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Heat and Moisture Production of Poultry and Their Housing Systems – A Literature Review

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ABSTRACT

An extensive literature review and comparative analysis of heat and moisture production of various poultry types and their housing systems are presented. From each published article, the data extracted included breed, body mass (M), and age of the birds; temperature, RH, and photoperiod maintained during the study; measured values of latent heat (LH), sensible heat (SH) and total heat (TH) production; the type of study used (direct vs indirect calorimetric studies); feeding regimen (ad-libitum vs restricted); number of birds used; duration of the study and the type of waterers used. LH, SH and TH were explicitly indicated in some articles while in others, regression equations were published. Specific total heat production (THP, W/kg) was observed to have increased over the years in all poultry types. Specifically, THP increased by about 21 to 44% over a 14-year period (1968 to 1982) for broilers weighing 0.1 to 1.6 kg and by 15 to 22% for broilers at 1.4 to 1.6 kg over a 32 year period (1968 to 2000). Only one study was found for pullets and data were thus insufficient to draw any conclusions about the trend of THP. Data for pullets & layers between 7 and 33 wk old at thermoneutral environment are not available. Tom turkeys weighing 0.4 to 1.0 kg experienced an increase in THP of 36 to 63% over a 24-year period (1974 to 1998). Data for heavier turkeys were insufficient to make reasonable comparisons in the trend of THP. The metabolic rate equations derived from the literature data were in good agreement with the standard metabolic rate HP (W/bird)= a M^{b}, where b = 0.66 to 0.75. Specifically, it was 10.60 $M^{0.74}$(1982 to 2000) and 8.31 $M^{0.71}$(1968) for broilers; 6.20 $M^{0.71}$for pullets and layers; and 9.83 $M^{0.74}$(1992 to 1998) and 7.74 $M^{0.48}$(1974 to 1977) for turkeys.

KEYWORDS: Latent heat, Sensible heat, Metabolic rate, Ventilation, Calorimetry.

INTRODUCTION

Reliable data on heat and moisture production (HP and MP) of housed animals are crucial for use in building ventilation design specifications (Hartung, 1994; Reece and Lott, 1982a; Reece and Deaton, 1971). The quantity of HP and MP from poultry varies with breed, age, body weight, degree of activity, nutritional plane, and environmental temperature (Deighton and Hutchinson, 1940, Meltzer, 1987).

Improved bird nutrition and especially bird genetics have contributed to dramatic increases in poultry growth rates. Havenstein et al. (1991) claimed an increase in growth rate in today's broiler chicken of about 350% compared to that of the 1957 broiler chicken. Reece and Lott (1982c) reported that the growth rate of broilers approximately doubled that reported by Longhouse et al. (1960) and was about 40% greater than that reported by Deaton et al. (1969) and Reece et al. (1969). Flood et al. (1992) reported growth rates of about 25% greater than those reported by Simmons et al. (1987) and Reece and Lott (1982c).

HP and MP are measured by either direct calorimetry (DC) or indirect calorimetry (IC). DC requires the physical measurement of total heat loss from an enclosure housing the animals (ventilation and conductive heat losses) while IC relates respiratory gaseous exchange to energy production.

HP and MP data in the literature date as far back as 20 to 50 years. The specific total heat production (THP, W/kg) is often partitioned into specific sensible heat and latent heat production (SHP and LHP).

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Several authors (Reece and Lott, 1982a, b; Gates et al., 1996; ASHRAE, 1997; Xin et al., 1998) have pointed out an urgent need to update the HP and MP characteristics of modern poultry production facilities for the design and operation of environmental control systems. This urgent need is warranted by the significant changes over the years in animal genetics, nutrition, housing equipment and management practices. The objective of this paper was to perform a comprehensive review and comparative analysis of the HP and MP data in the literature.

METHOD OF DATA COLLECTION AND PRESENTATION

From each published paper, the necessary data were extracted and organized into a summary table. The data were presented to include or represent the following conditions: a) *type of study* – DC or IC with or without inclusion of moisture evaporation from feces conducted at lab-scale or whole-house; b) *drinker type* – open trough or nipple; c) *lighting condition* – light or dark; d) *nutritional level* – ad-lib or limited feeding; e) *genetic strain* where possible; f) *bird age or body mass*; g) *ambient temperature*; h) *relative humidity (RH)* where possible; i) number of birds involved in the measurement; and j) duration of the measurement.

All the numerical data (body mass or M, HP, and MP) were converted to SI units, where necessary. In some papers, the HP data were explicitly presented while in others, reported regression equations were used to calculate HP values. Some original authors were contacted for information that could not be obtained from their published articles. To examine and illustrate the magnitude of change in THP over the time period, THP associated with the thermoneutral (TN) conditions from various sources were plotted.

RESULTS AND DISCUSSION

HP & MP data for broilers

The HP and MP data for broilers over the years 1958 to 2000 are presented in Table 1. THP data over the years between 1968 and 2000 at TN environment (21 to 30 °C, depending on bird age), are plotted in Figure 1.

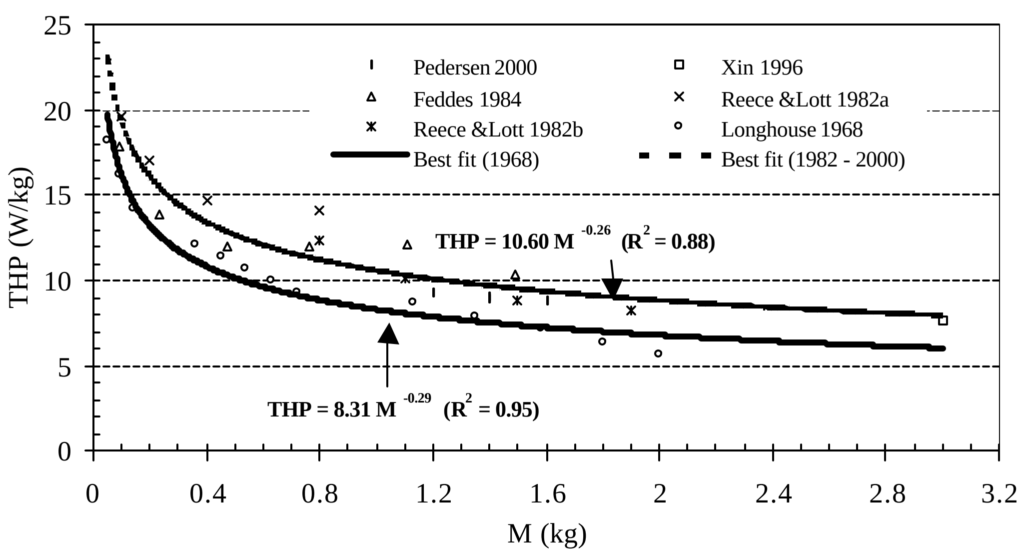

Figure 1. Total heat production (THP) of broilers fed ad-libitum as a function of body mass at thermoneutral environment (21 – 30°C), as measured over the past three decades.

The best-lines-of-fit of THP were separately performed into the scatter plot for the 1982 to 2000 and 1968 data. The results were:

for 1982 to 2000, $\quad$ THP (W/kg) = 10.60 $M^{-0.26}$ $\quad$ (R^2 = 0.88) $\quad$ (1)

for 1968, $\quad$ THP (W/kg) = 8.31 $M^{-0.29}$ $\quad$ (R^2 = 0.95) $\quad$ (2)

On a per bird basis, the equations for the best-lines-of-fit were:

for 1982 to 2000: $\quad$ THP (W/bird) = 10.60 $M^{0.74}$ $\quad$ (3)

for 1968: THP (W/bird) = 8.31 M $^{0.71}$ (4)

These equations compared very well to the general relationship that animals expend energy in proportion to the metabolic mass, kg $^{0.75}$. For broilers, the following equations had been reported:

THP (W/bird) = 9.6 M $^{0.75}$ (Jorgensen et al., 1996) (5)

THP (W/bird) = 10.0 M $^{0.75}$ (CIGR Handbook, 1999) (6)

THP seems to be generally higher in the recent studies than in old studies at a given M. For example, at 0.1, 0.4, 0.6, 1.4, and 1.6 kg, THP was about 25, 21, 44, 27 and 35% higher, respectively, in 1982 than in 1968 (14 years). It was also 40% higher in 1984 than in 1968 at 1.4 kg (16 years). Between 1968 and 2000 (32 years), THP for the 1.4 and 1.6 kg increased by 15 and 22%, respectively.

HP & MP data for pullets and layers

The HP and MP data for layers over the years 1953 to 1990 are presented in Table 2. THP data over the years between 1961 and 1990 at TN environment (21 to 30 °C, depending on bird age), are plotted in Figure 2.

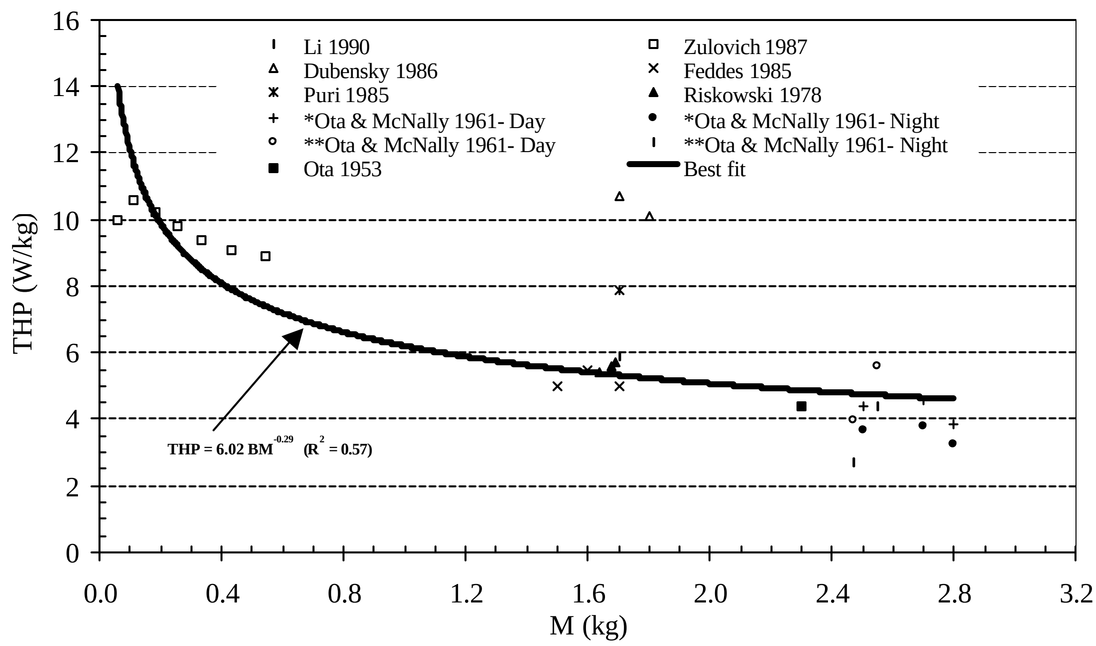

Figure 2. Total heat production (THP) of pullets and layers as a function of body mass at thermoneutral environment (21 – 30°C), as measured during the past four decades. * = New Hampshire; ** = Rhode Island Reds.

A best-line-of-fit of THP was performed into the scatter plot, of the form:

THP (W/kg) = 6.20 M $^{-0.29}$ (R^2 = 0.57) (7)

On a per bird basis, the equation for the best-line-of-fit was:

THP (W/bird) = 6.20 M $^{0.71}$ (8)

This compared very well to the general relationship that animals expend energy in proportion to the metabolic mass, kg $^{0.75}$. For layers kept in cages, it is specifically:

THP (W/bird) = 6.28 M $^{0.76}$ + 25Y (CIGR Handbook, 1999) (9)

For layers reared on the floor:

THP (W/bird) = 6.80 M $^{0.76}$ + 25Y (CIGR Handbook, 1999) (10)

where Y is the egg production (kg/d).

For 1.7 kg layers, THP was 5.7, 7.9, 10.7, and 5.9 W/kg in 1978, 1985, 1986, and 1990, respectively. The difference in THP was as high as 88% during this period, although the data was quite limited. Data by Li et al. (1990) may not compare very well to others (Riskowski et al., 1978; Puri et al., 1985; and Dubensky et al., 1986) as the former used only 4 birds over 4 days in their measurements while the latter used at least 90 birds with trials performed over more than 4 days (Table 2). Ota & McNally (1961) used 10 to 11 birds per chamber. Although data by Ota & McNally were not a weighted average between light and dark periods, they did fit quite well in the general trend. The ASHRAE Handbook (1997) and ASAE Standards (1997) use data by Ota & McNally (1961) in the design of ventilation systems for laying hens. All data presented in Figure 2 were obtained using DC method except for the data by Li et al. (1990) that were determined using IC.

The only data found for pullets (up to 7 wks or 0.54 kg) were reported by Zulovich et al. (1987). It is also the only pullet data referenced in the ASHRAE Handbook (1997). Data between 7 and 33wk (0.54 to 1.50 kg) old birds was not found (fig. 2). Research is thus needed to generate more and new data for pullets (up to 20 wks of age).

HP & MP data for turkeys

The HP and MP data for turkeys over the years 1974 to 1998 are presented in Table 3. THP data over the years between 1992 to 1998 and 1974 to 1977 at TN environment (15 to 30 °C, depending on bird age), are plotted in Figure 3.

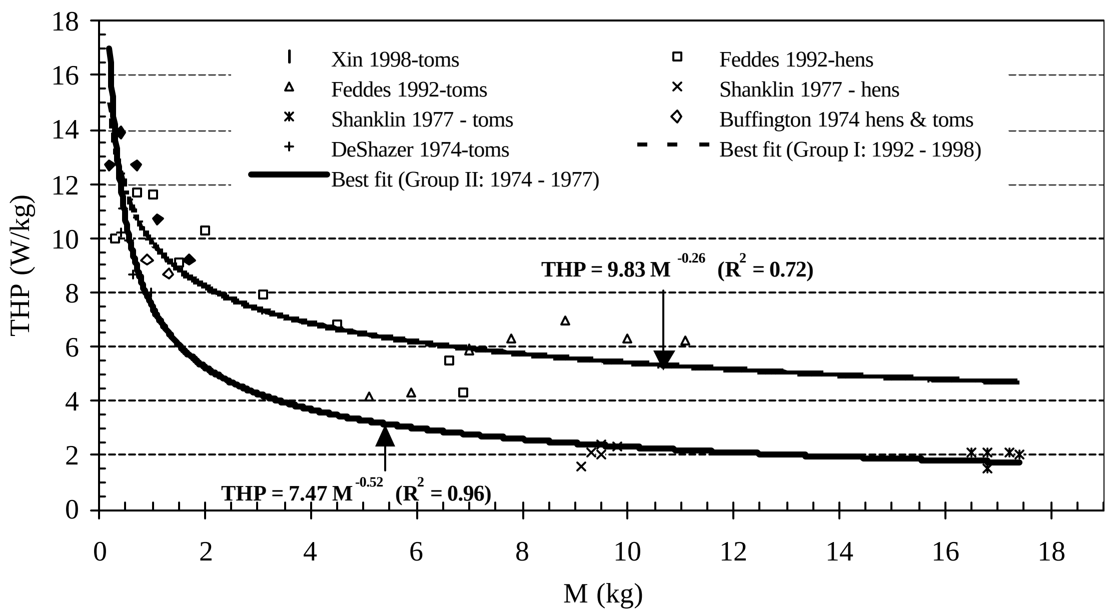

Figure 3. Total heat production (THP) of turkeys fed ad-libitum as a function of body mass at thermoneutral environment (15 – 30°C), as measured over the past two decades.

The best-lines-of-fit of THP were performed into the scatter plot. The results were:

for 1992 to 1998, THP (W/kg) $=9.83\ M^{-0.26}$ ($R^2 = 0.72$) (11)

for 1974 to 1977, THP (W/kg) $=7.47\ M^{-0.52}$ ($R^2 = 0.96$) (12)

On a per bird basis, the equations for the best-lines-of-fit are:

for 1992 to 1998: THP (W/bird) $=9.83\ M^{0.74}$ (13)

for 1974 to 1977: THP (W/bird) $=7.47\ M^{0.48}$ (14)

The 1992 to 1998 data compared very well to the general relationship that animals expend energy in proportion to the metabolic body mass, kg $^{0.75}$ while the 1974 to 1977 data did not. The relationship between THP (W/bird) and M for turkeys was not found in the literature.

For M of 0.4, 0.7 and 1.0 kg, THP values for toms increased by 36, 63 and 47%, respectively between 1974 and 1998 (24 years). For M of 9.1 kg, THP was about 1.6 and 6.8 W/kg for the 1977 hen and 1992 tom, respectively. Data were not sufficient to make comparisons for heavy toms. More research to generate such data is thus warranted. The ASHRAE Handbook (1997) and the ASAE Standards (2000) presented data by Buffington et al. (1974) and DeShazer et al. (1974) that are widely used in the design of ventilation systems for turkeys. Data for heavier turkeys are not presented in the ASHRAE Handbook, and the ASAE Standards (2000) only presented data by Shanklin et al. (1977).

For turkeys of 1.1 kg, THP was about 17% higher in 1998 (Xin et al.) than in 1974 (Buffington). Interestingly, for 1.7 kg, THP in 1998 and 1974 was similar. The 1998 study involved only toms while the 1974 study involved both hens and toms. It took 28d and 39d for a turkey to reach 1.1 kg in 1998 and 1974, respectively. For 1.7 kg, the growth period was 35d and 50d for 1998 and 1974, respectively. The faster growth of modern turkeys is presumably attributed to improved genetics, nutrition and management practices.

CONCLUSIONS

This review of literature has clearly demonstrated that THP of poultry has increased over the years presumably due to the factors suggested by many authors in the literature such as genetics, nutrition, housing and management improvements. Accompanying this increase in THP would be changes in the magnitudes of SHP, LHP, and MP. These changes may have significant effect in the physical design of modern poultry structures and environmental control, particularly ventilation for heat and air quality control which directly affects animal health and production efficiency. The review further revealed the existence of data gaps for certain body mass. Hence there is a need to conduct an intensive, systematic research to update and bridge the gaps in HP and MP of modern poultry.

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Table 1. Summary of literature data on heat and moisture production of ad-lib fed broilers. Values in italics were calculated from the other two known HP variables (i.e. THP = LHP + SHP)

M	Age	T_a	RH	LHP	SHP	THP	No. birds	Duration	Light	Type	Waterer	Ref.
(kg)	(d or wk)	(^{o}C)	(%)	(W/kg)								
1.2	28d	22.0	60	4.7	4.6	9.3	6000	cont.	cont.	B/D	nipple	**[1]***
1.4	30d	22.0	65	4.6	4.5	9.1	6000					
1.4	32d	22.4	65	4.5	4.6	9.0	7200					
1.6	35d	22.4	65	4.3	4.4	8.8	7200					
3.0	6.5wk	24.0	52	*4.1*	4.3	8.4	96	4d	8h: L	A/I	nipple	**[2]**
				3.2	3.1	6.3			4h: D			
				3.8	3.9	7.7			24h			
0.10	4d	28.3	50	13.7	2.3	*16.1*	26000	cont.	24h***	B	nipple	**[3]***
0.16	6d			14.3	5.5	*19.8*	per flock					
0.23	8d			12.1	5.8	*18.0*	of 6					
0.30	10d	25.6	50	10.4	6.1	*16.5*						
0.40	12d			9.1	6.3	*15.5*						
0.46	14d			8.3	6.5	*14.8*						
0.54	16d			7.9	6.6	*14.5*						
0.60	18d	22.8	50	7.6	6.6	*14.2*						
0.75	21d	15.6	50	6.8	5.9	*12.8*						
1.07	28d			5.5	4.6	*10.2*						
1.41	35d			4.7	4.4	*9.1*						
1.80	42d			4.4	4.3	*8.8*						
0.75	21d	21.1	50	7.1	5.7	*12.8*						
1.07	28d			5.8	4.1	*9.9*						
1.41	35d			4.6	3.5	*8.1*						
1.80	42d			4.1	3.4	*7.4*						
0.75	21d	26.7	50	7.1	4.6	*11.7*						
1.07	28d			6.4	3.2	*9.7*						
1.41	35d			6.1	3.2	*9.3*						
1.80	42d			6.0	3.2	*9.3*						
0.05	2d	33.2	30	*21.1*	8.9	30.0	7535	8d	cont.	B/D	bell	**[4]**
0.16	9d	27.7	41	*8.3*	5.4	13.7						(barn A)
0.36	16d	26.6	38	*6.2*	3.7	9.8						
0.63	23d	24.3	43	*5.4*	5.0	10.4						
0.95	30d	22.6	41	*5.4*	6.3	11.7						
1.32	37d	21.8	58	*4.1*	5.0	9.1						
1.71	44d	21.6	48	*4.4*	4.9	9.3						
0.09	5d	30.4	23	*6.5*	5.2	11.8	6635	7d				(barn B)
0.23	12d	28.2	28	*6.1*	9.4	15.4						
0.47	19d	25.7	37	*5.0*	9.0	14.0						
0.76	26d	25.1	42	*5.5*	7.5	13.0						
1.11	33d	24.1	50	*5.7*	7.8	13.5						
1.49	40d	21.1	53	*4.2*	7.3	11.5						

Table 1. (continued)

M	Age	T_a	RH	LHP	SHP	THP	No. birds	Duration	Light	Type	Waterer	Ref.
(kg)	(d or wk)	(°C)	(%)		(W/kg)							
0.1	7d	29.4	46	14.8	4.7	19.6	640	8h/d	cont.	A/D	jugs &	**[5]***
0.2	14d	26.7	53	10.9	6.2	17.1	320	for 4 wk			trough	
0.4	21d	23.9	57	8.0	6.7	14.7	160					
0.8	28d	21.1	52	7.1	6.5	14.1	80					
0.8	28d	15.6	58	6.5	5.5	*12.1*	640	4 wk	cont.	A/D	trough	**[6]***
1.2	35d		48	5.3	4.7	*10.0*	320					
1.6	42d		60	4.9	4.7	*9.6*	160					
2.0	49d		61	4.3	4.9	*9.3*	80					
0.8	28d	21.1	52	7.2	5.2	*12.4*	640					
1.1	35d		56	5.8	4.3	*10.1*	320					
1.5	42d		54	4.7	4.1	*8.8*	160					
1.9	49d		54	4.1	4.2	*8.3*	80					
0.7	28d	26.7	44	7.1	3.3	*10.4*	640					
1.1	35d		46	6.6	3.3	*9.9*	320					
1.5	42d		56	6.2	3.3	*9.5*	160					
1.8	49d		63	6.1	3.3	*9.4*	80					
0.5	21-28d	15.6$\pm$2.8	*60*	5.5	7.5	13.0	2100	4 wk	cont.	B/D	N/A	**[7]**
0.8	29-35d		*70*	5.0	6.1	11.1						
1.1	36-42d		*55*	4.1	5.6	9.7						
1.3	43-49d		*53*	3.8	4.9	8.7						
1.5	50-56d		*56*	3.5	4.6	8.0						
0.5	21-28d	32-35	40-90	8.2	6.6	14.8	2100	4 wk	cont.	B/D	N/A	**[8]**
0.7	29-35d		(ave. 70)	7.1	5.6	12.7						
0.9	36-42d			6.5	4.8	11.3						
1.1	43-49d			7.2	4.1	11.2						
1.4	50-56d			6.9	3.3	10.2						
0.05	N/A	28.9	N/A	2.2	16.0	*18.2*	1200	7d	24h***	C/D	fountain	**[9]***
0.09		28.9		2.8	13.4	*16.2*						
0.14		28.9		3.4	10.8	*14.2*						
0.36		25.0		2.6	9.4	*12.1*						
0.45		25.0		2.5	8.9	*11.4*						
0.54		25.0		2.3	8.3	*10.7*						
0.63		25.0		2.2	7.8	*10.0*						
0.72		25.0		2.1	7.2	*9.3*						
1.13	N/A	19.4	N/A	1.8	6.9	*8.7*						
1.35		19.4		1.6	6.3	*7.9*						
1.58		19.4		1.4	5.8	*7.2*						
1.80		19.4		1.2	5.3	*6.4*						
2.00		19.0		0.9	4.8	*5.7*						

Table 1. (continued)

M (kg)	Age (d or wk)	T_a (°C)	RH (%)	LHP	SHP	THP	No. birds	Duration	Light	Type	Waterer	Ref.
					(W/kg)							
0.6	32d	18.3	70	7.4	8.0	15.4	49	44d	Day	A/D	fountain	**[10]***
0.9	44d			6.6	6.7	13.3	49	(cont.)				
1.1	52d			6.2	6.0	12.2	35					
1.3	64d			5.6	5.2	10.8	35					
1.5	76d			5.2	4.5	9.7	34					
0.6	32d	18.3	70	5.7	7.4	13.0	49	44d	Night			
0.9	44d			5.1	6.0	11.0	49	(cont.)				
1.1	52d			4.8	5.2	10.0	35					
1.3	64d			4.4	4.3	8.7	35					
1.5	76d			4.1	3.5	7.6	34					
0.2	11d	29.4	70	9.4	5.6	14.9	69	65d	Day			
0.3	16d			8.7	5.1	13.7	69	(cont.)				
0.4	24d			7.9	4.6	12.5	69					
0.6	32d			7.4	4.3	11.6	50					
0.9	46d			6.7	3.8	10.5	50					
1.1	52d			6.4	3.7	10.1	50					
1.2	58d			6.2	3.5	9.8	35					
1.3	64d			6.1	3.4	9.4	35					
1.4	76d			5.7	3.2	8.9	35					
0.2	11d	29.4	70	7.8	5.5	13.4	69		Night			
0.3	16d			7.2	4.9	12.2	69					
0.4	24d			6.5	4.4	10.9	69					
0.6	32d			6.1	4.0	10.1	50					
0.9	46d			5.5	3.4	8.9	50					
1.1	52d			5.3	3.3	8.5	50					
1.2	58d			5.1	3.1	8.2	35					
1.3	64d			5.0	3.0	7.9	35					
1.4	76d			4.7	2.7	7.4	35					

* = values calculated from regression equations (see Appendix 1)

*** = Source data presented as weighted average of light and dark periods

LHP = Latent Heat Production; MP(g/(h.kg)) = Moisture Production = LHP/2450*3600; SHP = Sensible Heat Production;

THP = Total Heat Production

Type of study: A/I = Lab-scale indirect calorimetry & LHP values include evaporation of moisture from feces, litter & drinkers

A/D = Lab-scale direct calorimetry and LHP values include evaporation of moisture from feces, litter and drinkers

B/D = Whole-house direct calorimetry and LHP values include evaporation of moisture from feces, litter & drinkers

C/D = Lab-scale direct calorimetry and LHP values do not include evaporation of moisture from feces, litter and drinkers. Oil pans were used to submerge bird droppings

N/A = Information not available

Values in italics have been calculated from the relation: THP = SHP + LHP

[1] Pedersen & Thomsen, (2000)**;** **[2]** Xin et al., (1996); [**3]** Gates et al., (1996); **[4]** Feddes et al., (1984); **[5]** Reece and Lott, (1982a); **[6]** Reece & Lott, (1982b); [**7]** Deaton et al., (1969); [**8]** Reece et al., (1969); **[9]** Longhouse et.al., (1968); **[10]** Ota & Garver, (1958).

Table 2. Summary of literature data on heat and moisture production of ad-lib fed (otherwise noted) pullets and layers. Values in italics were calculated from the other two known HP variables (i.e. THP = LHP + SHP)

Breed	M	Age	T_a	RH	LHP	SHP	THP	No. birds	Duration	Light	Type	Waterer	Ref.
	(kg)	(d or wk)	(°C)	(%)		(W/kg)							
Hy-Line GP male chicks	0.037	0 - 3d	29.4	40+5	*11.1*	8.0	19.1	1280	3d	Int.	A/I	Aqua-Jel	**[1]**
	0.0340	0-2d	35	17	*3.2*	5.2	8.4	2112	2d	cont.	A/I[nf]	no water	**[2]**
			30	22	*2.8*	5.7	8.5						
			25	30	*2.7*	6.4	9.1						
			20	40	*2.5*	7.8	10.3						
Shaver Starcross 288	1.7	54 wk	17 - 25	N/A	N/A	N/A	6.8	4	4d	14h: L	A	bell	**[3]**
							4.6			10h: D			
							5.9			24h			
Dekalb XL Pullets	0.06	7d	27.2	*13 - 32*	5.7	11.4	*17.1*	2500	7 wk	10h: L	B/D	bell	**[4]***
	0.11	14d	24.4	*20 - 38*	4.4	11.1	*15.5*						
	0.18	21d	21.6	*29 - 43*	3.8	10.1	*13.9*						
	0.25	28d	21.0	*41 - 62*	3.6	9.2	*12.8*						
	0.33	35d	21.0	*40 - 61*	3.6	8.5	*12.1*						
	0.43	42d	21.0	*32 - 53*	3.6	7.9	*11.5*						
	0.54	50d	21.0	*36 - 53*	3.7	7.4	*11.1*						
	0.06	7d	27.2	*13 - 32*	5.2	-0.3	*4.9*			14h: D			
	0.11	14d	24.4	*20 - 38*	3.9	3.2	*7.1*						
	0.18	21d	21.6	*29 - 43*	3.3	4.2	*7.5*						
	0.25	28d	21.0	*41 - 62*	3.1	4.4	*7.5*						
	0.33	35d	21.0	*40 - 61*	3.0	4.4	*7.4*						
	0.43	42d	21.0	*32 - 53*	3.0	4.4	*7.4*						
	0.54	50d	21.0	*36 - 53*	3.0	4.3	*7.3*						
	0.06	7d	27.2	*13 - 32*	*5.4*	*4.6*	*10.0*			24h			
	0.11	14d	24.4	*20 - 38*	*4.1*	*6.5*	*10.6*						
	0.18	21d	21.6	*29 - 43*	*3.6*	*6.7*	*10.2*						
	0.25	28d	21.0	*41 - 62*	*3.3*	*6.4*	*9.8*						
	0.33	35d	21.0	*40 - 61*	*3.2*	*6.1*	*9.4*						
	0.43	42d	21.0	*32 - 53*	*3.2*	*5.9*	*9.1*						
	0.54	50d	21.0	*36 - 53*	*3.3*	*5.6*	*8.9*						
Arbor Acres broiler breeders	3.6	31-57wk	17.5	55	2.9	*3.4*	6.4	11546	24h/4wk	14h: L	B/D	bell	**[5]**
					2.6	*2.6*	5.2			10h: D			
					2.8	*3.1*	5.9			24h			
		27-55wk	18.9	58	2.0	*3.5*	5.5			14h: L			
					1.9	*2.9*	4.8			10h: D			
					2.0	*3.2*	5.2			24h			

Table 2. (continued)

Breed	M	Age	T_a	RH	LHP	SHP	THP	No. birds	Duration	Light	Type	Waterer	Ref.
	(kg)	(d or wk)	(°C)	(%)	(W/kg)								
Arbor	3.6	33-49wk	18.8	60	2.8	*3.0*	5.9	11546	24h/4wk	14h: L	B/D	bell	**[5]**
Acres					2.6	*3.1*	5.7			10h: D			
broiler					2.7	*3.1*	5.8			24h			
breeders													
White	1.8	44-58wk	20.0	68	4.1	5.4	*9.5*	144	7d	16h: L	A/D	cup	**[6]**
Leghorn					2.9	4.1	*7.0*			8h: D			
					3.7	4.9	*8.6*			24h			
White	1.7	44-58wk	20.3	73-54	4.3	6.8	*11.1*			16h: L			
Leghorn			$\pm$ 4.8		2.5	7.3	*9.8*			8h: D			
					3.7	7.0	*10.7*			24h			
	1.8	44-58wk	20.6	62-77	2.6	9.8	*12.4*			16h: L			
			+ 6.1		2.8	7.5	*10.3*			8h: D			
					2.6	9.0	*11.6*			24h			
White	1.7	31wk	19.0	63	4.6	4.4	*9.0*	48	7d	16h: L	A/D	cup	**[7]**
Leghorn					4.4	1.5	*5.9*			8h: D			
					4.5	2.8	*7.3*			24h			
			20.0	80	3.7	3.2	*6.9*			16h: L			
					5.3	3.5	*8.8*			8h: D			
					4.5	3.4	*7.9*			24h			
White	1.5	33wk	14.3	61	1.2	*5*	6.2	24850	24h/20d	18h: L	B/D	cup	**[8]**
Leghorn					0.9	*3.7*	4.6		(6 times)	6h: D			
					1.1	*3.9*	5.0			24h			
	1.6	53wk	15.0	58	1.2	*4.8*	6.0			19.5h: L			
					1.1	*4.3*	5.4			4.5h: D			
					1.2	*4.3*	5.5			24h			
	1.7	56wk	15.4	49	1.1	*4.5*	5.6			20h: L			
					0.9	*3.8*	4.7			4h: D			
					1.0	*4*	5.0			24h			
Hy-Line W-36	1.67	41 wk	23.0	58	1.2	4.4	*5.6*	90	24h	24h	C/D	cup	**[9]**
White	1.62	58 wk	23	N/A	N/A	N/A	5.37	6	6d	24h***	A/I[nf]	N/A	**[10]**
Leghorn	1.63	62					4.87						
hybrid	1.69	78					4.68						
strain	1.84	90					5.35						
H & N'	1.93	102					4.86						
hens	1.95	106					4.76						

Table 2. (continued)

Breed	M (kg)	Age (d or wk)	T_a (^oC)	RH (%)	LHP (W/kg)	SHP	THP	No. birds	Duration	Light	Type	Waterer	Ref.
White	1.69	58 wk	23	N/A	N/A	N/A	2.58	6	6d	24h***	A/I[nf]	N/A	**[10]**
Leghorn	1.78	62					2.75						
hybrid	1.96	78					3.22						
strain	1.99	90					3.25						
H & N'	2.00	102					4.04						
cockerels	2.01	106					3.82						
White	1.61	26-48wk	17.8	70	1.8	4.5	*6.3*	10 per	3wk/age	Day	C/D	fountain	**[11]**
Leghorn	1.54	34-39wk	18.3	70	1.6	5.1	*6.7*	chamber	group				
	1.61	26-48wk	17.8	70	1.3	4.4	*5.7*			Night			
	1.54	34-39wk	18.3	70	1.1	4.6	*5.7*						
New	2.5	51-70wk	18.9	75	1.17	3.52	*4.69*	11 per	3wk/age	Day			
Hampshire	2.7		18.3	75	1.09	3.47	*4.56*	chamber	group				
×	2.5		23.9	N/A	1.29	2.81	*4.10*						
Cornish	2.8		23.9	N/A	1.15	2.72	*3.87*						
Cross													
	2.5	51-70wk	18.9	75	0.94	2.93	*3.87*			Night			
	2.7		18.3	75	0.87	2.93	*3.80*						
	2.5		23.9	N/A	0.82	2.58	*3.40*						
	2.8		23.9	N/A	0.73	2.51	*3.24*						
Rhode	2.48	37wk	-3.9	70	0.8	3.7	*4.45*	10 per	3wk/age	Day			
Island	2.55	43	-0.6	85	0.9	4.7	*5.58*	chamber	group				
Reds	2.52	46	5.0	85	1.2	4.7	*5.97*						
	2.62	37	7.2	83	1.2	4.8	*5.98*						
	2.55	39	15.6	64-70	1.3	4.3	*5.58*						
	2.47	42	24.4	50-60	1.4	2.5	*3.94*						
	2.24	37	33.3	36-46	2.0	1.0	*3.01*						
Rhode	2.48	37wk	-3.9	70	0.7	2.8	*3.6*			Night			
Island	2.55	43	-0.6	85	0.8	3.3	*4.1*						
Reds	2.52	46	5.0	85	1.0	3.3	*4.2*						
	2.62	37	7.2	83	1.0	2.4	*3.3*						
	2.55	39	15.6	64-70	0.9	3.5	*4.4*						
	2.47	42	24.4	50-60	1.0	1.7	*2.7*						
	2.24	37	33.3	36-46	1.6	0.5	*2.1*						
Rhode	2.3	N/A	5.5	88	2.7	4.1	*6.8*	20	25d	24h***	A/D	fountain	**[12]**
Island			13.9	76 - 89	3.0	3.4	*6.4*						
Reds			29.8	57	3.8	0.6	*4.4*						

* = values calculated from regression equations (see Appendix 2); N/A = Information not available; nf = No feed
*** = Source data presented as weighted average of light and dark periods
LHP = Latent Heat Production; SHP = Sensible Heat Production; THP = Total Heat Production
Type of study: A/I = Lab-scale indirect calorimetry and LHP values include evaporation of moisture from feces, litter & drinkers
A/D = Lab-scale direct calorimetry and LHP values include evaporation of moisture from feces, litter and drinkers
B/D = Whole-house direct dalorimetry and LHP values include evaporation of moisture from feces, litter & drinkers
C/D = Lab-scale direct calorimetry and LHP values do not include evaporation of moisture from feces, litter and drinkers. Oil pans were used to submerge bird droppings
[1] Han & Xin (2000); [2] Xin & Harmon (1996); [3] Li et al. (1990); [4] Zulovich et al. (1987); [5] O'Connor et al. (1987); [6] Dubensky et al. (1986); [7] Puri et al. (1985); [8] Feddes et al. (1985); [9] Riskowski et al. (1978); [10] O'Neill & Jackson (1974); [11] Ota & McNally (1961); [12] Ota et al. (1953)

Table 3. Summary of literature data on heat and moisture production of ad-lib fed turkeys. Values in italics were calculated from the other two known HP variables (i.e. THP = LHP + SHP)

Breed	M (kg)	Age (d or wk)	T_a (°C)	RH (%)	LHP (W/kg)	SHP (W/kg)	THP (W/kg)	No. birds	Duration	Light	Type	Waterer	Ref.
Nicholas toms	0.2	7d	29.4	35-60	*10*	2.3	12.7	332	35d	cont.	A/I	fountain	**[1]***
	0.4	14d	28.3		*8.9*	5.0	13.9						
	0.7	21d	26.7		*7.3*	5.4	12.7						
	1.1	28d	23.9		*5.9*	4.8	10.7						
	1.7	35d	21.1		*4.8*	4.4	9.2						
Nicholas hens	6.8	15-16wk	32	*60*	1.6	1.3	2.9	72	42h	3.5h: L	A/I	cup	**[2]**
	7.1		32	*80*	1.1	1.9	3.0						
	6.8		36	*51*	2.3	1.0	3.3						
	7.4		36	*68*	1.7	1.8	3.5						
	6.5		40	*43*	3.2	0.8	4.1						
	7.4		40	*58*	2.3	2.0	4.3						
Large white hens	0.3	16d	27.2	38	8.7	1.3	10.0	4692	24h/wk	cont.	B/D	automatic waterers	**[3]**
	0.7	21d	24.5	46	6.4	5.3	11.7	4665					
	1.0	29d	22.2	66	6.8	4.8	11.6	4616					
	1.5	36d	23.0	59	5.5	3.7	9.1	4595					
	2.0	44d	19.6	66	5.6	4.8	10.3	4579					
	3.1	57d	16.3	63	4.0	3.8	7.9	4562	24h/2wk				
	4.5	71d	17.8	47	2.9	4.0	6.8	4544					
	6.6	79d	18.0	73	2.4	3.1	5.5	4537					
	6.9	94d	16.3	52	2.0	2.3	4.3	4526					
toms	5.1	64d	14.0	68	1.6	2.5	4.2	2710	24h/2wk				
	5.9	70d	12.1	63	1.7	2.7	4.3	2692					
	7.0	77d	12.8	70	3.0	3.0	5.9	2673					
	7.8	84d	11.0	81	1.8	4.5	6.3	2658					
	8.8	92d	13.2	85	2.0	5.0	7.0	2636					
	10.0	99d	15.8	62	3.1	3.2	6.3	2610					
	11.1	106d	11.3	73	2.3	3.9	6.2	2575					
Broad Breasted Bronze hens	9.8	41-63wk	10	60	0.2	2.1	2.3	4	2h / temp	2h: L	A/D	no water	**[4]nf**
	9.5		15	60	0.5	1.9	2.4						
	9.5		20	60	0.4	1.6	2.0						
	9.3		25	60	0.5	1.5	2.1						
	9.1		30	60	0.6	1.0	1.6						
	8.7		35	60	0.8	0.6	1.4						
Broad Breasted Bronze toms	17.2	41-63wk	10	60	0.2	1.9	2.1	4	2h / temp				
	17.4		15	60	0.3	1.7	2.0						
	16.8		20	60	0.4	1.6	2.1						
	16.5		25	60	0.6	1.5	2.1						
	16.8		30	60	0.7	0.8	1.5						
	15.8		35	60	1.0	0.4	1.4						

Table 3. (continued)

Breed	M (kg)	Age (d or wk)	T_a (°C)	RH (%)	LHP (W/kg)	SHP (W/kg)	THP (W/kg)	No. birds	Duration	Light	Type	Waterer	Ref.
Wrolstad	0.6	28d	21	42	N/A	N/A	11.6	5	cont.	12h: L	A/I	metal	**[5]***
white	0.9	35d					10.8					pan	
toms	1.3	42d					10.2						
&													
hens	0.6	28d	21	42	N/A	N/A	7.9			12h: D			
	0.9	35d					7.5						
	1.3	42d					7.2						
	0.6	28d	21	42	N/A	N/A	*9.7*			24h			
	0.9	35d					*9.2*						
	1.3	42d					*8.7*						
	1.8	51d	21	42	N/A	N/A	9.3		cont.	daytime			
	2.2	58d					8.7						
	2.6	65d					8.2						
	3.0	72d					7.7						
	3.4	79d					7.2						
	3.6	84d					6.9						
Large	0.106	6d	35.0	N/A	11.9	5.0	16.7	10/chamber	24h	cont.	C/D	metal	**[6]**
white male	0.111	7d	29.4		8.7	7.8	17.0					reservoir	
Orlopp	0.129	9d	40.6		21.0	-2.1	18.4						
strain	0.235	14d	32.2		7.0	5.8	13.1						
	0.221	15d	37.8		11.0	1.6	12.1						
Large	0.364	19d	35.0	N/A	6.9	2.0	8.7	12/chamber	24h				
white male	0.419	21d	29.9		4.6	5.0	10.2						
Amerine	0.437	23d	23.9		4.0	7.1	11.1						
strain	0.568	27d	23.9		1.7	7.8	9.9						
	0.629	28d	26.7		2.8	6.0	8.7						
	0.740	29d	32.2		3.7	3.8	7.8						
	0.906	36d	29.4		2.6	4.4	7.3						

N/A = Information not available

* = values calculated from regression equations (see Appendix 3)

LHP = Latent Heat Production; MP(g/(h.kg)) = Moisture Production = LHP/2450*3600; SHP = Sensible Heat Production;

THP = Total Heat Production

Type of study: A/I = Lab-scale indirect calorimetry and LHP values include evaporation of moisture from feces, litter & drinkers

A/D = Lab-scale direct calorimetry and LHP values include evaporation of moisture from feces, litter and drinkers

B/D = Whole-house direct calorimetry and LHP values include evaporation of moisture from feces, litter and drinkers

C/D = Lab-scale direct calorimetry and LHP values do not include evaporation of moisture from feces, litter and drinkers. Oil pans were used to submerge bird droppings

Values in italics have been calculated from the relation: THP = SHP + LHP

[1] Xin et al., (1998); [**2]** Xin et al., (1992); [**3]** Feddes & McDermott., (1992); **[4]** Shanklin et al., (1977); **[5]** Buffington et al., (1974)
[6] DeShazer et al., (1974)

APPENDIX 1

Regression equations for calculating HP & MP for broilers

Pedersen & Thomsen (2000) [all heat production values are in W; t = temperature, ^oC]

$THP = 9.84\ M^{0.75}\ (4 \times 10^{-5} (20 - t)^3 + 1)$
$SHP = 0.83\ THP\ (0.8 - 1.85 \times 10^{-7} (t + 10)^4)$

Gates et al. (1996) [all heat production values are in Btu/(hr-lb) if K = 1, and W/kg if K = 0.64631; x = bird age, day]

For all brooding temperatures

$SHP = K \exp(-6.5194+2.9186x-0.24162x^2)$	$3 \le x \le 5$
$SHP = K \exp(1.8662+0.054213x-0.00161x^2)$	$6 \le x \le 19$
$LHP = K (-42.961+27.415x-2.84344x^2)$	$2 \le x < 5$
$LHP = K (36.424-2.8998x+0.08676x^2)$	$6 \le x \le 15$
$LHP = K (15.812-0.22611x)$	$16 \le x \le 19$

For temperature of 15.6^{o}C

$SHP = K (38.612-2.6224x+0.072047x^2-0.00066x^3)$	$20 \le x < 41$
$SHP = 6.717K$	$42 \le x \le 48$
$LHP = K (22.285-0.78279x+0.011503x^2-0.000038x^3)$	$20 \le x < 43$
$LHP = 6.87K$	$44 \le x \le 48$

For temperature of 21.1 ^{o}C

$SHP = K (36.070-2.3107x+0.058862x^2-0.00051x^3)$	$20 \le x < 39$
$SHP = 5.220K$	$40 \le x \le 48$
$LHP = K (11.221+0.40495x-0.02727x^2+0.000353x^3)$	$20 \le x < 43$
$LHP = 6.278K$	$44 \le x \le 48$

For temperature of 26.7 ^{o}C

$SHP = K \exp(5.3611-0.16177x)$	$20 \le x < 23$
$SHP = 5.0K$	$24 \le x \le 48$
$LHP = K (20.094-0.70318x+0.015182x^2-0.000108x^3)$	$20 \le x < 42$
$LHP = 9.340K$	$43 \le x \le 48$

Reece & Lott (1982a) [all heat production values are in Btu/(hr-lb); MP = kg/(h-1000 birds); x = bird age, day]

$SHP = 9.85 \text{ Log } x - 0.0043x^2 - 0.869$	$2 \le x \le 28$
$LHP = 8.6 + 3.4x - 0.009x^2 - 0.04x^3 + 0.0019x^4$	$x < 13$
$LHP = 30.8 - 1.1x + 0.0005x^3$	$x \ge 13$
$MP = 0.005x^2 + 0.24x + 0.29$	$x \le 7$
$MP = 0.00061x^3 - 0.021x^2 + 0.42x + 0.23$	$x > 7$

Reece & Lott (1982b) [all heat production values are in Btu/(hr-lb); M = bird weight, g]

For temperature of 15.6 ^{o}C $500 \le M \le 2000$

$SHP = 20.3 - 0.0247M + 1.498M^2 \times 10^{-5} - 2.95M^3 \times 10^{-9} + 2.2M^4 \times 10^{-14}$
$LHP= 33.6 - 0.0605M + 5.455M^2 \times 10^{-5} - 2.21M^3 \times 10^{-8} + 3.29M^2 \times 10^{-12}$

For temperature of 21.1 ^{o}C $500 \le M \le 2000$

$SHP = 15.9 - 0.0143M + 4.96M^2 \times 10^{-6} +1.02M^2 \times 10^{-9} - 6.47M^2 \times 10^{-13}$
$LHP = 25.8 - 0.0382M + 3.752M^2 \times 10^{-5} - 1.9M^2 \times 10^{-8} + 3.69M^4 \times 10^{-12}$

For temperature of 26.7 ^{o}C $500 \le M \le 2000$

$SHP = 5$
$LHP= 13 - 0.0034M + 4.57M^2 \times 10^{-7} + 1.74M^2 \times 10^{-10}$

Longhouse et al. (1968) [all heat production values are in Btu/(hr-lb); M = bird weight, lb]

For temperature of 28.9 ^{o}C $0.1 \le M \le 0.3$

$SHP = 28.57 - 40.02M$
$LHP = 2.43 + 9.42M$

For temperature of 25.0 ^{o}C $0.7 \le M \le 1.7$

$SHP = 17.95 - 4.30M$

$LHP = 4.89 - 1.07M$

For temperature of 19.4 °C $2.1 \le M \le 4.4$

$SHP = 14.53 - 1.60M$
$LHP = 4.45 - 0.67M$

Ota & Garver (1958) [all heat production values are in Btu/(hr-lb); x = bird age, day]

For temperature of 18.3 °C (65F) $29 \le x \le 90$

THP during day time:	$58.37 - 23.10 \log x$
night time:	$53.14 - 22.01 \log x$
SHP during day time:	$33.38 - 14.04 \log x$
night time:	$35.23 - 15.84 \log x$
LHP during day time:	$25.12 - 9.13 \log x$
night time:	$18.17 - 6.31 \log x$

For temperature 29.4 °C (85F) $10 \le x \le 90$

THP during day time:	$34.20 - 10.90 \log x$
night time:	$31.95 - 10.97 \log x$
SHP during day time:	$13.23 - 4.44 \log x$
night time:	$13.60 - 5.00 \log x$
LHP during day time:	$21.34 - 6.67 \log x$
night time:	$17.80 - 5.63 \log x$

APPENDIX 2
Regression equations for calculating HP & M for pullets

Zulovich et al. (1987) [all heat production values are in kJ/(hr-bird); x = bird age, day]

For light periods $0 \le x \le 50$

$SHP = 0.274x + 0.662$
$LHP = 1.89 \times 10^{-3} x^2 + 2.82 \times 10^{-2} x + 1.01$

For dark periods $0 \le x \le 50$

$SHP = 0.193x - 1.410$
$LHP = 1.40 \times 10^{-3} x^2 + 2.81 \times 10^{-2} x + 0.908$

$M\,(g) = 28.94 + 3.66x + 0.18x^2 - 1.00 \times 10^{-3} x^3$ $0 \le x \le 50$

APPENDIX 3
Regression equations for calculating HP, MP & M for turkeys

Xin et al. (1998) [all heat production values are in W/kg; MP = g/(h-kg); x = bird age, day]

$THP = 7.155 \times 10^{-4} x^3 - 5.4102 \times 10^{-2} x^2 + 1.0605x + 7.70$ $1 \le x \le 35$
$SHP = 6.296 \times 10^{-4} x^3 - 4.9979 \times 10^{-2} x^2 + 1.2164x - 3.94$ $1 \le x \le 35$
$MP = -0.3027x + 17.26$ $1 \le x \le 35$

Buffington et al. (1974) [all heat production values are in kcal/(kg-hr); x = bird age, day]

For the light period

$THP = 12.9 \exp(-0.0093x)$ $28 \le x \le 43$

For the dark period

$THP = 8.2 \exp(-0.0068x)$ $28 \le x \le 43$

THP, (kcal/(hr-bird)) as a function of x:

$THP = 12.9 \exp(-0.0093x) \times (5.91 \exp(-4.736 \exp(-0.0271x)))$ $50 \le x \le 84$

$M\,(kg) = 5.91 \exp(-4.736 \exp(-0.0271x))$ $28 \le x \le 84$