Maintenance Energy Requirement of Broilers and the Impact of Ambient Temperatures

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Abstract

Eight broiler weight groups, housed in metabolic chambers, were exposed to 3-5 ambient temperatures (AT) such that AT exposure fell below, near and above the projected thermoneutral (TN) zone. Birds were fed 0, 5, and 10% of body weight (W), or allowed to consume food *ad libitum*, to vary energy consumption. Energy needs for body weight homeostasis, efficiency of metabolizable energy (ME) use for maintenance and the exponent needed to convert live body weight to metabolic weight was estimated. Energy (Kcal W^{-1} d^{-1}) and oxygen (l W^{-1} d^{-1}) needs for body weight homeostasis declined curvilinearly as body weight increased from 0.042 kg to 2.44 kg. Such needs were impacted by AT. The efficiency of ME use to support maintenance energy need varied in a cubic fashion with bird mass. The estimated zone of thermoneutrality, at body weight homeostasis, was inversely related to W (kg), expressed as: TN (ºC) = 31.896 − 0.4625·W (R^2 = 0.99). Under metabolic basal rate (MBR) conditions, the TN zone was curvilinearly related to weight as: TNMBR = 32.6466 − (94.4603·W) − (0.7660·W^2) (R^2 = 0.99). The exponent, to linearize live body weight with heat production (HP) of birds fed to W homeostasis, was determined to be 0.758 with all birds strictly housed at TN. Further, the exponent to linearize HP of birds under MBR (fasted) conditions was estimated to be 0.679. Equations relating chick energy and oxygen consumption need with body weight and AT, metabolizable energy for gain homeostasis (MEmg), metabolizable energy for retained energy homeostasis (MEmr), metabolizable energy for protein homeostasis (MEmp), and metabolizable energy for fat homeostasis (MEmf) are presented.

Keywords: broilers, ambient temperature, maintenance energy

1. Introduction

A quantitative understanding of broiler ME requirements, over an array of ambient temperatures (AT), is useful in the quest to optimize the broiler nutrition-environment interface. Indeed, it is well documented that both bird body size and AT impact broiler performance (Hurwitz et al., 1980; Koh & MacLeod, 1999). These conditions can make final bird partitioning of consumed ME into maintenance, activity, and tissue accretion components uncertain, even though such utilizations account for the bulk of absorbed energy use (MacLeod, 1997). Though considerable information is available concerning overall broiler ME need, generally less is known regarding the utilization dynamics of the aforementioned variables.

Many studies have documented that the efficiency of ME use (for maintenance and growth) is influenced by a number of factors including bird age (Blaxter & Wainman, 1966; Luiting, 1990; Chwalibog, 1991), ambient temperature (AT) (Close, 1978; Luiting, 1990; Chwalibog, 1991), sex (Ferrell, 1979) and carcass composition (Emans, 1987; Luiting, 1990; Chwalibog, 1991). Whether such influences may be attributed to fluctuations in maintenance and/or accretion efficiency above maintenance is generally unknown. Studies have also examined the potential advantages of the net energy (NE) system over the ME system (MacLeod, 1997). Birds fed on the basis of NE had higher body weight and lower FCR, suggesting that the heat increment gap between ME and NE was not accounted for and was variable. De Groote (1974) noted similar observations. However, few if any investigations examine the dynamics of energy partitioning when AT, bird live weight and feed intake are simultaneously varied.

Basal metabolic rate (BMR) is defined as the rate of heat production by a mature, resting post-absorptive animal housed within a thermoneutral (TN) environment (Brody, 1945). Though the relationship between BMR and body weight is accepted as exponential, there is a disagreement between researchers as to the appropriate exponent that should be used to linearize live body weight-HP (heat production) relationship. Brody (1945) converted live weight to "metabolic weight" across species by raising live weight to 0.75 power, but further suggested that live weight to 0.67 power may be more appropriate for poultry. Both values have historically been used to quantify metabolic body size in poultry (Close, 1978; Hurwitz et al., 1980; Close & Stainer, 1984; MacLeod, 1990; Pinchasov, 1990). In this study, an exponent that can be used to convert body weight to metabolic body size was determined.

The ME system is the main method of feed formulation practiced by poultry producers however, the ME system will not account for the energy that is used for body maintenance purposes. The classical definition of maintenance describes maintenance as the state "in which there is neither gain nor loss of nutrient by the body" (Blaxter, 1966). Therefore, the ME requirement for maintenance is the amount of energy required to balance anabolism and catabolism, giving energy retention around zero. However, the net energy system accounts for maintenance and provides an energy value that is closest to the "true" energy value of the feed since it predicts more accurately the performance of birds and also allows the possibility of implementing new approaches (Noblet, 2001). Traditionally, the factorial approach has been used to partition the ME energy requirements into maintenance and production. The coefficients determined can then be used to elaborate energy requirement models and establish better and more profitable feeding programs for poultry. These models consider the body weight, weight gain, protein, and fat accretion, and in some instances ambient temperature to partition energy requirements for poultry. However, an earlier study in our laboratory (Lema and Teeter, 1994) indicated that the factorial approach to estimating ME need for body weight homeostasis based on no body weight change may not be the right approach. At body weight homeostasis, they found that the birds have lost fat and gained protein without any indication of a change in body weight.

Therefore, the study reported herein was designed to quantify broiler maintenance energy needs using two factorial approaches as well as an exponent to convert live weight to metabolic body size under an array of ambient temperatures and energy consumption levels.

2. Materials and Methods

Three groups of commercial Cobb-500 (Cobb-Vantress, Inc., Siloam Springs, Arkansas, USA) male chicks that hatched from the same age and strain parents were obtained from a commercial hatchery at regular intervals. Groups were reared to 0.045, 0.074, 0.112, 0.318, 0.647, 1.90, 2.003, and 2.4 kg live body weight to create 8 weight groups that could be examined in 3 experimental periods (0.045 and 0.074 kg-period 1; 0.112, 0.318 and 0.647 kg-period 2; 1.900, 2.003 and 2.400 kg-period 3). Varying the AT exposure and feed intake of each age group enabled the collection of BW and body composition data over 252 AT-weight-feed consumption combinations. Some, but not all data point combinations were replicated. If a bird weight-AT combination occurred within an experimental period, it was examined at the 4 feeding levels employed (0, 5, or 10% of the 10 h fasted weights at experimental initiation; *ad libitum* consumption).

To collect data representing the 252 AT-weight-feed consumption combinations, birds were first reared to the appropriate live weight in floor pens as specified by the primary breeder (Cobb-Vantress, 1998). Upon reaching the desired body weight, 36 chicks (12 per weight group) were selected at random from the original population and placed in individual open circuit respiratory chambers. Oxygen consumption and CO_2 production were measured for each bird as the differential concentration between incoming and outgoing gas concentration multiplied by the airflow rate. Both metabolic chambers and the general operating procedures have been described elsewhere (Wiernusz & Teeter, 1993; Belay & Teeter, 1993). The 36 respiratory chambers, used in the study, were housed within 3 thermostatically controlled rooms (12 chambers/room) so that three different ambient temperatures (1/room) could be monitored simultaneously. Each room provided an AT exposure for 3 weight groups of 4 chicks with each group consuming the 4 feeding levels. An attempt was made to select ambient temperatures for each weight group that fell near, below and above the chick's anticipated TN zone as follows: 0.045 and 0.074 kg chicks were exposed to 28, 30 and 32 ℃; 0.112, 0.318, and 0.647 kg chicks were exposed to 24, 26, 28, 30, and 32 ℃; while the 1.90, 2.003 and 2.4 kg chicks were exposed to 18, 22, and 26 ℃.

Chick handling during the 4-day chamber resident time occurred as follows: Day 1, chick adaptation to facilities with feed (Table 1) and water continuously available; Day 2, chicks were deprived of feed for the first 12 h, weighed between 10-11.5 h and received the first feeding at 12 h; Day 3 and day 4, chicks received 3 feed

allocations in 12 h intervals such that fasting occurred during the last 12 h. Birds had continuous access to water and maintained a 23 h light cycle throughout the experiment.

Though bird gaseous exchange was monitored continuously over the 4-day period, the addition of day 2 feed (Table 1) to feeders was used to mark the study initiation. Upon completion of the 60-h feeding and 12 h fasting phases, birds were weighed and humanely sacrificed by cervical dislocation (AVMA, 1986). All excreta voided during the feeding and post feeding restriction phase was collected in trays located at the bottom of each chamber. Sacrificed birds and excreta were weighed, sealed in polyethylene bags and frozen (-20 ℃) until analysis. At analysis, feed and excreta samples were dried at 55 ℃ to constant weight, ground to pass a 1 mm sieve and analyzed for DM and gross energy using a bomb calorimeter (Parr Moline, Illinois, USA) as well as carbon (C) and nitrogen (N) content via Leco-2000 (Lecco Corp., St. Joseph, Michigan, USA).

Table 1. Composition of the experimental diet

Ingredients	%
Corn, ground yellow	50.94
Soybean meal (49% CP)	38.23
Fat (animal and vegetable)	6.52
Dicalcium phosphate	1.81
Limestone	1.21
Salt	0.45
Vitamin mix[1]	0.25
Methionine (99%)	0.22
Trace mineral mix[2]	0.10
Ethoxyquin	0.02
Diet composition	
Energy (kcal kg^{-1})	3246
Crude protein (%)	23

Note. [1] Mix supplied the following per kilogram of diet: Vitamin A, 5.25 mg; cholecalciferol, 0.125 mg; vitamin E, 0.025 mg; vitamin B12, 0.03 mg; riboflavin, 15 mg; niacin, 75 mg; d-panthothenic acid, 25 mg; choline, 705.5 mg; menadione, 5 mg; folic acid, 1.5 mg; pyridoxine, 6.25 mg; thiamine, 3.03 mg; d-biotin, 0.127 mg.

[2] Mix supplied the following per kilogram of diet: Manganese, 120 mg; zinc, 100 mg; copper, 10 mg; iodine, 2.5 mg; calcium, 135 mg; iron, 75 mg; selenium, 0.15 mg.

2.1 Statistical Analysis

Data were analyzed by ordinary regression procedures. To ascertain the regression function used adequately fit the data, a lack of to fit test was performed. The regression model was considered inappropriate when P < 0.05. Gas consumption and production values were regressed against time, time^2 and time^3 so that time dependent polynomial equations could be developed to describe and quantify gas exchange like others (Wiernusz & Teeter, 1993; Belay & Teeter, 1993). The resulting gas exchange estimates were then utilized to estimate HP according to Brouwer (1965). Oxygen and metabolizable energy consumed, as well as heat production, were each regressed on weight gain so that the magnitude of these variables could be estimated at body weight homeostasis (intercept value).

Intercept values were subsequently subjected to a multiple regression model that included body weight (linear and quadratic), AT (linear and quadratic) and the interaction between the linear effects of body weight and AT. The resulting equations were used to construct 3-dimensional plots displaying the relationships. Subsequently, the regression equations were also solved to determine the AT associated with minimal HP, presumed to center within the TN zone. The resulting TN zones AT estimates were then regressed on body weight to describe the relationship. Finally, the log HP for birds fed to body weight homeostasis, while housed within the TN zone, was regressed on log body weight so that the exponent to convert live weight to metabolic body-size might be estimated according to Brody (1945). This last process was also repeated using the HP values of birds that fasted for 40-46 h (the classical fasting period for BMR) for MBR determination (Brody, 1945). Similarly, data of ME intake at various live weight and TN ambient temperature combinations were regressed on retained energy, fat and protein accreted. Intercept values were subjected to multiple regression models that included live weight, TN

ambient temperatures (both linear and quadratic) and their combination so that ME need at TN could be estimated from the resulting equations. Metabolizable energy intake estimates at TN for each tissue accreted were then regressed on metabolic body weight ($W^{0.75}$) so that an estimated coefficient that could be used to estimate MEm using metabolic body size could be determined. The effect of ambient temperature deviation from TN on MEm need was also estimated.

3. Results and Discussion

Results indicate that live initial bird weight (W) increased linearly with increasing age. Similarly, within a weight classification, weight gain, O_2 consumption and CO_2 production also increased linearly with feed consumption level. These observations suggest, assuming that the composition of tissue loss and gain over the feed intake levels examined herein is constant, that the efficiency of energy use for tissue loss and gain is similar. The validity of this assumption, however, remains to be tested.

Regressing ME consumed, O_2, and HP on live weight gain enables quantification of values at body weight homeostasis, defined as the abscissa intersection for the resulting regressions. These maintenance-intercept values were examined using multiple regression that included body weight (linear and quadratic), AT (linear and quadratic) and the interaction between the linear effects of body weight with AT. The ensuing equations (Table 2) were used to form the 3-dimensional plots displayed in Figures 1 to 3.

Table 2. Equations predicting the oxygen consumption (O_2), metabolizable energy need (ME) and heat production (HP) of broilers fed to maintenance from W and ambient temperature (AT)

Equation	P	R	n[1]
$O_2 = 476.5 - 123.6 \cdot W + 4.69 \cdot W^2 - 28.29 \cdot AT + 0.45 \cdot AT^2 + 3.86 \cdot W \cdot AT$	< 0.01	0.78	63
$ME = 1054 - 459 \cdot W + 50.68 \cdot W^2 - 46.65 \cdot AT + 0.61 \cdot AT^2 + 11.02 \cdot W \cdot AT$	< 0.01	0.71	63
$HP = 2292 - 602 \cdot W + 21.24 \cdot W^2 - 135.28 \cdot AT + 2.12 \cdot AT^2 + 18.97 \cdot W \cdot AT$	< 0.01	0.72	63

Note. [1] Number of data points utilized in regression equations. Each data point consists of 1 bird age-AT combination result regressed on the 4 food intake levels. Overall, this resulted in 8 bird ages at 8 AT.

W = body weight (kg). AT = ambient temperature (ºC). n = number of observations. WAT = weight ambient temperature interaction.
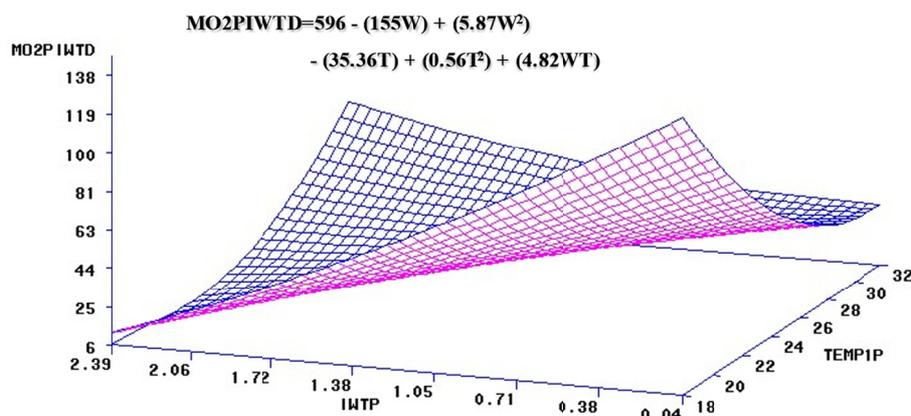

Figure 1. Maintenance oxygen requirement of broilers

Note. MO2PIWTD = Maintenance oxygen (Lit/w/d), W = IWTP = Body weight (Kg), T = TEMP1P = Ambient temperature (ºC).

$$MEPIWTPD = 5510 - (2402W) + (265W^2)$$
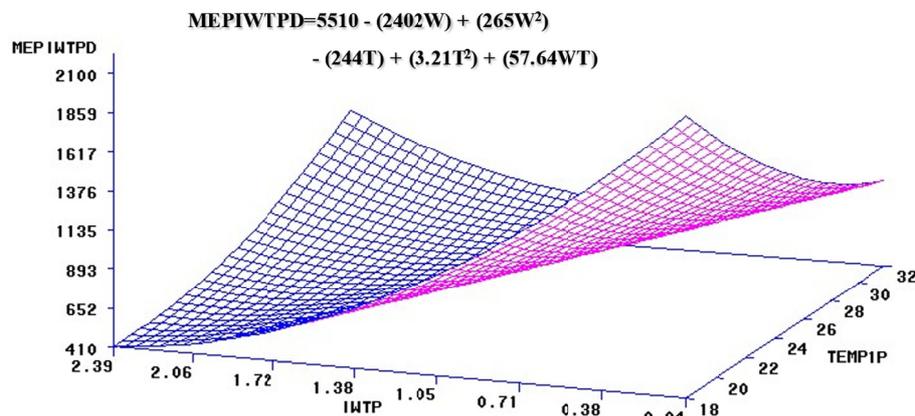$$- (244T) + (3.21T^2) + (57.64WT)$$

Figure 2. Maintenance energy requirement of broilers

Note. MEPIWTPD = Maintenance energy (Kj/w/d), W = IWTP = Body weight (Kg), T = TEMP1P = Ambient temperature (°C).
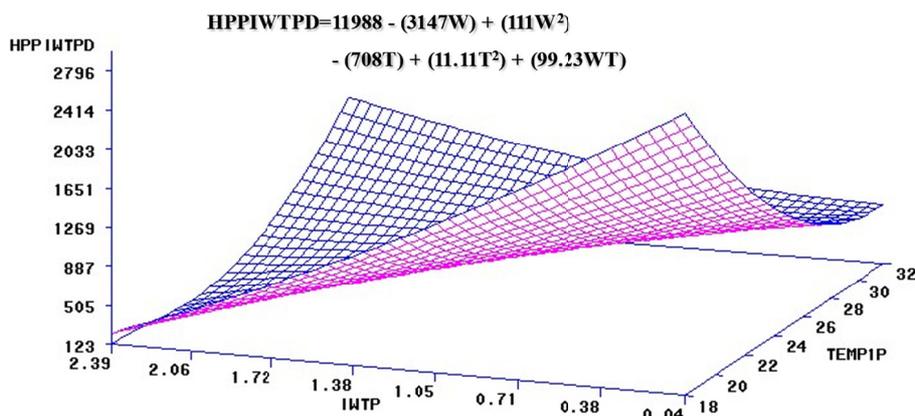
$$HPPIWTPD = 11988 - (3147W) + (111W^2)$$
$$- (708T) + (11.11T^2) + (99.23WT)$$

Figure 3. Heat production at maintenance of broilers

Note. HPPIWTPD = Heat production (Kj/w/d), W = IWTP = Body weight (Kg), T = TEMP1P = Ambient temperature (°C).

Relative to a specific body weight homeostasis, the AT exhibiting a minimal value would presumably represent the bird's TN zone. As AT deviates from TN, all maintenance associated values (O_2 consumed, ME, and HP) increase. The Table 2 equations may be used to estimate bird oxygen and energy need, as well as the associated HP at body weight homeostasis for various AT. Caution must be exercised, and it is not recommended that the equation be applied to extrapolated live body weights and/or ambient temperatures.

O_2 consumption (l kg^{-1} d^{-1}), ME (Kcal kg^{-1} d^{-1}) consumption as well as heat production (Kcal kg^{-1} d^{-1}) associated with body weight homeostasis, declined as body weight rose from 0.042 to 2.44 kg (Figures 1-3). The decline presumably reflects a changing surface area per unit of body mass of the birds (Brody, 1945). As ambient temperature deviated from the determined TN zone, all maintenance energy values increased (Figure 2). Although most studies reporting bird maintenance energy needs fail to describe the AT condition (summarized in Table 3; De Groote, 1968; Pinchasov, 1990; Sakomura, 2004), the values reported were higher than the values reported herein. This might be due to limited activity by our birds in the metabolic chambers.

Table 3. Metabolizable energy need for maintenance (MEm), protein retained (PR) and fat retained (FR) at body weight homeostasis of boilers during their grow out maintained below (C), above (H) and at Thermoneutral (TN) ambient temperature

Period	Environmental Zone	MEm (Kcal/mwt/d)	PR (g/d)	FR (g/d)
Starter	C	174	1.12a	0.17c
	H	139	0.44bc	0.68a
	TN	139	0.84b	0.45b
Grower	C	148	5.39a	1.75b
	H	150	2.10c	2.84a
	TN	145	3.40b	1.67b
Finisher	C	118	6.73b	2.36b
	H	121	8.51a	15.91a
	TN	151	5.03c	-3.81c
		---------------------------- Probability ----------------------------		
Period		0.2877	0.0001	0.0930
Environmental Zone		0.3706	0.0186	0.0080
Period × Environmental Zone		0.3954	0.0055	0.0004

Note. [abc] Means within each period (row) with different superscript are different ($P < 0.05$).

C = Below thermoneutral temperature, H = Above thermoneutral temperature, TN = Thermoneutral temperature.

Deviation of ambient temperature from TN presumably necessitates nutrient oxidation to generate energy for enhancing heat dissipation or generation in returning bird body temperature to the TN state. Under heat stress (HS), food intake frequently declines (MacLeod et al., 1979; Wiernusz & Teeter, 1993) while under cold stress it increases (MacLeod et al., 1979). Overall HP of birds consuming feed *ad libitum* might therefore be expected to decline for HS and increase in cold environments. Such low AT conditions are presumably related to development of the pulmonary hypertension-ascites syndrome in broilers. Indeed, Beker et al. (1995) reported a strong relationship between O_2 consumption and ascites incidence ($R^2 = 0.96$). The equation presented in Table 2 enables quantification of the AT impact on bird O_2 consumption.

Energetic efficiency of broilers has long been documented to be influenced by AT. However, the confounding of food intake and AT changes can make interpretation of strict energetic-environment relationships uncertain. A decrease in broiler maintenance energy as AT approaches TN suggests that birds housed outside TN are less efficient energetically for that reason. Assuming that the regression technique employed in this study estimates the TN zone midpoint, it becomes possible to examine divergent, yet equivalent, AT changes from TN (Table 4).

Table 4. Live body weight gain (LBWG) of broilers at body weight homeostasis during their grow out maintained below (C), above (H) and at Thermoneutral (TN) ambient temperature

Period	Environmental Zone	LBWG (g/d)
Starter	C	-0.15
	H	0.07
	TN	0.13
Grower	C	-0.04
	H	0.38
	TN	-0.14
Finisher	C	-0.43
	H	-0.61
	TN	0.18
		--------- Probability --------
Period		0.3980
Environmental Zone		0.1763
Period × Environmental Zone		0.0670

Note. C = Below thermoneutral temperature, H = Above thermoneutral temperature, TN = Thermoneutral temperature.

As such, an AT decrease below TN was found to cost more energy ($P < 0.05$) for the birds than an equivalent increase above TN. Feed consumption changes, for birds consuming feed *ad libitum*, would also be expected to play a significant role concerning the proportion of consumption used for maintenance energy demand. As fixed maintenance cost become a greater proportion of consumption, either because of an elevated energy demand or feed intake decline, energetic efficiency would be expected to decline. Indeed, environment and feed consumption effects on energetic efficiency are well-documented (Wiernusz & Teeter, 1993; MacLeod, 1997).

That the rearing of birds within the TN zone enhances feed and energetic efficiency is indisputable (Beker et al., 1995; Wiernusz & Teeter, 1993), solving the Figure 3 equation for the AT associated with minimal energy need enables estimation of the thermoneutral AT. The resultant thermoneutral AT for each weight group was regressed on mean group live body weight (kg) yielding the following relationship (Figure 5):

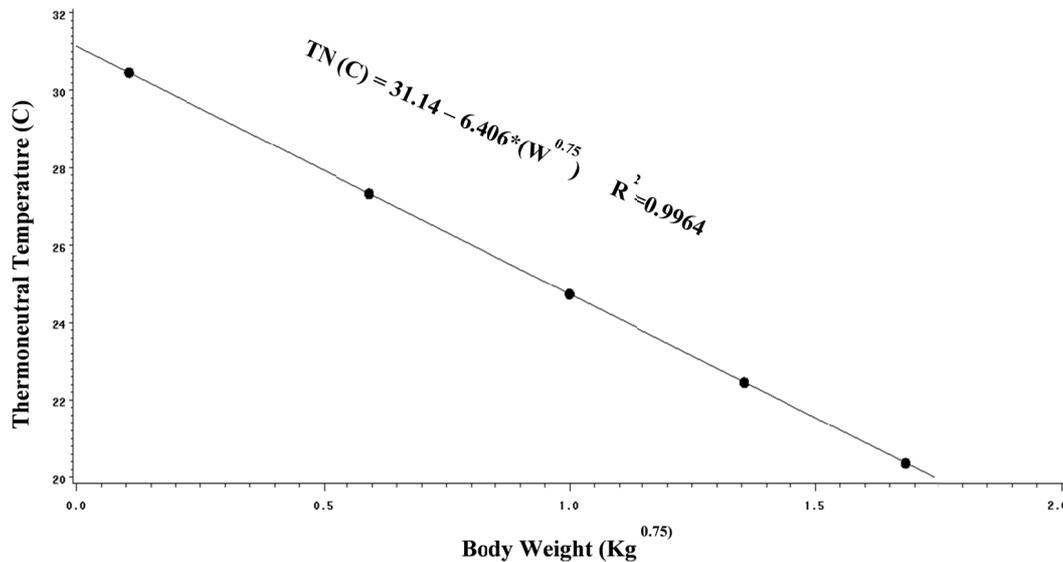$$\text{TN (°C)} = 31.896 - (4.625 \cdot W) \qquad (R^2 = 0.99) \qquad (1)$$

Figure 5. A plot of thermoneutral ambient temperature versus metabolic body weight ($Kg^{0.75}$) of broilers

Note. TN = Thermoneutral ambient temperature, $W^{0.75}$ = Metabolic body weight, R^2 = Coefficient of determination.

Accordingly, the TN temperature decreased from 32 °C at 0.042 kg to 21 °C at 2.44 kg (Table 5) with birds consuming feed quantum sufficient to support body weight. This decline is presumably the result of a declining surface area per unit of body weight as proposed by Brody (1945). Altering feed consumption levels might be expected to alter the thermoneutral AT as a change in heat increment would occur. However, insufficient AT-feeding level combinations were employed with the various weight classes to test this concept herein.

Table 5. Protein gain (PG) and fat gain (FG) at maintenance of boilers during their grow out maintained below (C), above (H) and at Thermoneutral (TN) ambient temperature

Period	Environmental Zone	PG (Kcal/d)	FG (Kcal/d)
Starter	C	0.93a	-0.56b
	H	0.80b	-0.48b
	TN	0.33c	-0.20a
Grower	C	3.40a	-2.05b
	H	-0.01c	0.00a
	TN	1.88b	-1.13b
Finisher	C	7.12a	-4.30b
	H	3.74b	-2.26a
	TN	3.87b	-2.34b
		--------------------- Probability ---------------------	
Period		0.0001	0.0001
Environmental Zone		0.0075	0.0075
Period × Environmental Zone		0.0411	0.0411

Note. [abc] Means within each period (row) with different superscript are different (P < 0.05).

C = Below thermoneutral temperature, H = Above thermoneutral temperature, TN = Thermoneutral temperature.

Since bird HP was determined under both the fasting condition and with ME consumption to support body weight homeostasis, it is possible to compute the efficiency of dietary ME use for maintenance (MEF). In this study, MEF was defined as the fasting HP/ME consumed at body weight homeostasis. Results (Table 6) indicated that MEF estimates varied in a cubic fashion (P < 0.05) with bird weight as efficiency rose from 75% for the 0.045 kg bird to a peak of 89% at 3 weeks followed by a subsequent decline to 25% for the 2.4 kg bird. It is important to keep in mind that these values are based upon body weight and not energy homeostasis and that all birds consumed a starter type (high protein) ration. Additional work is needed to investigate the impact of ration composition on MEF. Under TN conditions, the MEF decline in older birds in this study may be due to an inefficient calorie to protein ratio for that body weight.

Table 6. Coefficients for estimation of energy (CE), protein (CP) and fat (CF) metabolizable energy need for maintenance[1] of boilers during their grow out maintained below (C), above (H) and at Thermoneutral (TN) ambient temperature

Period	Environmental Zone	CE	CP	CF
Starter	C	132a	65b	162a
	H	113b	55b	130b
	TN	97b	70a	109b
Grower	C	120a	61b	154a
	H	95b	95a	95b
	TN	97b	62b	113b
Finisher	C	139a	54a	181a
	H	107b	51a	135b
	TN	98b	27b	124b
		------------------------ Probability ------------------------		
Period		0.5222	0.3715	0.2264
Environmental Zone		0.0156	0.8931	0.0013
Period × Environmental Zone		0.9169	0.6243	0.7042

Note. [1] Metabolizable energy need for maintenance = Coefficient/MWT.

[ab] Means within each column with different superscript are different (P < 0.05).

C = Below thermoneutral temperature, H = Above thermoneutral temperature, TN = Thermoneutral temperature.

Once HP at TN is known for the various bird body weight, regressing log HP on log body weight (kg) yields an equation whereby the slope estimates the exponent for linearizing HP with live body weight (Brody, 1945). Such transformation converts body size into "metabolic body size" whereby maintenance energy needs are in direct proportion to W (Figure 6). Using the data reported herein at body weight homeostasis yields:

$$\text{LogHP} = 6.327 - (0.758 \times \text{logW}) \quad (R = 0.99) \tag{2}$$

Utilizing the fasted bird HP values at 40-46 h yields:

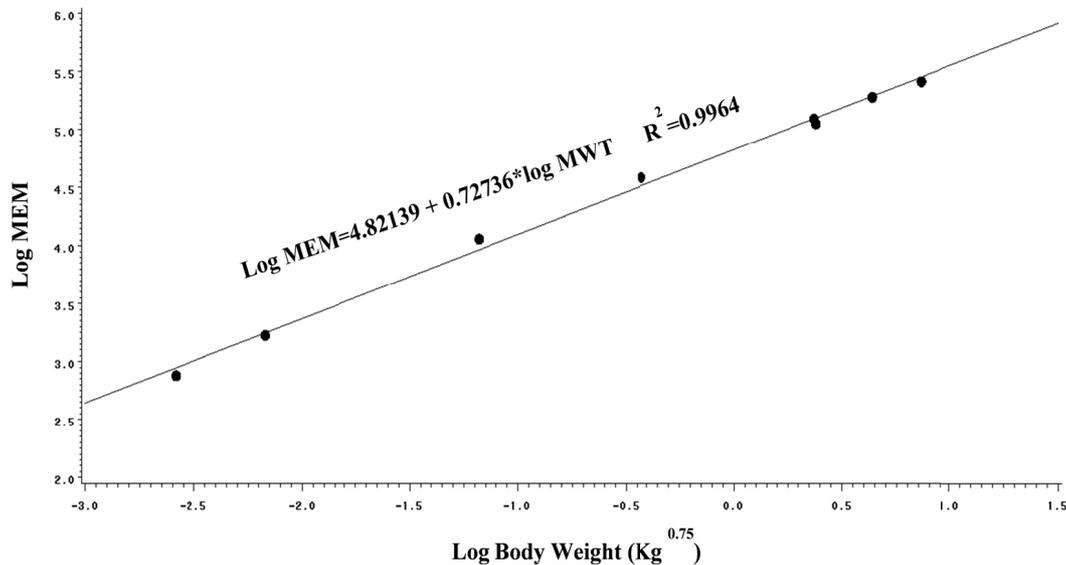$$\text{LogHP} = 5.322 + (0.679 \times \text{logW}) \quad (R = 0.76) \tag{3}$$

Figure 6. A plot of log metabolizable energy need for maintenance versus log body weight ($Kg^{0.75}$) of broilers

Note. MEM = metabolizable energy for maintenance, MWT = metabolic body weight ($Kg^{0.75}$), R^2 = coefficient of determination.

As such, the equation slope of 0.758 would be the estimated transformation constant for birds at body weight homeostasis via consumption of a corn-soy ration. The 0.67 value would be utilized under MBR (fasting) conditions. Brody (1945) examined the HP of numerous adult animal species and postulated that 0.75 was the exponent to convert body weight to "metabolic body weight" for all species except poultry, with birds requiring 0.67. His estimates were derived from animals fasted for 48 hours and consequently in negative energy balance. Applicability of Brody's 0.75 exponent to a given species at different stages of growth was questioned (Meltzer, 1983; Lopez, 2005). Nonetheless, the data attained in this study suggests 0.75 for birds consuming ME to body weight maintenance, with HP consequently including the wasted ME and/or tissue retention difference, and 0.67 under MBR conditions where animals are in negative energy balance according to maintenance energy need. Presumably, the fact that the 0.67 exponent has not changed since 1945, suggests that improvements in broiler feed conversion (Havenstein et al., 1994) are either due to reasons other than BMR or that heat production changes result in parallel heat dissipation curves.

Over the years researchers have used both the 0.75 (Close, 1978; Close & Stainer, 1984; MacLeod, 1990) and 0.67 values (Hurwitz et al., 1980; Pinchasov, 1990). While others (Meltzer, 1983), in contrast, reported that 0.88 should be used for broilers of both genders to 26 days of age and thereafter 0.63 for females and 0.43 for males. Such differences may be the result of ill-defined live bird weight-AT-HP relationships. Indeed, it is presumed that such studies utilize birds housed under TN conditions, but unless the AT is reported, results become speculative. Further, the exponent to linearize HP, at W homeostasis, with W has not been previously addressed and may indeed be of higher nutrition theory value. To the author's knowledge, the reported study is the first to utilize HP data from birds at their determined TN temperature with feeding levels to support W homeostasis.

Once the exponent to linearize body weight to metabolic body size is known, ME need for homeostasis of a specific tissue can be estimated as a function of metabolic body size. Using multiple regression equation that was

developed to estimate ME need for body weight homeostasis, energy retained (Kcal), protein and fat (g) accreted enabled estimation of ME need at TN ambient temperature (Figures 7, 8, and 9).
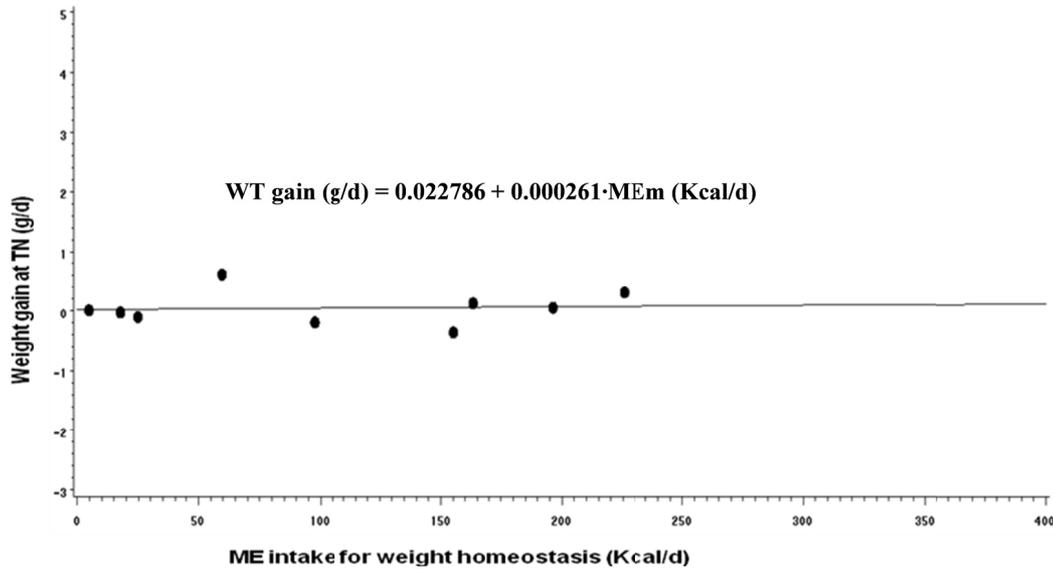

Figure 7. A plot of body weight gain (g/d) at thermoneutral ambient temperature versus metabolizable energy intake for body weight homeostasis (Kcal/d) of broilers

Note. MEm = Metabolizable energy need for body weight maintenance, WTgain = Body weight gain.
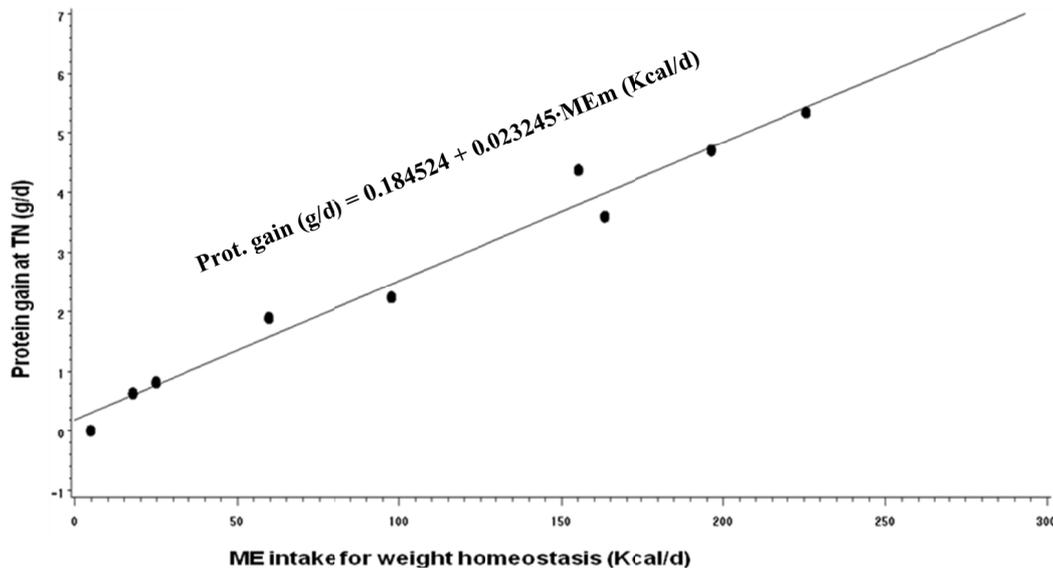

Figure 8. A plot of protein gain (g/d) at thermoneutral ambient temperature versus metabolizable energy intake for body weight homeostasis (Kcal/d) of broilers

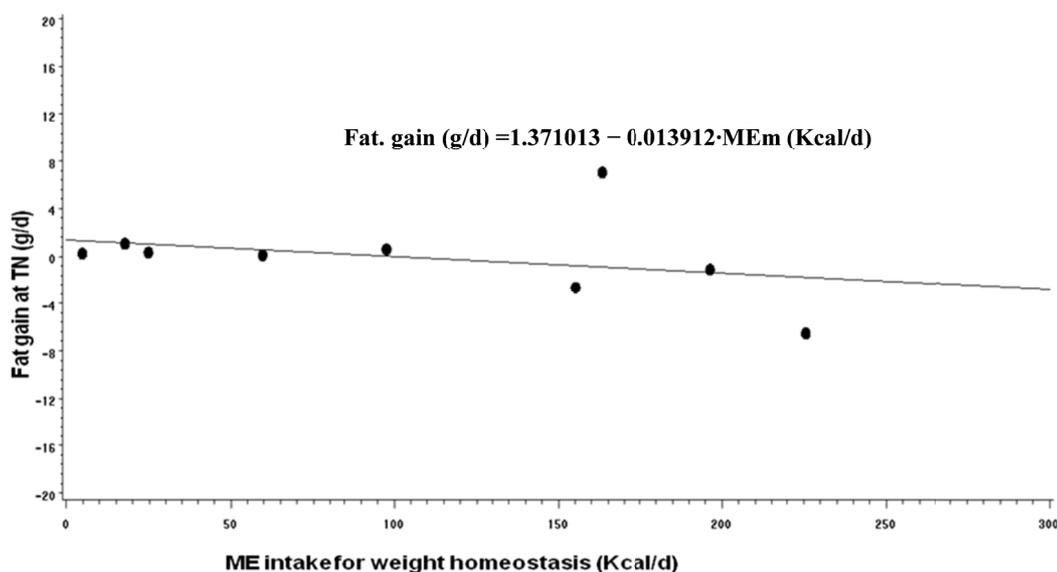*Note*. MEm = Metabolizable energy need for body weight maintenance.

Figure 9. A plot of fat gain (g/d) at thermoneutral ambient temperature versus metabolizable energy intake for body weight homeostasis (Kcal/d) of broilers

Note. MEm = Metabolizable energy need for body weight maintenance.

Regressing ME at TN on metabolic body size ($W^{0.75}$) yield the following relationship:

$$MEmg = 116.63W^{0.75} \quad (R^2 = 0.9925) \tag{4}$$

$$MEmr = 106.45W^{0.75} \quad (R^2 = 0.9911) \tag{5}$$

$$MEmp = 54.70W^{0.75} \quad (R^2 = 0.9780) \tag{6}$$

$$MEmf = 131.11W^{0.75} \quad (R^2 = 0.9853) \tag{7}$$

Where, MEmg = metabolizable energy for gain homeostasis, MEmr = metabolizable energy for retained energy homeostasis, MEmp = metabolizable energy for protein homeostasis, MEmf = metabolizable energy for fat homeostasis.

Coefficient values determined that could be used with metabolic body weight (MWT) to estimate metabolizable energy need for body weight and retained energy homeostasis here in were comparable to some previously reported values (Latshaw & Bishop, 2004, Latshaw & Metzler, 2009) and a slightly higher coefficient value observed could be due to metabolic rate associated with body water. Metabolizable energy need for fat homeostasis is higher than that of the need for protein homeostasis (131 *vs.* 55 coefficients) (Table 6). This is presumably the result of a low metabolic rate for fat compared to that of protein.

4. Conclusions

In summary, the study reported herein suggests that body size, feed consumption and ambient temperature impact energy and oxygen requirements for body weight maintenance and associated heat production. The equations developed from this study relate body weight, ambient temperature and food intake in a manner that may aid future energetics research.

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