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Heat and Moisture Production of Molting Laying Hens

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Abstract. *Heat and moisture production rates (HP, MP) of modern 68- to 75-week-old Hy-Line W-36 laying hens during the molting stage were measured using large-scale indirect calorimeters that mimic commercial production settings. The HP and MP were measured continuously during acclimation, fasting, restricted feeding, and postmolt or normal periods. Total HP (THP) was partitioned into latent and sensible HP (LHP, SHP), which incorporated the influence of fecal moisture evaporation. THP during fasting (averaging 4.8 W/kg) and restricted feeding (averaging 6.0 W/kg) periods averaged 29 and 13% lower than that during postmolt period (averaging 6.8 W/kg). Correspondingly, LHP averaged 1.9 W/kg and 1.8 W/kg and was 31 and 34% lower than that during postmolt period, which averaged 2.7 W/kg. Likewise, SHP averaged 2.9 W/kg during fasting period and was 28% lower than during postmolt period, which averaged 4.1 W/kg. The average SHP between restricted feeding and postmolt periods were similar (4.2 vs. 4.1 W/kg, respectively). The respiratory quotient (RQ) averaged 0.71, 0.76, and 0.92 during fasting, restricted feeding, and postmolt periods, respectively. HP values during the light period were significantly higher (P<0.05) than those during the dark period. The daily mean and diurnal LHP as a percentage of THP were similar during fasting and postmolt periods and were comparatively 10% lower during restricted feeding period. The results of this study provide a new thermal load database for design of building ventilation systems for laying hens undergoing molting phase.*

Keywords. Thermal load, Ventilation, Bioenergetics

Introduction

Molting is a natural process of all birds in an endeavor to renew their feathers (Lucas and Stettenheim, 1972; North, 1984) prior to migration, shorter days, or cooler weather (North, 1984); and is regulated by hormones (Van der Meulen, 1939; Blivaiss, 1947b; Perek et al., 1957; Whittow, 1976). Normally, wild chickens molt once a year, and the molt is not associated with the laying cycle (North, 1984). Domestic chickens are bred for high egg production and go into molting after a long and intensive laying period. In order to give them rest, molting is often induced, particularly at or near the time when they naturally molt (Van der Meulen, 1939; Sturkie, 1954). This is achieved through several means such as feed withdrawal (Noles, 1966; North, 1984; Witham, 2001), drugs and chemicals (Van der Meulen, 1939; Sturkie, 1954; Adams, 1955; Whitehead and Shannon, 1974; Scott and Creger, 1976; North, 1984), and light reduction (North, 1984). The methods that are widely adopted are those that create the least amount of stress, produce a rapid molt, and get birds back to egg production quickly.

The thyrotrophic and thyroid hormones have been reported to promote molting (Van der Meulen, 1939; Blivaiss, 1947; Whittow, 1976), impair egg laying (Zawadowsky and Nesmeyanova, 1937), and increase metabolic activity (Whittow, 1976). Loss of feathers, naturally or artificially, causes an increase in heat production and heat loss (Perek and Sulman, 1945; Hoffman and Shaffner, 1950).

Economic circumstances, such as anticipation of high egg prices or lack of available cash due to depressed egg prices, often drive decisions to put hens into a molt (North, 1984; Bell and Swanson, 1974). The merits of molting laying hens include increased egg production (up to 85-90% of the first year production), larger egg size, and improved eggshell quality (North, 1984; Witham, 2001). However, these levels would be somewhat lower than their best pre-molt values (Hy-Line W-36 Commercial Management Guide, 2000-2001).

In view of the above-mentioned physiological implications on molted birds, there is need to provide them with optimum environment through adequate ventilation. Building ventilation rate designs are based on the heat and moisture production rates (HP and MP) of the housed animals. Data on HP and MP of nonmolting laying hens have recently been collected (Chepete and Xin, 2002a) and that of molting hens was not found in the literature search (Chepete and Xin, 2002b). This suggests that ventilation rates for molting hens are designed presumably using data of nonmolting ones. In order to provide molting hens with optimum ventilation rates, specific HP and MP data on this situation are needed. The objective of this study was to measure HP and MP of W-36 laying hens during the molting conditions that follow the current commercial production practices, as part of the effort to systematically update the HP and MP data for design and operation of modern poultry housing systems.

Materials and Methods

Experimental Birds and Facility

The Iowa State University (ISU) indirect calorimeter system, consisting of four calorimeter chambers as described by Xin et al. (1998), was used for this study. The gas (O_2 and CO_2) analyzers were calibrated twice daily throughout the measurement period (7 weeks continuous) to ensure measurement accuracy of ± 0.5 W per chamber (>65-W output). In all trials performed, metal pans were placed under each cage compartment to collect feces, and thus the MP included that from both the birds and their housing components (i.e., litter and fecal matter). The latent and sensible heat production rates (LHP or SHP) measured were thus *room* values. The commercial management practices (feeding, photoperiod, temperature, stocking density, and manure handling) were followed throughout the trial, as will be described.

Specifically, manure was removed from all chambers twice weekly. Birds were group-weighed weekly throughout the trial.

HP and MP Measurements

A flock of 252 hens at 68 weeks of age and averaging 1.7 kg was procured from a commercial farm in Iowa and delivered to the ISU Livestock Environment and Animal Physiology (LEAP) Laboratory in Ames. Upon arrival, the birds were group-weighed and randomly allocated to the four indirect calorimeter chambers with 63 birds per chamber (or 7 hens per cage). These bird numbers ensured sufficient changes in air composition (O_2 and CO_2) for the instruments to make accurate measurements. Each chamber had a movable supporting stand with nine cages (55 cm L × 50 cm W × 41 cm H each).

The birds were acclimated for a week. During this period, birds were fed *ad libitum* (Table 1). The lighting schedule was 16hL:8hD, and the initial temperature set point was 26.7 ^oC, which was then reduced by 1^oC daily until it reached 20^oC. At the beginning of the second week, feed was withdrawn, temperature was kept at 20^oC, and lighting schedule changed to 9hL:15hD. The objective of feed withdrawal was to induce molting and reduce the bird body mass (M) to an equivalent of 20-week-old pullet of the same breed (1.22 to 1.27 kg/bird). The birds were expected to stop laying eggs at this M range. To monitor the bird M, a group of 18 birds was randomly sampled from each calorimeter every 2 days and weighed. When the aforementioned M range was reached, birds were put on restricted feeding with pullet ration (Table 1) for 2 weeks at an average of 5.2 kg/(100-day) to provide maintenance energy while maintaining their M strictly between 1.22 to 1.27 kg. If M increased, a day was skipped without providing feed to the birds. After the restricted feeding period, the temperature was raised to 24.4^oC, lighting increased to 13hL:11hD, and birds were fed layer ration (Table 1) *ad libitum* for 3 weeks during which they were expected to increase M and resume laying. Throughout the experimental period, the birds had free access to water through nipple drinkers. Relative humidity (RH) ranged from 37 to 45%. Light intensity was maintained at 5 to 11 lux. The experimental protocols complied with the guidelines on the care and use of animals for research by the institutional committee.

Data Analysis and Presentation

For each 24-h period of the trial, the data were separated into dark and light periods and their time-weighted averages (TWA) determined. The data were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS) (SAS Institute, Inc. 1999-2000). The measured parameters were presented graphically as functions of bird age and in a summary table of their mean values. Data collected during cleaning of the calorimeters and weighing of the birds were excluded from the analysis.

Results and Discussion

Figure 1 shows the changes in plumage of the birds during fasting through postmolt period. Egg production and bird M are both depicted in figures 2 through 4. Total heat production (THP), LHP, SHP, and respiratory quotient (RQ, CO_2/O_2) of the *room* (LHP and SHP) under light, dark and TWA conditions are summarized in Table 2 as 2- to 4-day averages. The HP parameters are shown in figures 2 through 4, while RQ is shown in figure 5. LHP as a percentage of THP is shown in figure 6.

Egg Production

During the acclimation period, egg production averaged 39 g/(bird-day). Upon fasting, egg production dropped drastically and ceased by the end of the fasting period. This is consistent with reports by Witham (2001) and Zawadowsky and Nesmeyanova (1937). Most of the eggs laid 2 days after onset of fasting broke into the metal pans, presumably due to thin eggshells as the birds lacked calcium. During restricted feeding period, there were no eggs produced. Egg production resumed about 11 days after start of the postmolt period when birds were fed *ad libitum.*

Bird Mass

Upon arrival, the birds averaged 1.7 kg which was reduced to an average of 1.2 kg/bird when fasting. During restricted feeding, the M ranged from 1.2 to 1.3 kg/bird and was within the industry-recommended range in order for the birds not to lay eggs. During the postmolt period, M increased to a range of 1.4 to 1.5 kg/bird.

Behavioral and Physical Observations

The birds were observed to peck on different objects, a feed-seeking activity when fasting, as reported by Lundy et al. (1978). During the restricted feeding period, the birds scrambled at the feed and ate vigorously and competitively the entire time. The scramble for feed was also observed during the first day of the postmolt period and thereafter stopped as birds continued to have access to feed *ad libitum*. During fasting period, the birds had good feather cover (fig. 1a). The birds then shed a lot of their feathers during the first week of the restricted feeding period (fig. 1b), and this was consistent with reports by Lucas and Stettenheim (1972) and North (1984). The feathers rejuvenated during the post molt period (fig. 1c).

THP

The relationship between THP and bird age is shown in figure 2. There were significant differences ($P<0.05$) in THP between acclimation, fasting, restricted feeding, and postmolt periods for both light and dark periods. THP was significantly reduced by 19 to 37% upon switching from light to dark. Chepete and Xin (2002a) found 23 to 34% reduction on non-molting 2- to 64-week-old W36 birds under thermoneutral conditions.

During the acclimation period, the average THP ranged from 6.2 to 6.8 W/kg. Chepete and Xin (2002a) reported 6.7 W/kg for 1.53 kg (64 weeks of age) layers at 24.4^{o}C. When fasting, the average THP was reduced to a range of 4.4 to 5.6 W/kg, a 21 to 41% reduction as compared with THP during acclimation. O'Neill and Jackson (1974) reported 4.9 and 4.7 W/kg on fasted white leghorn hybrid H & N cockerels at 62 (1.63 kg) and 78 (1.69 kg) weeks of age, respectively, and 23^{o}C air temperature. According to Brody (1945), the heat produced by animals is a result of oxidation of carbohydrates during respiration. During fasting, carbohydrates were expected to be insufficient in the birds' bloodstreams which would reduce the metabolic rate and consequently lower the total heat output. Comparatively, THP was significantly higher during the first 2 days of fasting (averaging 5.6 W/kg), while the latter 4 days had lower THP (averaging 4.5 W/kg). The higher THP during the initial stage of fasting was a result of the utilization of feed that was still in the birds' digestive tract (i.e., postabsorption), and they probably began using body fat to provide energy during the latter part, which is evidenced by gradual reduction in M. Further, animals tend to conserve energy for use in maintenance when fasted by reducing heat-generating mechanisms such as cessation of lay and reduced locomotor activity (Lundy et al., 1978).

During the restricted feeding period, there was a sharp increase in average THP up to 6.5 W/kg during the first 3 days, after which it gradually declined. The sharp increase in THP may be due to loss of feathers that is reported to cause an increase in HP (Perek and Sulman, 1945; Hoffman and Shaffner, 1950). Other contributing factors may include increased bird activities such as vigorous feeding (Yunianto et al., 1997) and changes in posture (Lundy et al., 1978). Up to 25% of the increase in THP is related to physical activity in laying hens (Boshouwers and Nicaise, 1985). Standing alone was reported to increase HP of Light Sussex cocks by 40 to 50% (Deighton and Hutchinson, 1940). The oscillations in the trend of THP were caused by days when feed was not provided while trying to keep the birds' M within the recommended range. In the latter 10 days of this period, the average THP stabilized within a range of 5.4 to 5.9 W/kg and was 13% lower or 5 to 23% higher than that during acclimation and fasting, respectively. Energy restriction decreases the metabolic rate, since the latter increases with the increase in metabolizable energy (Mitchell, 1962).

During the postmolt period, the average THP increased slightly and stabilized at 6.7 to 6.9 W/kg. Besides activity, heat increment of feeding and the cost of egg synthesis and oviposition (van Kampen, 1976) are likely to be responsible for the nature of the THP trend during this period. Under similar conditions, Chepete and Xin (2002a) reported a value of 6.7 W/kg for 1.53 kg (64-week-old) hens. THP during the postmolt period was 23 to 52% higher than that of the fasting period. Meltzer (1987) noted a 25 to 68% higher THP in fed than starved adult birds. Lundy et al. (1978) reported a 27 or 29% lower THP in starved than in fed Babcock or Warren birds, respectively, under 19 to 21^{o}C temperature.

A THP range of 6.6 to 6.8 W/kg for a 1.8 kg leghorn laying hen (Albright, 1990) has been widely used in ventilation design for laying hens. For molting birds, such data may result in over-ventilation during fasting and restricted feeding periods, and this may have a negative impact on bird welfare and production costs. The values are 21 to 50% and 5 to 22% higher than that measured in this study during fasting and restricted feeding periods, respectively.

LHP

Figure 3 shows LHP as a function of bird age. There were significant differences ($P<0.05$) in LHP between acclimation, fasting, restricted feeding, and postmolt periods for both light and dark periods. With reference to acclimation period, LHP reduction during the light period averaged 7 or 9% during fasting or restricted feeding, respectively. The corresponding reduction during the dark period was 13 or 19%. During the post molt period, LHP was 19 or 26% higher for light or dark period, respectively, when compared to that during the acclimation period. LHP was significantly reduced by 20 to 51% upon switching from light to dark. Chepete and Xin (2002a) reported 15 to 29% reduction on nonmolting 2- to 64-week-old W36 birds under thermoneutral conditions. The average LHP ranged from 2.1 to 2.4 W/kg during the acclimation period. Chepete and Xin (2002a) reported 3.1 W/kg for 1.53 kg (64 weeks of age) layers at 24.4^{o}C. When fasting, LHP steadily declined from an average high of 2.1 W/kg to a lower value of 1.7 W/kg. This decline was not as steep as was expected. Most eggs broke during this period, probably due to calcium deficiency, and the water contained therein may have contributed extra moisture production or LHP.

During the restricted feeding period, the average LHP increased to a peak value of 2.0 W/kg and then steadily declined to a range of 1.5 to 1.9 W/kg. For the postmolt period, the average LHP increased steadily and stabilized at 2.9 W/kg. It then varied between 2.5 and 2.8 W/kg as the birds began to lay eggs. As with THP, this higher LHP, compared with that during fasting and restricted feeding periods, may be a result of increased bird activity and physiological factors associated with egg production. Ota and McNally (1961) measured LHP of 1.1 to 1.3 W/kg or 0.7 to 0.9 W/kg during the day or night, respectively, on 51- to 70-week-old New Hampshire × Cornish cross layers kept at 18 to 24^{o}C ambient temperature. These values are less than those measured in this study (table 2) during postmolt period.

SHP

The variation of SHP with bird age is shown in figure 4. There were significant differences ($P<0.05$) in SHP between acclimation, fasting, restricted feeding, and postmolt periods for both light and dark periods. With reference to acclimation period, SHP reduction during fasting period averaged 21 or 24% during the light or dark period, respectively. The corresponding increase in SHP during restricted feeding period averaged 3 or 13% for light or dark period, respectively. During the post molt period, SHP averaged 4% higher during the light period and 2% lower during the dark period when compared to that during the acclimation period. SHP was significantly reduced by 13 to 35% upon switching from light to dark. Chepete and Xin (2002a) noted 27 to 47% reduction on nonmolting 2- to 64-week-old W36 birds under thermoneutral conditions. The average SHP ranged from 3.8 to 4.6 W/kg during the acclimation period. Chepete and Xin (2002a) reported 3.6 W/kg for 1.53 kg (64 weeks of age) layers at 24.4°C. Upon fasting, SHP dropped sharply from 4.6 W/kg at the end of the acclimation period, to 2.6 W/kg, where it remained fairly stable. This period coincides with the time when most of the eggs were broken. As such, part of the sensible heat was used in the evaporation of moisture contained in the eggs, thereby increasing the LHP and reducing the SHP.

During the restricted feeding period, the average SHP sharply increased in the initial 3 days from a low of 2.7 W/kg (at the end of fasting period) to an average high of 4.6 W/kg. This may be associated with bird activity as previously mentioned. The average SHP then gradually reduced to an average of 3.9 W/kg in the last week of this period.

During the postmolt period, SHP slightly increased initially and then dropped to a steady average value of 4.0 W/kg. As birds began to produce eggs, SHP increased slightly to about 4.4 W/kg and then dropped back to an average value of 4.0 W/kg. The increase in metabolic activity associated with egg production (van Kampen, 1976) may have caused the rise in SHP. Ota and McNally (1961) measured SHP of 2.7 to 3.5 W/kg or 2.5 to 2.9 W/kg during the day or night, respectively, on birds previously mentioned.

RQ

Figure 5 shows variation of RQ with bird age. RQ varies depending on the metabolic rate, feed intake, and individual status of the animal (Ouwerkerk and Pedersen, 1994). During acclimation, RQ ranged from 0.82 to 0.94 (averaging 0.88). During fasting, the RQ dropped to a range of 0.66 to 0.80 (averaging 0.71). RQ decreased probably because fat was preferentially metabolized during starvation (Koskemies, 1950). Lundy et al. (1978) reported an RQ of 0.74 and 0.96 for starved and fed birds, respectively. In the restricted feeding period, the RQ ranged from 0.65 to 0.82 (averaging 0.76). During the postmolt period, the RQ ranged from 0.85 to 0.98 (averaging 0.92). Chepete and Xin (2002a) and Ketelaars et al. (1985) reported average RQ values of 0.91 for laying hens at 21 to 64 weeks of age and 0.92 for laying hens at normal production, respectively.

LHP as a Percentage of THP

Figure 6 shows LHP as a percentage of THP. The variation between light and dark periods was not significantly different (P=0.65). This result might be due to the proportionate partition of THP into LHP and SHP, where they both increased or decreased during the light or dark periods, respectively. The ranges were 30 to 41 (averaging 36%), 36 to 42 (averaging 39%), 24 to 36 (averaging 30%), and 34 to 43% (averaging 40%) during acclimation, fasting, restricted feeding, and postmolt periods, respectively. HP data reported by Ota and McNally (1961) indicated a range of 22 to 32% for 51- to 70-week-old birds kept at 19 to 24°C temperature, while research by Albright (1990) indicated a range of 34 to 44% (averaging 39%) for a 1.8 kg leghorn laying hen at 18 to 28°C temperature.

Diurnal HP and MP Profiles

Diurnal HP and MP or LHP profiles for the different molting stages are shown in figures 7 through 9. LHP of the *room* has been expressed as a percentage of THP and it ranged from 33 to 60% (averaging 41%), 25 to 38% (averaging 31%), and 36 to 49% (averaging 41%) during fasting, restricted feeding, and post molt periods, respectively. As previously mentioned, the higher LHP during fasting was due to additional moisture from the eggs that broke. When the light was on, birds became more active and this may have resulted in higher HP as compared to dark period.

Conclusions

Heat and moisture production rates (HP and MP) of modern W-36 laying hens during the molting stage were measured using large-scale indirect calorimeters. Latent HP (LHP) and sensible HP (SHP) included the effect of moisture evaporation from the feces. The following conclusions were drawn.

- Total HP (THP) during fasting and restricted feeding periods averaged 29 and 13% lower than that during normal or postmolt period (4.8 and 6.0, respectively, vs. 6.8 W/kg).
- LHP averaged 31 and 34% lower during the respective periods when compared to postmolt period (1.9 and 1.8, respectively, vs. 2.7 W/kg).
- SHP during fasting period averaged 28% lower than that during postmolt period (2.9 vs. 4.1 W/kg, respectively), while the average SHP during restricted feeding period was similar to that during the postmolt period (4.2 vs. 4.1 W/kg, respectively).
- Respiratory quotient (RQ) averaged 0.71, 0.76, and 0.92, during fasting, restricted feeding, and postmolt periods, respectively.
- HP values during the light period were significantly higher ($P<0.05$) than during the dark period.
- The daily mean and diurnal LHP as a percentage of THP were similar during fasting and postmolt periods and were comparatively 10% lower during restricted feeding period.

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Table 1. Dietary ingredients (%, unless otherwise noted) of feed used in the study

Dietary content	Layer ration[1]	Pullet ration[2]	Layer ration[3]
ME (MJ/kg)	11.86	12.54	11.95
Crude protein	14.00	16.81	16.00
Crude fat	2.90	N/A	4.50
Crude fiber	2.40	N/A	2.40
Calcium	3.85	0.94	4.25
Total phosphorus	0.50	N/A	0.64
Available phosphorus	0.50	0.37	0.45
Sodium	0.18	0.15	0.19
Lysine	0.73	0.89	0.85
Methionine	0.33	0.39	0.40
Methionine & Cystine	0.60	0.68	0.69
Tryptophan	N/A	0.20	N/A
Threonine	N/A	0.63	N/A
Protein equivalent	N/A	18.96	N/A

[1] = acclimation period; [2] = restricted feeding period; [3] = postmolt period

N/A = information not available

Table 2. Heat production rates and respiratory quotient (RQ) of Hy-line *W-36* molting layers during daily light, dark, and time-weighted average (TWA) periods. Birds had free access to water through nipple drinkers during all phases. The latent and sensible heat production rate (LHP, SHP) included the effect of fecal moisture evaporation.

Feed regimen	Hours Light	Age (d)	M (kg)	T_a (^oC)	RH (%)	LHP (W/kg) Light	LHP Dark	LHP TWA	SHP (W/kg) Light	SHP Dark	SHP TWA	THP (W/kg) Light	THP Dark	THP TWA	RQ (VCO_2/VO Light	RQ Dark
ad-lib[2]	16	480	1.63	25.5	41	2.6	1.8	2.4	4.1	3.2	3.8	6.7	5.1	6.2	0.82	0.81
ad-lib[2]	16	482	1.53	23.6	41	2.5	1.8	2.3	5.1	3.5	4.6	7.6	5.3	6.8	0.93	0.95
no feed[2]	9	484	1.44	21.8	43	2.8	1.7	2.1	4.5	2.9	3.5	7.2	4.6	5.6	0.89	0.76
no feed[2]	9	486	1.38	21.5	45	2.3	1.5	1.8	3.2	2.3	2.6	5.5	3.9	4.5	0.67	0.68
no feed[2]	9	488	1.32	20.8	43	2.0	1.5	1.7	3.2	2.4	2.7	5.2	3.9	4.4	0.67	0.66
restricted[2]	9	490	1.26	21.0	41	2.3	1.8	2.0	4.8	3.9	3.9	7.1	5.8	5.9	0.66	0.64
restricted[2]	9	492	1.25	20.9	39	2.5	1.2	1.7	5.4	4.0	4.5	7.9	5.2	6.2	0.73	0.72
restricted[2]	9	494	1.26	21.1	40	2.4	1.6	1.9	5.2	4.3	4.6	7.7	5.8	6.5	0.81	0.79
restricted[3]	9	496	1.27	20.7	40	2.2	1.4	1.7	4.8	3.6	4.1	7.0	5.0	5.8	0.79	0.79
restricted[3]	9	499	1.26	20.7	38	2.0	1.2	1.5	4.3	3.7	3.9	6.3	4.9	5.4	0.78	0.78
restricted[4]	9	503	1.23	20.9	41	2.5	1.6	1.9	4.3	3.7	3.9	6.8	5.3	5.9	0.81	0.83
ad-lib[2]	13	506	1.26	24.4	38	2.8	2.0	2.4	4.9	3.6	4.3	7.6	5.6	6.7	0.88	0.99
ad-lib[2]	13	508	1.32	24.9	37	3.1	2.3	2.8	4.7	3.2	4.0	7.9	5.5	6.8	1.00	0.97
ad-lib[2]	13	510	1.37	24.9	38	3.3	2.4	2.9	4.8	3.1	4.0	8.0	5.5	6.9	0.95	0.95
ad-lib[3]	13	512	1.42	24.8	38	3.3	2.5	2.9	4.7	3.0	3.9	8.0	5.6	6.9	0.97	0.98
ad-lib[3]	13	515	1.45	24.6	37	2.9	2.0	2.5	5.1	3.5	4.4	8.0	5.5	6.9	0.87	0.83
ad-lib[3]	13	518	1.48	24.7	38	2.9	2.2	2.6	4.7	3.3	4.1	7.7	5.5	6.7	0.86	0.85
ad-lib[3]	13	521	1.48	24.8	39	3.1	2.5	2.8	4.5	3.2	3.9	7.6	5.7	6.8	0.88	0.86

The superscripts indicate the number of days over which the variable means, including bird age, were calculated.

M = body mass, kg; T_a = ambient temperature, ^oC; THP = total heat production rate; THP = LHP + SHP at corresponding light, dark, and TWA condition

Figure 1a. Laying hens during the fasting period.

Figure 1b. Loss of feathers during the restricted feeding period.

Figure 1c. Feathers rejuvenating during the postmolt period.

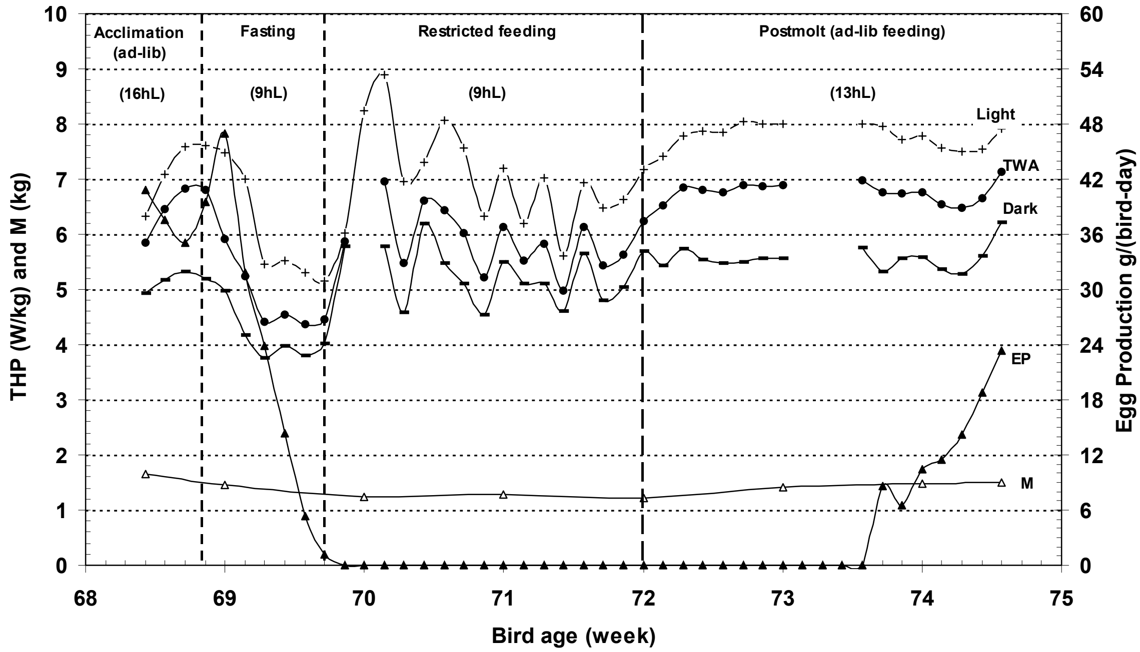
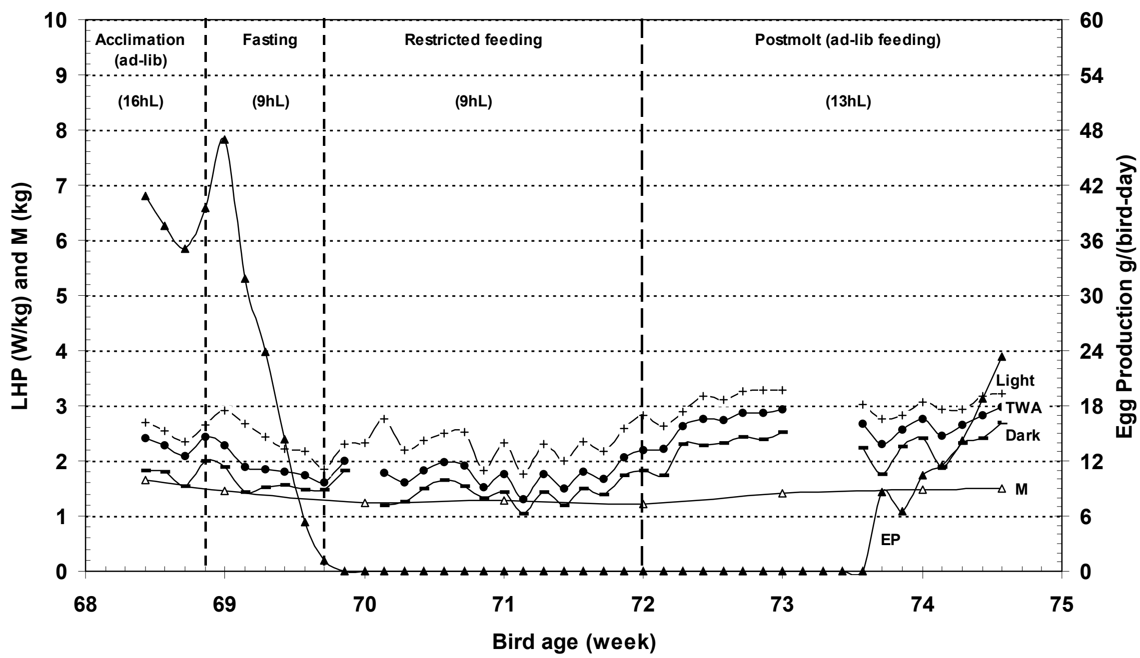
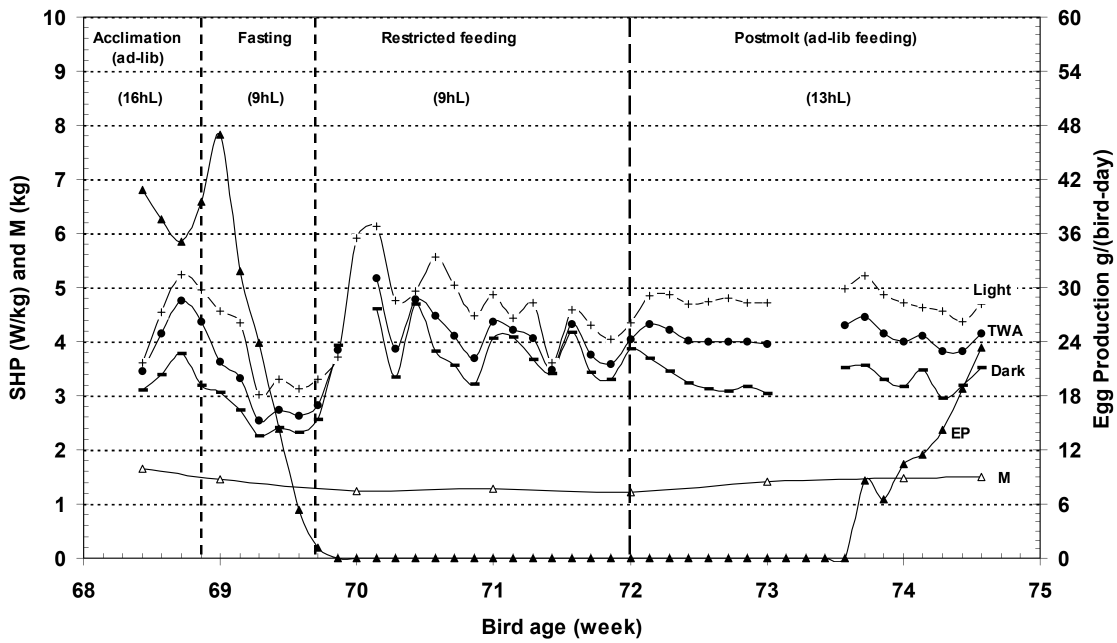


Figure 2. Total heat production rate (THP), body mass (M), and egg production (EP) of molting



W-36 laying hens as functions of bird age. TWA = time-weighted average.

Figure 3. Latent heat production rate (LHP), body mass (M), and egg production (EP) of molting W-36 laying hens as functions of bird age. TWA = time-weighted average.



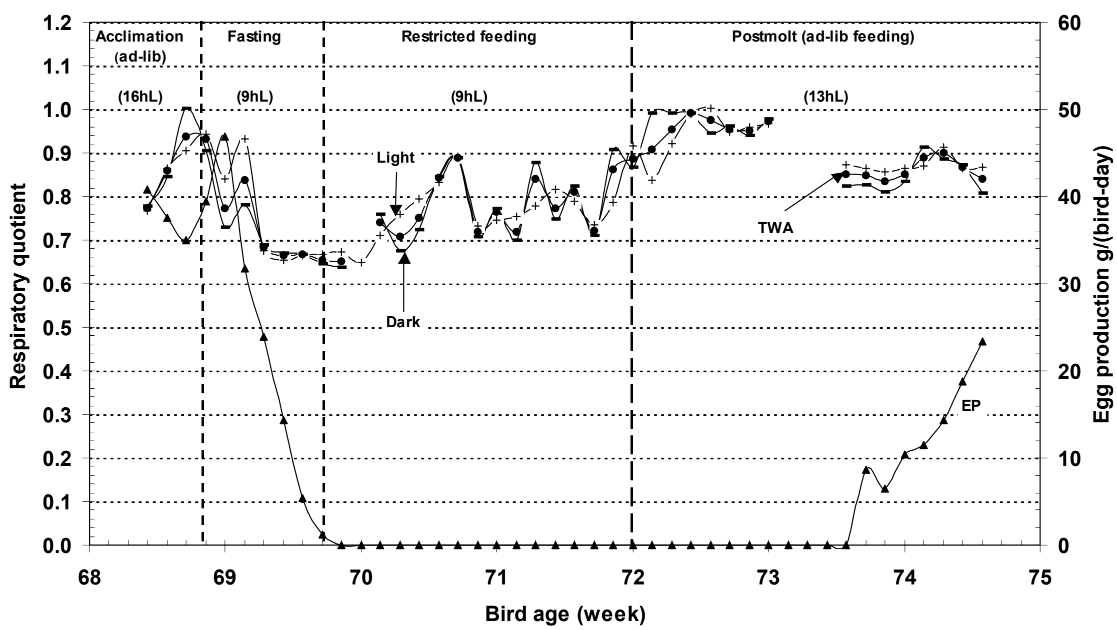
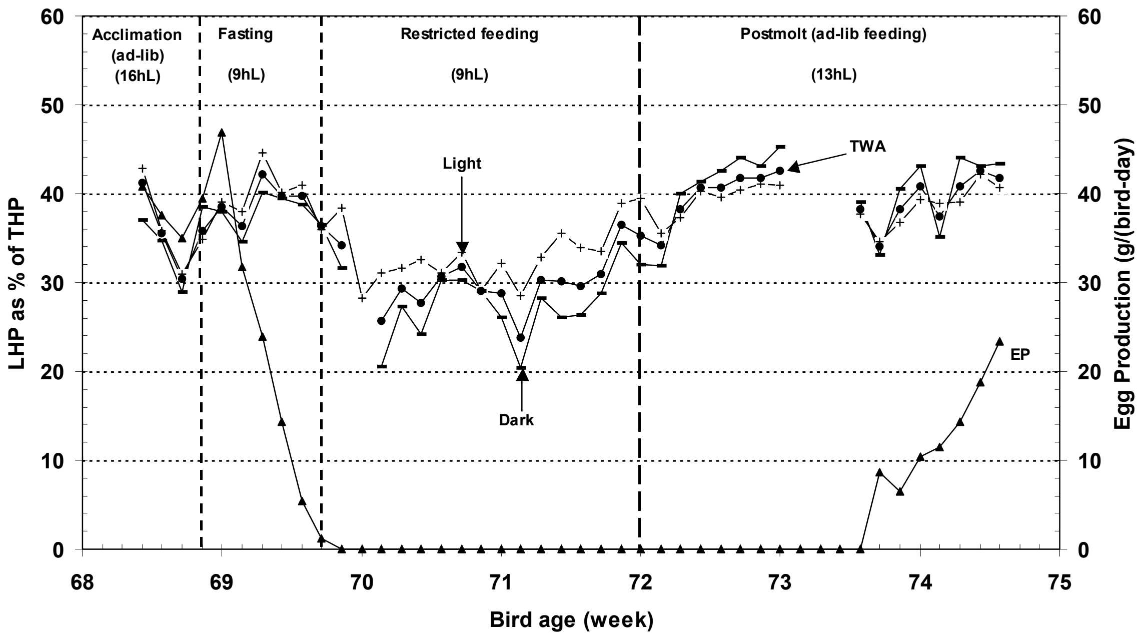


Figure 4. Sensible heat production rate (SHP), body mass (M), and egg production (EP) of molting W-36 laying hens as functions of bird age. TWA = time-weighted average.

Figure 5. Respiratory quotient (RQ) and egg production (EP) of molting W-36 laying hens as functions of bird age. TWA = time-weighted average.



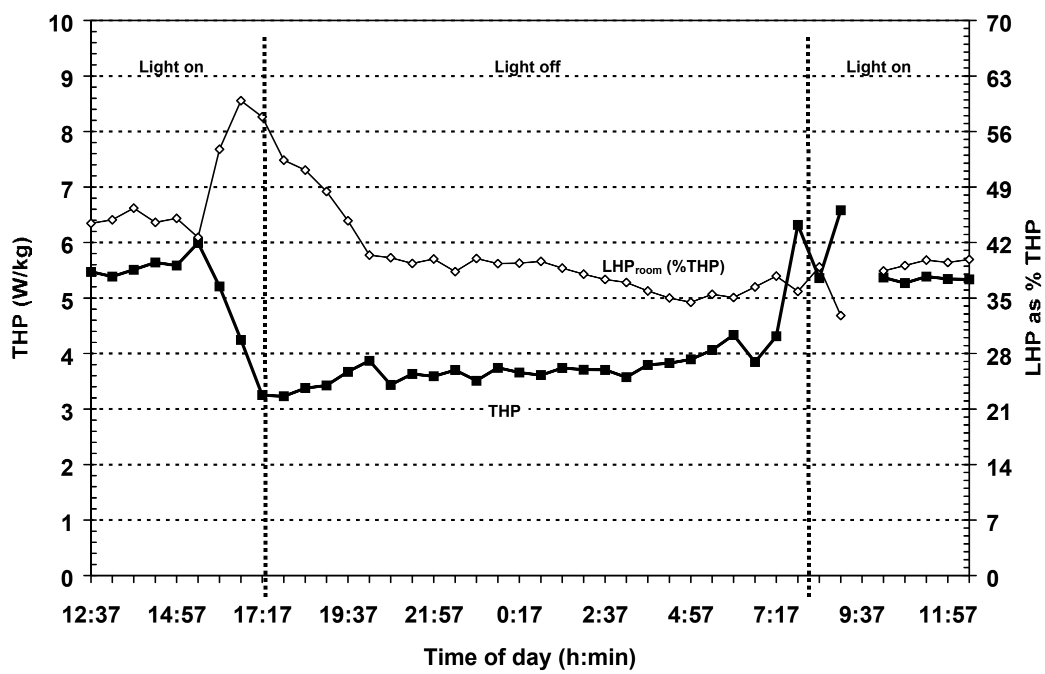
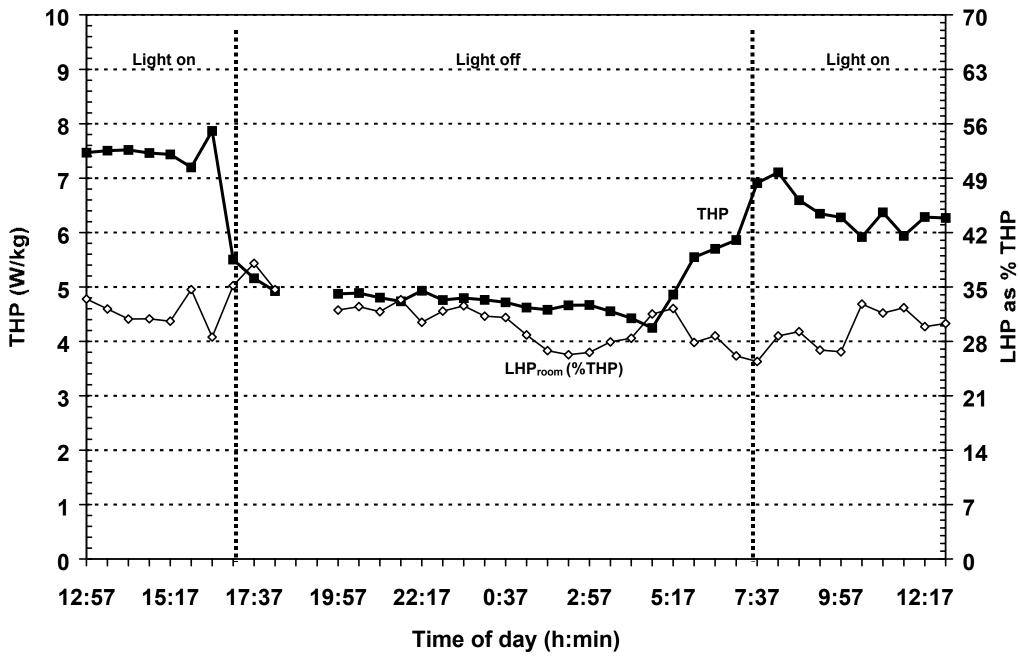


Figure 6. Latent heat production rate (LHP) as a percentage of total heat production rate (THP) and egg production (EP) of molting W-36 laying hens as functions of bird age. TWA = time-weighted average.

Figure 7. Diurnal profiles of total heat production rate (THP), respiratory quotient (RQ), and latent heat production rate of the *room* (LHP_{room}) as % THP for 69-week old W-36 layers during



the *fasting period* under 22°C temperature. Birds had water from nipple drinkers. Both THP and LHP_{room} are averaged over four chambers.

Figure 8. Diurnal profiles of total heat production rate (THP), respiratory quotient (RQ), and latent heat production rate of the *room* (LHP_{room}) as % THP for 70-week old W-36 layers during the *restricted feeding period* under 21°C temperature. Birds had water from nipple drinkers. Both THP and LHP_{room} are averaged over four chambers.

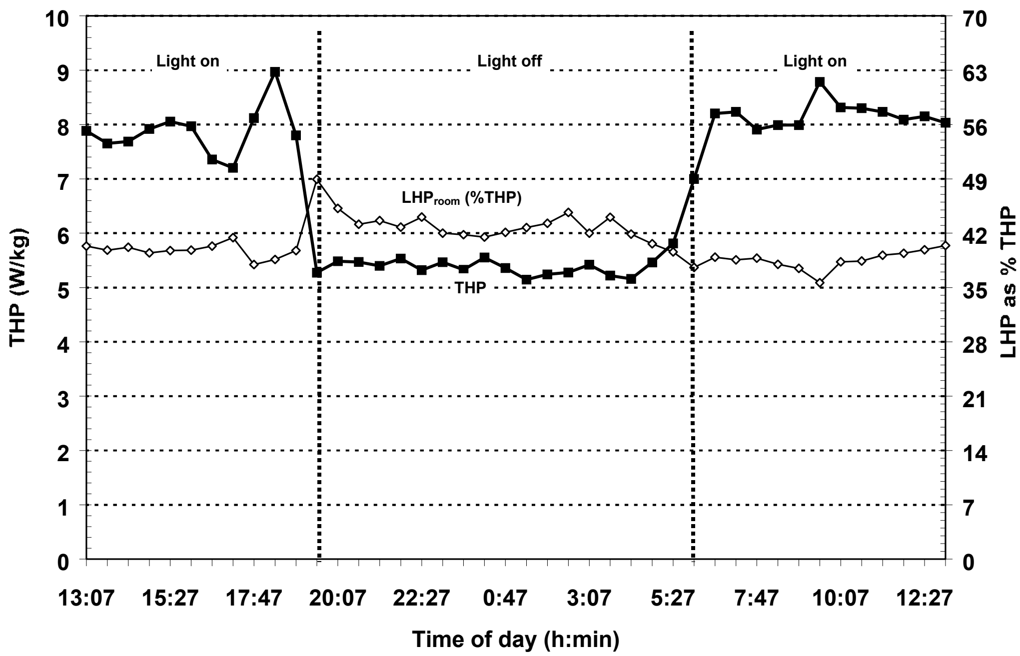


Figure 9. Diurnal profiles of total heat production rate (THP), respiratory quotient (RQ), and latent heat production rate of the *room* (LHP_{room}) as % THP for 72-week old W-36 layers during the *postmolt period* under 24^{o}C temperature. Birds had water from nipple drinkers. Both THP and LHP_{room} are averaged over four chambers.