/hen.

RESULTS

Total animal heat production is the sum of sensible heat and latent heat production, according to Equation 7. Sensible heat is released as transmission heat loss and ventilation heat loss. The latent heat loss is calculated as the increase of water in the ventilation flow from the building. The carbon dioxide produced is also exhausted with the ventilation air.

Sensible heat

Sensible heat production was strongly influenced by the indoor dry bulb air temperature (Figure 2). Sensible heat production decreased approximately linearly with increasing indoor dry bulb air temperature. The reason is that the hen's production of sensible heat is mainly governed by the temperature difference between the body and the air surrounding the animals. When the dry bulb air temperature reaches body temperature then the bird will be unable to release any sensible heat. According to the measurements, the release of sensible heat would reach zero at approximately 33°C in the day and 37°C at night. Surprisingly, the sensible heat production was lower during the day than at

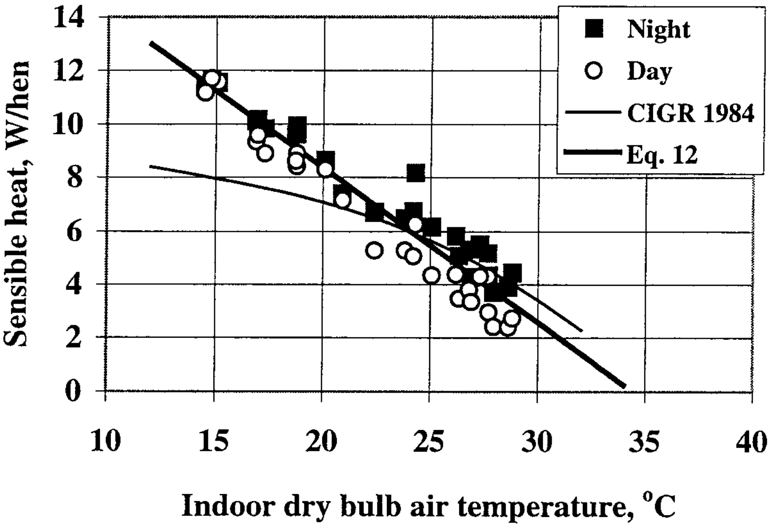


Figure 2. *Daily mean of sensible heat production as a function of indoor dry bulb air temperature.*

night. One explanation for the lower sensible heat production during the day may be that in this study the sensible heat was measured for the entire building. That means that some sensible heat produced by the birds was transferred to latent heat by evaporation of moisture, due to increased activity of the hens in the day (scratching in the bedding and drinking/spilling water). An increased latent heat production during the day was also verified (Figure 3).

A linear regression of sensible heat production as a function of indoor dry bulb air temperature on a mean daily basis gave the relationship.

$$P_s = 19{\cdot}91 - 0{\cdot}578 \cdot T_a \qquad R^2{=}0{\cdot}955 \qquad (12)$$

Latent heat

As shown in Figure 3, latent heat production increased with increasing indoor dry bulb air temperature. Latent heat production was higher during the day than at night which confirms that the hens transferred some sensible heat to latent heat by evaporation when agitating the bedding during the day and by spilling drinking water. An example of the daily variation in latent heat production in comparison to the activity pattern is presented in Figure 4 as relative values where the daily means are set to 100. Figure 4 also indicates that there was a time delay in release of latent heat during the day, resulting in an continuous increase in latent heat release from 04·00 until 18·00 after which the release decreased slowly.

Total heat

As shown by Equation 7, sensible heat plus latent heat make up total heat. Total heat production as a function of indoor dry bulb air temperature is presented in Figure 5 and decreased at increasing temperatures. The same trend was identified in a review by Brunsch (1999). The reason is that by thermoregulation the birds

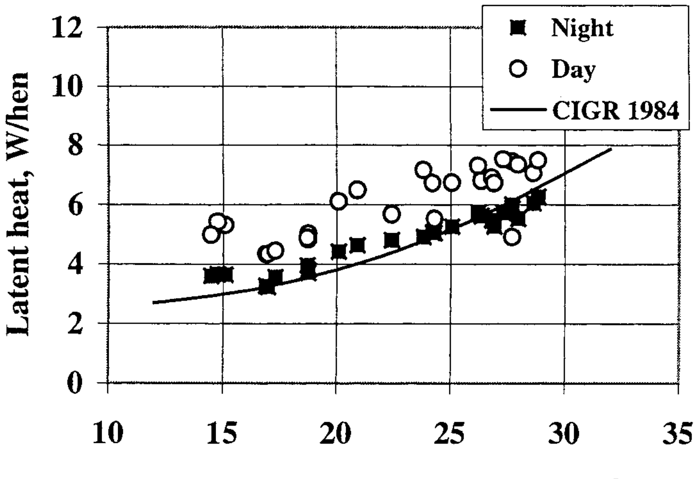


Figure 3. *Latent heat production as a function of indoor dry bulb air temperature.*

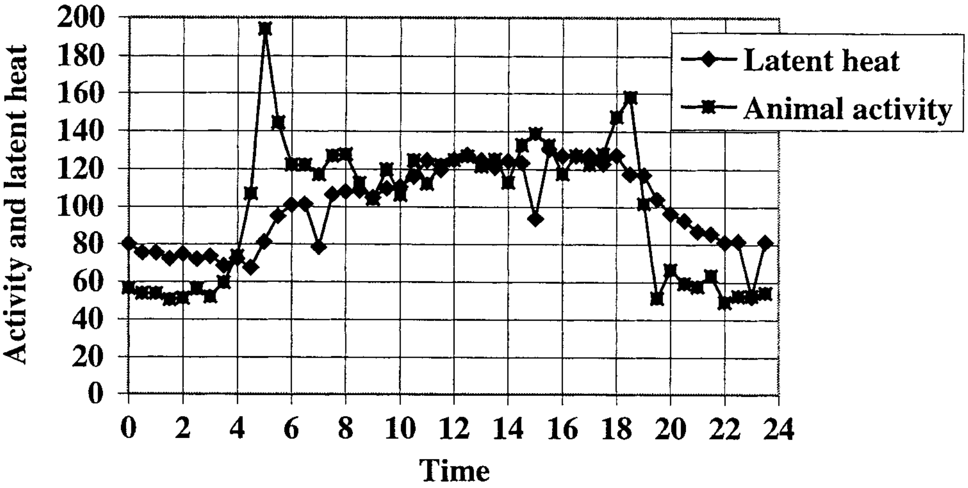


Figure 4. *Example of daily variations in latent heat production and activity of hens. Relative values where the daily means are 100. The indoor dry bulb air temperature was 15·1°C, indoor relative humidity 62·5% and ventilation rate 1·29m³/h and hen.*

decrease their metabolism in order to maintain a constant body temperature. The difference between day and night values of total heat production was less pronounced, compared to the differences in sensible and latent heat. A linear regression of total heat production as a function of indoor dry bulb air temperature gave the relationship.

$$P_{tot} = 22{\cdot}11 - 0{\cdot}428 \times T_a \qquad R^2 = 0{\cdot}917 \qquad (13)$$

The influence of body weight on total heat production from poultry is often described (CIGR 1984) as:

$$P_{tot} = b{\cdot}m^c \qquad (14)$$

The exponent cannot be determined from our data, because body weight was approximately constant during the investigations. A value of 0·75 has been used, as suggested by CIGR (1984). Results from our regression analyses with a body weight of 1·8 kg suggest that total heat production at 20°C should be calculated as:

$$P_{tot} = 8{\cdot}52{\cdot}m^{0{\cdot}75} \qquad (15)$$

Carbon dioxide

The measurements showed a large diurnal variation in carbon dioxide production. On average, carbon dioxide production during a 12 hour night period was only 66% of the production during the day. Variation was large compared to the diurnal variation in total heat production, where heat production during the night was 98% of the heat production during the day. These differences conflict with the CIGR guidelines from 1984, where it is assumed that the carbon dioxide production per heat producing unit (hpu) is constant. One heat producing unit is defined as a total heat production of 1000 W at 20°C.

One possible explanation for these differences in daily variation might be that the release of moisture (latent heat) from the litter causes a time delay in release of total heat, compared to

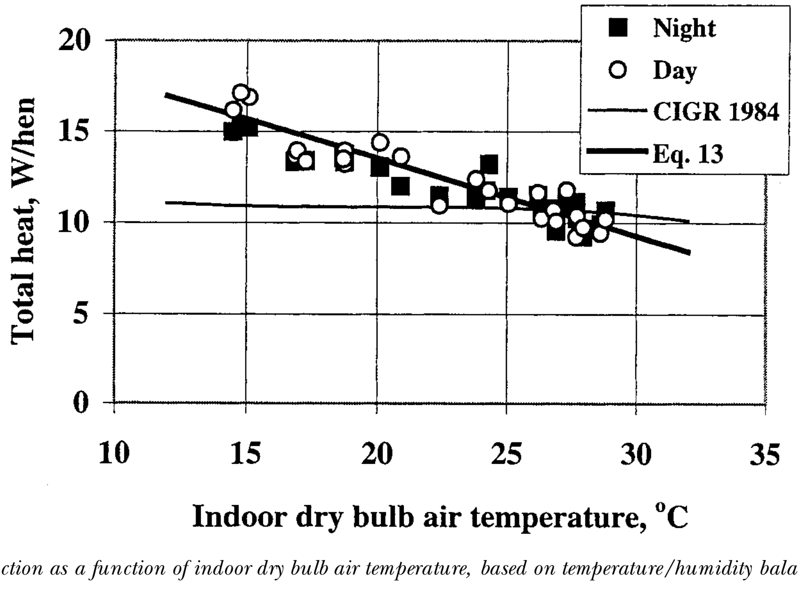
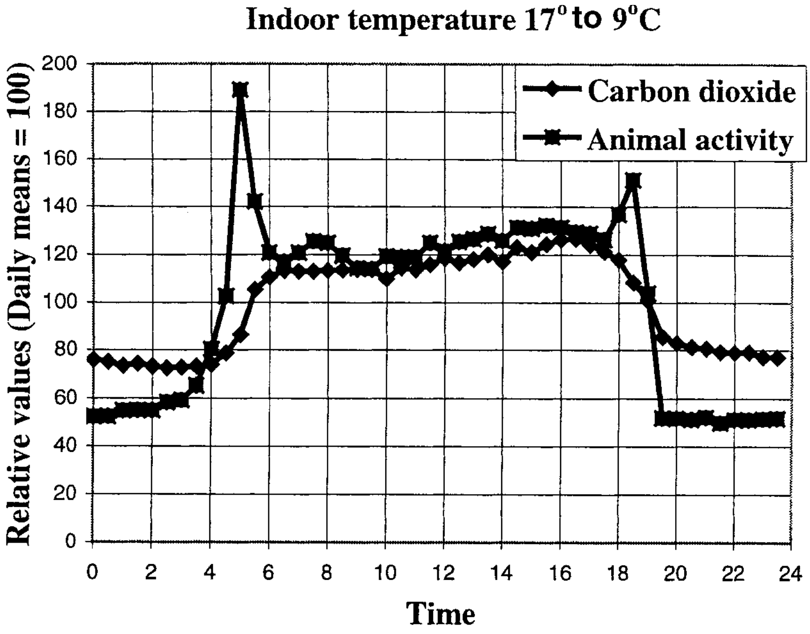


Figure 5. *Total heat production as a function of indoor dry bulb air temperature, based on temperature/humidity balances.*



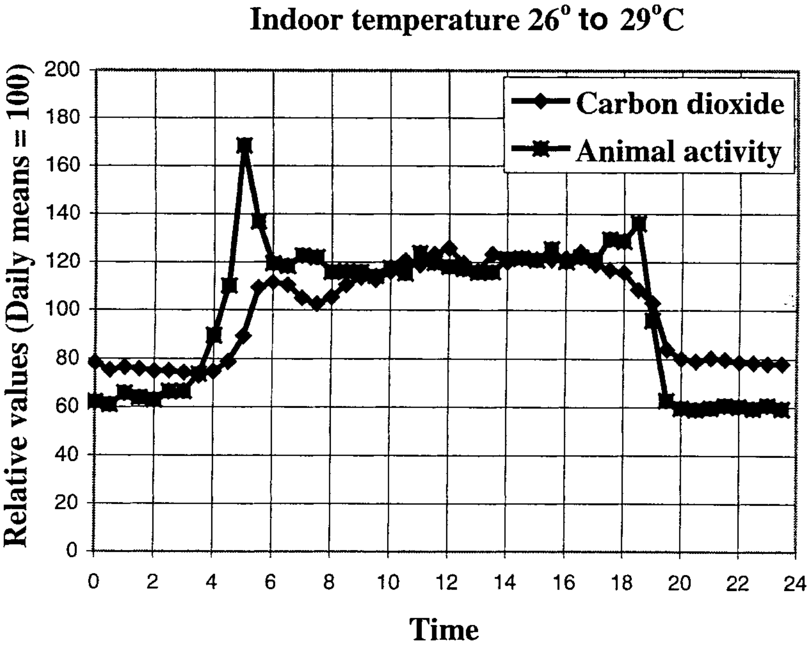


Figure 6. *Diurnal variations (relative values) in animal activity and carbon dioxide production based on 6 24-h periods for indoor temperatures of 17º to 19ºC and 26º to 26ºC.*

the release of carbon dioxide which occurs instantaneously from the metabolism of the hens. Also the heat capacity of the shell of the climate chamber functions as a buffer in accumulating heat during the day and releases it at night.

Figure 6 shows averages of relative values of carbon dioxide production and activity for six 24-h periods with indoor temperatures of 17° to 19°C and 26°C to 29°C, respectively. The patterns of activity and carbon dioxide production were nearly identical at the 2 temperatures. The increased activity in the morning when the light was turned on was probably a result of animal movement from the perches to the floor, and back again in the evening.

Figure 7 shows the night/day ratio in animal activity, as well as carbon dioxide and total heat production. The figure also shows that daily variation was higher for carbon dioxide production than for total heat production. This is surprising, because carbon dioxide production should be linearly related to total heat production, although it can partly be explained by the heat accumulation in and dissipation from the building itself.

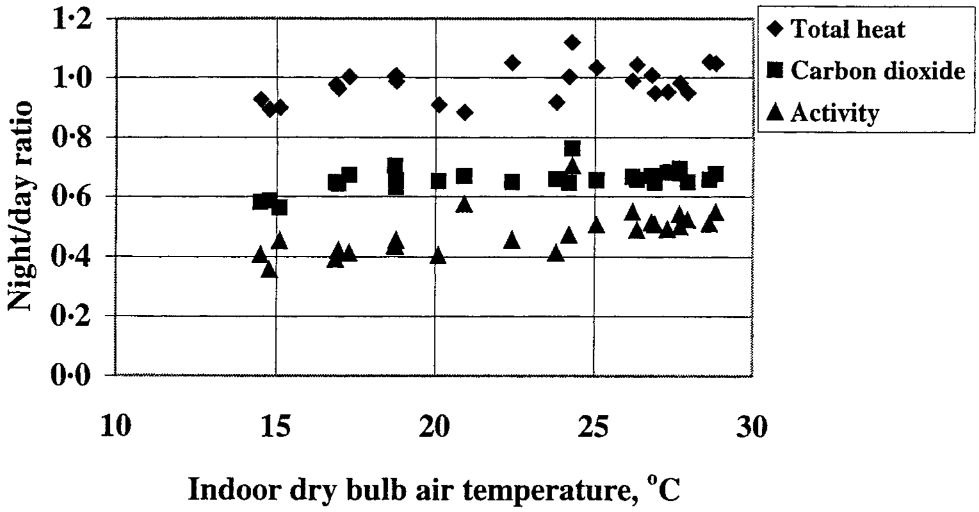


Figure 7. *Night/day ratio in activity and total heat and carbon dioxide production.*

DISCUSSION AND CONCLUSIONS

Current CIGR guidelines (1992) on sensible, latent and total heat production from laying hens are based on corrections of long-standing investigations carried out in climate chambers with a different building environment than in commercial housing systems. Several corrections have been carried out since the first CIGR guidelines (1984).

The most common housing system for laying hens for several decades has been houses with cages. Today there is a trend towards floor housing where hens can scratch in the bedding. When hens are in cages, they have no access to the manure and by removing the manure regularly by conveyors, the evaporation of water from the manure is restricted, as shown by Pedersen *et al.*, 1998. In aviary/perchery systems the manure can be stored for a longer period in the house, or it can be removed regularly (daily). For laying hens in cages sensible heat accounts for 69% of total heat at 20°C, but only for 52% for hens in floor systems with storage of manure over long periods. For the present aviary system, which is intermediate between cages and floor keeping, because the hens have access to both the floor and to semi-closed cages, the sensible part was calculated as 62%, which will fit in between hens in cages and hens in floor keeping systems.

For the system we investigated, with hens in an aviary and regular removal of manure by a conveyer, Figures 2 and 5 show more sensible and total heat at low indoor temperatures, than for the common curve. Normally, the influence of the temperature on total animal heat is expressed by common equations for cattle, pigs and poultry as in CIGR (1984), because of lack of specific information about different species and housing systems. Our investigation shows that total heat production of layers is strongly dependent on the indoor dry bulb air temperature, so this finding also supports the theory that the total heat production for broilers is strongly dependent on the indoor temperature. The release of sensible heat from homeothermic animals is governed by thermodynamic laws where the differences in temperatures between the body core and the surrounding air, according to Mount (1979), is the most important factor.

The animals ability to maintain a constant body temperature within a wide temperature range of the surrounding air depends in part on changes in latent heat production (release of moisture) which is also confirmed in this investigation. The CIGR-guidelines (1984) suggest total heat production remains relatively constant within a wide temperature range. Our investigation, however has shown total heat production to be dependent on temperature. With reference to an indoor temperature of 20°C, total heat production was reduced by 0·38 W/°C or approximately 3%/°C over the range from 14° to 28°C. Chwalibog and Pedersen (1985) also showed that total heat production very much depends on the indoor temperature for broilers. They found that heat production was reduced by 0·33 W/°C or approximately 2·4%/°C for broilers.

In contrast to the CIGR-guidelines (CIGR 1984) our measurements showed a higher total heat production (22% higher at 20°C). The CIGR-guidelines are however based on investigations mainly carried out quite a long time ago in climate chambers. Genetic improvements in egg production may have increased the total heat production of laying hens.

The highest indoor air temperature in our study was 28°C. Work carried out by Tzschentke *et al.* (1996) has shown that the total heat production of laying hens decreases at approximately 30°C whereafter the heat production increases, probably because of efforts to increase the release of moisture to maintain a constant body temperature. This fact should be considered when calculating ventilation requirements in hot areas.

Our study also shows that the housing system and the activity pattern of the hens have a strong influence on production of heat, moisture and carbon dioxide. This fact should therefore be considered when designing and installing environmental control systems in buildings for loose-housed hens.

ACKNOWLEDGEMENTS

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Notation

A	area, m^2
a	normalised activity level
b	coefficient
C	concentration of carbon dioxide, ppm
c	coefficient
Cp	specific heat capacity of air, J/kg, K
F	production of moisture, g/h
K	production of carbon dioxide, mg/h
m	body weight, kg
P	heat production, W
p	saturation pressure of air, mbar
q	ventilation rate, m^3/h
T	air temperature, °C
t	time, s
U	heat transmission coefficient of building surfaces, W/m^2, °C
u	voltage from activity sensor, V
X	water content of air, g/kg air
Δ	difference
ϕ	relative humidity, %
ρ	density, kg/m^3

Indices:

a	air
as	surrounding airspace
c	carbon dioxide
f	floor
g	gable
in	inlet
l	latent
out	outlet
s	sensible
tot	total
w,c	wall, ceiling

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