University of Alberta

Impacts of Environmental Temperature and Dietary Energy on Core Body Temperature and Efficiency in Broiler Breeder Females

by

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ABSTRACT

The effects of environmental temperature, dietary energy, housing system, time of feeding and day length on core body temperature (CBT) dynamics in broiler breeder females was studied in a series of experiments. Environmental temperatures within the range of 15 to 27˚C resulted in a CBT of 39.8 to 42.1˚C. Environmental temperature affected feed intake, growth, CBT dynamics and efficiency in pullets, but not the egg production, egg weight or feed efficiency in hens. Low energy diet-fed hens laid heavier eggs. Free-run and caged hens had similar egg production but free-run hens produced heavier eggs. However, free-run hens required by 17.2% more energy than caged hens, likely to support activity level. Feeding twice per day delayed oviposition relative to morning-fed hens. Photoperiod effects were seen in diurnal CBT patterns. Peak CBT occurred soon after feeding and could be shifted by changing feeding time, and may have potential for heat stress mitigation.

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DEDICATION

This thesis is dedicated to my parents (Bhakta M. Paul & Laxmi R. Paul) for their blessing throughout my life.

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FORMAT OF THESIS

This thesis is organized in accordance with the Journal style of Poultry Science and format allowing for independent chapters to be suitable for submission to the journal. Four papers have been prepared from research data collected from the project at the University of Alberta to partially fulfill the requirements for the degree of Master of Science. Each paper is complete in itself containing an abstract, introduction, materials and methods, results and discussion, and reference section.

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LIST OF ABBREVIATIONS

ADFI	Average daily feed intake
ADG	Average daily gain
BW	Body weight
BW^b	Metabolic body weight
CBT	Core body temperature
CP	Crude protein
DE	Digestible energy
EM	Egg mass production
FE	Fecal energy
GE	Gross energy
HI	Heat increment
HR	Heat retention
ME	Metabolizable energy
MEI	Metabolizable energy intake
ME_m	Metabolizable energy requirement for maintenance
NE	Net energy
NE_m	Net energy for maintenance
Nadg	Negative average daily gain
Padg	Positive average daily gain
RFI	Residual feed intake
RME_m	Residual maintenance ME requirement
THP	Total heat production
UE	Urinary energy
Ɛ	Residual error

CHAPTER 1: GENERAL INTRODUCTION

1.1. BACKGROUND

The foundation of the broiler industry is the broiler parent stock. Broiler breeders are unique in that they produce rapidly growing offspring for meat production and, at the same time, they need a high rate of egg production to supply the next generation of broiler chicks (Renema et al., 2008). The management of broiler breeders is more challenging than that of other commercial poultry due to the need to control body weight (**BW**) to optimise production (Robinson et al., 1993; Renema and Robinson, 2004). Most of the feed eaten by broiler breeders supports maintenance requirements (70 to 85%; Sakomura, 2004; Romero et al., 2009b), leaving a very small proportion of dietary energy for growth and production. Small changes in ME_m, dramatically affect growth and production in feed-restricted broiler breeders. Therefore, feed allocation is a big challenge in maintaining the target BW and maximising egg production.

Environmental temperature plays an important role in the use of feed energy because birds are homoeothermic animals and they need to maintain a relatively constant core body temperature (**CBT**). The rate of heat exchange with the environment is proportional to the difference between the surface body temperature and the environmental temperature (National Research Council, 1981). Estimates of the thermoneutral zone in which laying hens do not have to increase or decrease the rate of metabolic heat production to thermoregulate (National Research Council, 1981) ranges from 16 to 28˚C (Barott and Pringle, 1946), and 18 to 31˚C (Pereira et al., 2007) in broiler breeder hens. This zone is bound by the lower critical temperature below which birds must expend energy to increase their CBT, and the upper critical temperature above which birds must expend energy to keep their CBT from increasing. If environmental temperature is below the lower critical temperature, birds dissipate an increasing amount of body heat to the environment (McDonald, 1978). Heat production and heat loss becomes imbalancd, and that affects CBT. In cold environments, birds require more energy to maintain CBT, which means the energy requirement for maintenance increases, decreasing efficiency. Conversely, above the upper critical environmental temperature birds are unable to passively dissipate adequate heat to the environment. In this situation, they need to either expend energy to cool themselves by wing flapping or panting, or reduce heat production by reducing feed intake, which often leads to decreased growth or egg production. Broiler breeder hens give priority to maintenance; growth, and egg production receive nutrients after maintenance is taken care of (Reyes et al., 2011). Since the energy required for growth is relatively small (Sakomura, 2004), any changes in maintenance energy requirements can quickly affect growth rates. Since managing growth is important for reproductive success, accurate feed allocation that takes environmental temperature into account is necessary.

Housing systems can affect energy requirement for chickens. Free run hens have more spacious housing systems allowing them increased levels of activity compared to caged hens. Over 70% of ME intake is expended for the maintenance requirement (Sakomura, 2004) and 20 to 25% of energy was used for activity in free run laying hens (Boshouwers and Nicaise, 1985). In addition, Li et al. (1991) reported that 19% of total ME intake is used for activities in free run laying hens; whereas, Rabello et al. (2004) reported that a free-run broiler breeder hen required 21.8% higher ME intake for activities than a caged broiler breeder hen. Because maintenance requirements are dramatically affected by activity level, feed rationing needs to take the broiler breeder housing system into account to achieve target BW and egg production.

The main objective of this chapter is to review the effects of environmental temperature on CBT dynamics, heat loss to the environment, efficiency, energy partitioning and effects of activity on energy utilization under different housing systems in broiler breeder females.

1.2. A BRIEF HISTORY OF BROILER BREEDERS

1.2.1. General history

Poultry have been domesticated for thousands of years. The red jungle fowl of Indian origin was first domesticated in 8000 BC in Asia, Africa and Europe mainly for cock fighting (Alders and Pym, 2009; Lundeen, 2010). Once the fowl was domesticated, people used them as a source of nutrition in the form of meat and eggs. Early in the 20th century, cockerels were used as a meat bird in the USA. Some sporadic reports were found that the term “broiler” (meat producing chicken) was used from 1920, and chicken companies and interested academia worked to breed chickens for the development of broilers. Poultry enthusiasts have made many genetic changes during the process of domestication by establishing local varieties and selecting for various traits like growth rate, feed conversion rate, survivability etc. (Alders and Pym, 2009).

1.2.2. History of selection – priority traits

The history of breeding programs for meat producing birds (broiler) is relatively recent. In practice, a broiler breeding program was initiated in the 1957 in USA and came to light as a commercial broiler in the year 1976 (Lundeen, 2010). Primarily, growth rate was the first criterion for selection of broiler traits. The growth rate of broilers increased steadily based on rapid growth rate, short harvesting period, lower feed conversion rate and strong consumer demand (poultry meat is acceptable for almost all major religions), ensuring affordability for consumers. An annual growth rates by 2.4%, feed conversion ratio by 1.2% and breast muscle yield by 1.1% increased from 1976 to 1999 due to respective selection traits in broiler breeders (McKay et al., 2012). Over a 32-year period, the average BW target of Hubbard broilers increased by 34.8 g/year/bird (Renema et al., 2007). The continually increasing growth rate of modern broilers allows each new generation to potentially reach market weight between half-a-day (Havenstein et al., 2003) and one day less each year (Gyles,1989). An important criterion for economic efficiency is the amount of feed required to produce 1 kg of breast meat. The ratio of feed to breast meat yield was 20:1 (kg/kg) in 1976 and it is now around 7:1 (kg/kg) (McKay et al., 2009). To make the broiler industry profitable and sustainable, emphasis has been given to selection traits such as growth rate, breast meat yield, feed conversion rate, fertility, hatchability, egg production, egg weight, skeletal integrity, feathering, and mortality (McKay et al., 2012).

1.2.3. What is feed restriction?

Feed restriction means to reduce feed allocation compared to full-fed animals. When broiler breeder females are fed *ad libitum*, they become obese resulting in increased rates of lameness, skeletal disorder and heart failure as well as metabolic disorders like ascites (Savory et al., 1993). This results in reduced settable egg production, egg quality and chick production (Yu et al., 1992; Robinson et al., 1993; Renema and Robinson, 2004) and increased multiple ovulation, abnormal eggs, and irregular oviposition time (Hocking et al., 1996). *Ad libitum* feeding is detrimental to health, welfare, and reproductive efficiency (Bokkers and Koene, 2003; Hocking, 2004). Feed restriction has many positive effects on broiler breeders including control of BW, delayed sexual maturity, reduced metabolic disorders and mortality, and maximized egg production, fertility, hatchability and chick production (Katanbaf et al., 1989; Renema et al., 2007). The greatest economic benefit of feed restriction in broiler breeders is maximizing egg and chick production (Renema et al., 2007).

1.2.4. Importance of feed restriction for egg and chick production

Growth and production are negatively correlated in broiler breeder hens (Renema et al., 2007). The reproductive performance of broiler breeders is evaluated by considering the total number of settable eggs, age at onset of lay, average egg weight, and offspring produced per hen (Renema and Robinson, 2004; Richards et al., 2010). Broiler breeder females fed *ad libitum* have increased health disorders (Savory et al., 1993; Aviagen, 2007), leading to reduced settable egg production, egg quality, fertility, hatchability, and chick production (Jaap and Muir, 1968; Yu et al., 1992; Hocking et al., 1996; Robinson et al., 1993; Renema and Robinson, 2004). Egg production was highly affected by feed allocation, with 166, 159, and 137 settable eggs produced by the 100, 120, and 140% feed allocation groups, relative to primary breeder recommendations, respectively (Renema et al., 2006). Feed allocation in broiler breeder females decreased by 8%, 16% and 24% based on primary breeder's guideline and did not affect settable egg production, egg weight, fertility and hatchability (Fattori, et al., 1991). Severe feed restriction in broiler breeder pullets (25% of *ad libitum*) delayed lay until 40 wk of age and decreased egg production and egg weight (Hocking, 2004). Moderately feed restricted (primary breeder's recommended feed allocation) broiler breeder hens produced a higher number of settable eggs and chicks than full-fed or severely feed restricted broiler breeder hens (Yu et al., 1992). Feed restriction in broiler breeders has been increasing every year since the mid-1970s resulting in an increased health condition, egg production and chick production (Renema et al., 2007). Every year feed allocation decreased by around 3% to maximize the total number of settable eggs and chicks. Egg production increased from 145 to 170 eggs and chick production increased from 128 to 150 chicks per hen housed from 1973 to 2005 (Renema et al., 2007). It means an increase of more than one chick every two years.

1.2.5. Importance of feed restriction for chick quality

Moderate feed restriction has a positive correlation to egg and chick production, and it also influences chick quality. Physically, quality chicks should be uniform with a higher length, more alert and active, and well hydrated; additionally they should have good reflexes and well-healed navels with normal mortality of less than 0.5% by 5 d of age (Tona et al., 2003). Quality chicks perform well during incubation (33% of a broiler's life) and maximize post-hatch performance (growth rate, feed conversion rate, breast yield with minimum mortality) up to the end of the harvesting cycle. Chick quality mainly depends on maternal nutrition, maternal health, egg shape, egg storage time and management during incubation (Osman et al., 2010). It is necessary to provide enough but not excessive or inadequate nutrient intake to broiler breeder hens for maximizing settable egg production and minimizing health disorders. A balanced diet and feed allocation in broiler breeders influence chick weight. Summers (2010) reported that hatchling weight was higher with a maternal diet content of 5.52 g of protein per 100 kcal energy compared to any other ratios either higher or lower. Feed restriction (primary breeder guideline) in broiler breeders during rearing and breeding phases increased fertility (13%), hatchability (21%) and viability (13%) compared to full-fed broiler breeder females (Yu et al., 1992). Thus, feed restriction in broiler breeder hens contributed to chick quality as well as offspring performance including BW. Feed allocation in breeder hens is a big challenge to maximize reproductive output.

1.3. THE INCREASING DEGREE OF FEED RESTRICTION

In the history of feed restriction in laying chickens, Heywang (1940) was one of the first to investigate the effects of feed restriction (a laying hen was not allowed to consume all feed that she would normally consume) on egg production, egg weight and BW. Feed restriction in broiler breeders was reported first to control BW growth for increasing laying performance in the 1950s and 1960s (Novikoff and Byerly, 1945). A high fibre diet was used as a treatment to reduce growth rate of pullets BW around 8 wk of age but they did not observe any effect on layer performance (Issacks et al., 1960). Emphasis on feed restriction was given in pullets to delay sexual maturity (Lee et al., 1971) in order to maximize reproductive output.

The industry focus on feed restriction led to the development of a system of skip-a-day feeding to control broiler breeder BW. Due to increased growth potential in broiler breeders, the degree of feed restriction has increased in order to maintain egg production traits (Bruggeman et al., 1999). To optimize production, an average 3 g/year decrease in broiler breeder BW at 6 wk has occurred since the year 1978 guidelines (Renema et al., 2007). The recent female breeder guides provide the lowest BW recommendations for 6 and 12 wk for most strains, allowing greater gains between 18 and 24 wk of age for the nourishment and development of reproductive organs, which enhanced subsequent egg production (Renema et al., 2007). Nowadays feed restriction has increased compared to the primary breeder's recommended feeding guideline. A little decreasing rate of feed allocation to the broiler breeders does not show yet any sign of slowing down the growth potential of broilers. Every year feed allocation decreased 3 g resulting in a decreased BW in broiler breeders; at the same time, broiler BW increased 37g/year/bird (Renema et al., 2007). The degree of feed restriction in broiler breeders directly contributes to high productivity (Robinson et al., 1991) and indirectly to their offspring performances (Al-Murrani, 1978). The current levels of feed restriction are believed to maximize chick production.

1.3.1. Scarcity of feed as a resource

With increasing rates of growth in broilers, and no increase in BW targets for their parent stock, the relative rate of feed intake continues to decrease. Feed has become a scarce resource for modern commercial broiler breeders. This has increased competition for feed among broiler breeders within a flock, resulting in great problems with flock uniformity (Hudson et al., 2001).

1.3.2. Management of feed restriction in broiler breeders

Feed restriction is applied about 25 to 50% of *ad libitum* in broiler breeder during the rearing phase to control BW to avoid obesity from 4 to 20 wk of age (Savory et al., 1993; Ducuypere et al., 2006). Feed restriction from 7 to 15 wk of age is very critical because of its association with long term increases in reproductive performance (Bruggeman et al., 1999). After this period feed restriction begins to relax to allow rapid growth of body and reproductive organs up to sexual maturity (Hocking et al., 1993), especially from 20 to 24 wk of age when getting ready for onset of lay at 40 wk of age. Thereafter, feed restriction is much more relaxed with about 70% of ad libitum feed to supply adequate nutrient for production as well as growth and maintenance (Aviagen, 2007). This strategy will help to control body weight to maximize settable egg production. Renema et al. (2007) reported that the degree of feed restriction increased slowly each year to keep broiler breeders on a healthy growth curve and maximize reproductive output.

1.4. ENERGY SYSTEMS

1.4.1. Overview from Gross energy to Net energy

Energy is defined as potential capacity to perform work (Leeson and Summers, 2001). Energy partitioning in chickens is presented in Figure 1.1. The total energy contained in ingested feed is referred to as a gross energy (GE). Digestible energy (DE) is the remaining energy after subtracting the fecal energy from GE. Fecal energy is the gross energy in the feces. Fecal energy can be portioned into energy from undigested food and energy from compounds of metabolic origin. Metabolizable energy (ME) is the energy available after subtracting urinary energy and gaseous energy losses from DE. Urinary energy is the total gross energy in urine. It includes energy from non-utilized absorbed compounds from the food, end products of metabolic processes, and end products of endogenous origin. Net energy (NE) is the ME of the feed corrected for the energy losses due to heat increment (heat of fermentation, heat of digestion and absorption, heat of product formation, heat of waste formation and excretion). The remaining NE is used for maintenance and production. The energy requirement for maintenance is used energy for basal metabolism, thermoregulation and normal activities of birds (Emmans, 1994). The remaining energy after maintenance requirement of birds is productive energy, used for growth and other products such as eggs in chickens or milk in mammals. The proportion of ME for maintenance can vary based on the physiological status of an animal and environmental temperature (Sakomura, 2004).

1.4.2. Metabolizable energy vs. Net energy

The ME is the standard measure of energy in both energy requirements and diets for poultry (Lopez and Leeson, 2007. The ME partitioning in broiler breeders is complex and critical, because they are feed restricted. The daily ME requirement of birds depends on age, BW, body composition, growth rate, rate of egg production (Sakomura, 2004) and environmental temperature (Ahmad et al., 1974). The ME partitioning model is $MEI = aW^b(T) + c\Delta W + dEM$, where MEI is daily ME intake, W^b is metabolic body weight derived from $(BW)^{0.75}$, ΔW is body weight change, EM is egg mass output per bird per day, T is environmental temperature, a, c, and d are the coefficients of maintenance requirement, growth and production, respectively

(Sakomura et al., 2003). The energy requirement for maintenance is about 70 to 85% of the total ME intake in broiler breeders (Sakomura, 2004; Romero et al., 2009b). That means a very small proportion of energy remains available for growth and production. In any situation, if the energy requirement for maintenance increases then growth and production are hampered seriously because broiler breeders are feed restricted. Although broiler breeders have the capacity to increase feed intake to compensate for increased maintenance requirements, they cannot do so voluntarily.

The ME includes the total heat increments of digestion and absorption, product formation, fermentation, and waste formation and excretion. NE is the energy used by animal after subtracting the total heat increment from ME. In poultry, metabolizable energy is used for diet formulation.

1.4.2.1. ME calculation

Measurement of feed intake and excreta collection of chickens is difficult because excreta become contaminated with spilled feed and fallen feathers, scale, and down shed of birds. Inert indicators or markers such as chromic oxide, silicon, celite, ferric oxide, or barium sulphate are used to avoid this contaminating problem. In the current study, the ME was determined using celite as a marker according to the formula developed by Olukosi et al. (2007) and all values are expressed on a dry matter basis.

ME (kcal/g) of feed = GE per g of feed – [GE per g of excreta * (Concentration of marker in diet/ Concentration of marker in excreta)].

1.4.2.2. Body heat transfer systems

The amount of energy in the form of heat transferred from one subject to another depends on the difference of temperatures between two subjects. There are four ways to transfer heat from chickens’ bodies to the environment (National Research Council, 1981). Conduction is the process of heat transferring from homoeothermic animals by direct contact to litter and walls. Convection is a process of heat dissipation from the chickens’ body to the surrounding environment depending on air movement. Radiation is another process of heat transferring from the animal body to the environment by radiation, if the surface body temperature of a bird is higher than the environmental temperature. Conversely warmer walls and roofs may radiate heat to the bird surfaces. About 95% of heat in birds is transferred by conduction and convection, and 5% is transferred by radiation (Wolf and Walsberg, 2000). Evaporation is an important method to dissipate body heat to the environment at above the upper critical environmental temperature, birds lose heat through evaporative cooling and it depends on the panting rate of a chicken (Richards, 1976; Mack et al., 2013). Water evaporation cools the liquid remaining because it must extract the necessary heat of vaporization from that liquid in order to make the change from a liquid to a gaseous state.

1.4.2.3. Metabilic source of heat production

The heat increment is the increase in heat production following consumption of food by an animal (Smith et al., 1978). The following four heat increments can be referred to as the total heat increments of maintenance and production (National Research Council, 1981). Heat of fermentation is the heat produced in the digestive tract by microbial action. The heat of fermentation was established as an additional indicator of metabolic activity. Microbial fermentation occurs mainly in cellulose-eating animals. In poultry, microbial fermentation is negligible. However, caeca take part in the digestion of cellulose particularly in geese because they are good forager. The role of caeca in chickens is limited due to less intake of cellulose in their diet. Heat of digestion is the heat produced by the action of digestive enzymes on the feed within the digestive tract. Heat of absorption is produced by moving digesta and it is a by-product of absorption of nutrients through the digestive tract. Heat of product formation is a by-product of metabolic process of product formation from absorbed metabolites. This is the heat produced by biosynthetic pathways. Heat of waste formation and excretion is the heat production associated with the synthesis and excretion of waste products. Synthesis of urea from ammonia is an energy-costly process in mammals and results in an increased in total heat production.

1.4.3. Implications of feed restriction for nutrient partitioning

1.4.3.1. The energy requirement for maintenance

The energy requirement for maintenance is the energy required to maintain basal metabolism, activity and thermoregulation. The energy requirement for maintenance in chickens depends on body size, activities, and environmental temperature. Sakomura (2004) and Romero et al. (2009b) reported that around 70 to 85% of the total ME intake is required for maintenance in feed restricted broiler breeders. The energy requirement for maintenance includes energy required for basal metabolism, normal activities, and thermoregulation (Sakomura et al., 2005).

Basal metabolism is the basic energy used by a healthy animal without changing BW in the fasting, awake and resting states under thermoneutral temperature. This energy is required to maintain vital cellular activity, respiration, and blood circulation. The energy used for basal metabolism in laying chickens was calculated using the equation $79*BW^{0.75}$ ME kcal/kg metabolic body weight per day developed by Carpenter (2005).

Energy is required for normal activities of chickens such as standing, walking, wing flapping, and lying down. Energy required for normal activities in full fed laying hens by 26 to 29% of maintenance energy (Sakomura et al., 2005) in floor housing systems. However, Rabello et al. (2004) reported that activities required about 22% more energy for broiler breeder hens in a floor housing system than in a cage housing system. Activities in chickens shared a significant amount of maintenance requirement.

Endothermic animals like chickens need energy for thermoregulation. Chappell et al. (1990) reported that the energy required for thermoregulation in adult penguins was about 10 to 16% of basal metabolism at an environmental temperature of 5 to 6˚C. However, the energy requirement for thermoregulation could vary in chickens with changing environmental temperature below the lower or above the upper critical temperature.

1.4.3.2. The energy requirement for growth

Broiler breeder pullets use only around 20% of the total ME intake for growth (Sakomura, 2004). In cold environments below the lower critical temperature, birds dissipate an increasing amount of heat to the environment due to the greater temperature difference between the surface body and the environment. As the energy requirement for maintenance increases to maintain their CBT, the remaining small proportion of energy is further decreased, which dramatically affect growth in birds (Sakomura, 2004). Because of feed restriction, broiler breeders cannot increase voluntary feed intake to compensate for increased energy used for maintenance. For example, if the energy requirement for maintenance would increase only 1% in a cold environment, it would reduce growth in feed-restricted broiler breeder pullets. Assuming the total metabolizable energy intake was 192 kcal/day, 85% of total ME intake (163.2 kcal/day) would be used for maintenance requirement; a 1% increase would be total 164.83 kcal/day; the remaining small proportion of energy further decreased by about 10.67% (1.63 kcal/day) which would decrease growth 1.63 g/bird/day in feed restricted breeder pullets. An example for broilers, assuming the total ME intake was 496 kcal/day, 50% of the total ME intake was 248 kcal/day for maintenance requirement (Sakomura, 2004). If the energy requirement for maintenance would increase by 1%, the energy requirement for maintenance would be total 250.5 kcal/day. On the other side, if energy would decrease only by 1% (2.48 kcal/day) and this energy would decrease growth (0.81 g/bird/day) in a full-fed broiler. It seems negligible and they can minimize the effect by increasing feed intake because feeds were supplied *ad libitum* to broilers.

1.5. ENVIRONMENTAL TEMPERATURE: IMPLICATIONS IN FEED RESTRICTED ANIMALS

Heat production and heat loss in birds depend on environmental temperature. This can affect core body temperature, feed intake, heat production, heat retention, egg production and efficiency (Figure 1.2).

1.5.1. Role of CBT in heat exchange with the environment

The thermoneutral zone is the range of environmental temperatures (Bligh and Johnson, 1973) in which a homeothermic animal does not have to increase or decrease normal metabolic heat production for maintaining CBT (National Research Council, 1981). The CBT of adult full-fed layer chickens ranges from 40.6 to 41.4˚C (Deeb and Cahaner, 1999). Savory et al. (2006) reported that the CBT of feed-restricted broiler breeder females ranges from 39.6 to 41.2˚C, while full-fed broiler breeder hens exhibited a range in CBT from 40.8 to 41.2˚C. Diet-induced thermogenesis occurs more or less continuously in full-fed birds, compared to once per day for feed restricted broiler breeder hens (Savory et al., 2006). This is likely the reason for both the higher mean and the lower range in CBT in full fed hens.

Environmental temperature has a great impact on birds' physiology including CBT dynamics and energy requirements (Khalil et al., 2004). In environmental temperatures below the lower critical temperature, when the difference between the surface body temperature and environmental temperature is high (ΔT > 25˚C), birds lose an increasing amount of heat to the environment and eat more to increase the rate of metabolic heat production to maintain a relatively constant CBT (National Research Council, 1981). In addition, a decrease in CBT can lead to behavioural responses, including huddling, reducing body surface area, and adjusting feathers to increase insulation and to minimise body heat loss (Richards, 1971). Birds also try to maintain their CBT by reducing heat dissipation through vasoconstriction (Wolfenson, 1983). Initially, birds can regulate all physiological functions but when environmental temperature continuously decreases after 15˚C, then birds increase feed intake as much as possible. Presumably, egg production could be sustained due to higher amount of feed intakes. In this situation, egg production and egg weight may not be affected by a colder environment but increased feed intake will lead to decreased efficiency. Heat retention decreased due to a higher amount of heat dissipation to the colder temperature resulting in decreased CBT (Figure 1.2). When the temperature difference increases between the surface body and environment (e.g. environmental temperature less than 4˚C), birds cannot control core body temperature by increasing the rate of metabolic heat production due to higher rate of heat dissipation. Presumably, the CBT in chickens would decrease if CBT dropped down to lower lethal point at 22˚C and then they would die (Robert and Shafner, 1951). Heat retention and egg mass production also would decrease in severe cold weather (Figure 1.2).

Conversely, at environmental temperatures above the upper critical temperature, the difference between the surface body temperature and the environmental temperature decreases (< 12˚C), and birds cannot dissipate adequate heat to the environment. Birds show behavioural responses to increase heat dissipation including separating from each other, increasing surface area by standing, trying to stay near window (presumably looking for a colder area or finding a way to lose heat through convection (air movement) and shadow, wing drooping and spreading, and eventually dissipating excess heat by panting (a faster rate of breathing to promote evaporative water loss; Freeman, 1965; Donkoh and Atuahene, 1988). They also try to maintain their CBT by increasing body heat loss through vasodilation in hot environments (Brody, 1945). When they fail to control from their CBT increasing, birds decrease the rate of metabolic heat production by decreasing feed consumption (May. and Lott, 1992). Sufficiently reduced feed consumption results in reduced productive outputs such as growth or egg production or both. Feed intake, total heat production, egg mass production and efficiency decrease with increasing environmental temperatures above the upper critical temperature (Figure 1.2). However, heat retention increases due to decreased rate of heat dissipation with increasing environmental temperature. Increased heat retention above the upper critical temperature may raise CBT in chickens. When CBT is reached at the upper lethal point at 45 to 47˚C, birds would die (Robert and Shafner, 1951). Heat stress has a greater negative impact on production than cold stress.

1.5.1.1 Diurnal CBT pattern

Diurnal CBT patterns in birds depend on controlling physical heat loss and chemical heat production (Freeman, 1966). Environmental temperature and feed consumption influence physical heat loss and chemical heat production, respectively. As birds are homoeothermic animals, they balance energy in their bodies by controlling heat production and heat loss (Monteith, 1974). Generally, during the day birds increase feeding related activity and feed metabolism (Khalil et al., 2004). These activities produce heat, leading to increased CBT compared to night time CBT in birds. The CBT elevated before lights were turned on and peaked after feeding; thereafter CBT gradually decreased and dropped suddenly after lights were turned off (de Jong et al., 2002). Boiler breeder management is more difficult than commercial layers and broilers, because broiler breeders are feed restricted and they are unable to increase the rate of diet induced heat production to maintain their CBT. An accurate feed allocation and a proper feeding time may optimize energy partitioning for maximizing production using limited resource. Diurnal CBT patterns generate a clear idea of heat production during the day. Studying CBT patterns in broiler breeders can enrich fundamental knowledge for future research related to core body temperature dynamics, and aid feed management in different environmental temperatures.

1.5.1.2 Energy sparing strategies

Homeothermic animals can save energy by physiological and physical changes in both hot and cold environments (Richards, 1971; Mustaf et al., 2009). The comb and wattles act as a radiator in birds (Wilson and Plaister, 1951). Vasoconstriction is the mechanism in homeothermic animals under the lower critical temperature to constrict the muscular wall of the arterial blood resulting in a decreased blood flow to the skin, wattle and comb, and they become pale in color (Wolfenson, 1983). This mechanism reduces the blood flow to the skin, comb and wattles resulting in reduced heat loss to the environment. Vasoconstriction in homoeothermic animals minimizes heat loss mainly by constricting blood vessels which increase tissue insulation under cold stress (below the lower critical temperature; Ames et al., 1970). In addition, in colder environments, animal increase muscular movement and shivering to maintain core body temperature (Richards, 1971; Khalil et al., 2004). Cold environments produce a reduced blood flow and decreased heat loss through the comb and wattles to the environment; thus chickens thermoregulate in cold environments.

The smaller the temperature difference between birds and the environment, the less heat will be exchanged (Richards, 1971). For an example, ducks and many other animals can swim or walk on ice; they have a counter-current heat exchange system between the arteries and veins in their legs (Thomas and Fordyce, 2007). Arteries carry warm blood from the heart to extremities including the feet. Similarly, veins carry cold blood from the feet. The arterial blood warms up the venous blood when they pass each other through the upper part of legs. The relatively cold arterial blood circulates through the feet. Thus, ducks reduce the temperature difference between the feet and the ice resulting in a reduced heat loss and they can swim or walk on ice. However, food and oxygen are supplied to the feet tissues through arterial blood, making them just warm enough to avoid frostbite. In addition, the lower legs and feet have less soft tissue, mainly tendon connected with bone, which require less warm blood.

Interestingly, this same system can work when a bird is standing in excessively warm water. Overheated venous blood returns from the feet to the heart and comparatively cold arterial blood from the heart heats up while passing each other through the upper part of legs and this warm arterial blood circulates to the feet. This counter current heat exchange reduces the temperature of venous blood before entering the core organs of the body; comparatively warm arterial blood keeps the temperature of the feet above normal. In this case, the small temperature difference between the feet and environment reduces the heat exchange from the environment into the feet (Midtgard, 1981). Thus, birds also resist hot environments.

1.5.1.3 Energy releasing strategies

The initial response of homoeothermic animals exposed to environmental temperatures above the upper critical temperature (under heat stress) is to increase heat loss by vasodilation (Hammel et al., 1963; Mustaf et al., 2009). Vasodilation is a mechanism which enlarges blood vessels resulting in relaxation of smooth muscle in the large veins and arteries. Blood circulation increases and blood pressure decreases in the peripheral part of skin, wattle and comb, and heat dissipation is increased to the environment. The skin, comb and wattles become red due to increased blood flow. In hot environments, blood flows increase and dissipate heat through un-feathered skin, combs and wattles to the environment, and thus chickens regulate the thermoregulation in hot environments.

1.5.2. Effects of heat loss on maintenance requirements

Heat loss of homoeothermic animals depends on environmental temperature. When environmental temperature is below the lower critical temperature, they dissipate heat to the environment and they eat more to increase the rate of metabolic heat production to maintain a relatively constant core body temperature. The energy requirement for maintenance thus increases in colder environments, and that decreases energetic efficiency. When environmental temperature goes above the upper critical temperatures, birds increase blood flow to the surface and decrease tissue insulation resulting in increased heat dissipation by vasodilation (Brody, 1945) and increase body surface area by changing posture. Thus, they facilitate the rate of heat loss to the environment. When environmental temperature rises above the upper critical temperature, the homeothermic animals start to dissipate heat to the environment by evaporative cooling (Richards, 1976). Birds lose energy through evaporative cooling and they increase the energy requirement for maintenance in the hot environments.

1.5.3. Effects of environmental temperature on production

The balance between heat production and heat loss in chickens is an important factor to ensure optimal performance. Heat loss to the environment increases the energy requirements of the birds for thermogenesis; hence they increase their feed intake to meet their increased energy requirements (Teeter et al., 2005). Above thermoneutral environmental temperatures, laying hens reduce feed intake to maintain a relatively constant CBT by reducing heat production; however, reduced feed intake may reduce feed efficiency and production (May. and Lott, 1992).

In laying hens, every 1˚C decrease in temperature from 30 to 22˚C increased feed intake by 0.85% and energy intake by 0.86% (Ahmad et al.,1974). This might be due to less heat dissipation to the higher environmental temperature. Donkoh (1989) reported that feed intake decreased by 0.7%, 8.7%, and 12.9% in broilers during 3 to 7 wk of age, when the environmental temperature was 25, 30 or 35˚C respectively, compared to 20˚C. As a consequence, BW gain decreased by 1.6%, 21.6%, or 32.4%, respectively, at 7 wk of age. Sakomura (2004) concluded that below the lower critical temperature, ME_m increased by 6.73 kcal (6%) in laying-type pullets for every 1˚C decrease of environmental temperature; above the upper critical temperature the ME_m decreased by 0.88 kcal per 1˚C increase of environmental temperature. This decrease in feed and energy requirement with an increase in environmental temperature compels birds to eat less, resulting in decreased growth, egg production and egg weight (Donkoh and Atuahene, 1988). De Andrade et al. (1977) reported a decrease in egg production by 17% and egg weight by 8% when environmental temperature increased from 21 to 31˚C in laying hens. Al-Bashan and Al-Habibi (2010) also observed a decrease in egg production by 11% when the environmental temperature increased from 30 to 35˚C in laying hens.

The published literature leads us to conclude that environmental temperatures have a large effect on feed intake and maintenance energy requirements of chickens, which can dramatically change the amount of energy remaining to support growth and egg production. The role of change in environmental temperature in broiler breeders has not been studied extensively.

A major difference in modern broiler breeders compared to full-fed chickens is that feed intake is controlled by the flock manager. Therefore, voluntary changes in feed intake in feed-restricted broiler breeders to meet growth and productivity targets do not occur. A very small proportion of the total ME intake of broiler breeders is productive energy, and small changes in energy partitioned to maintenance can dramatically affect the amount of energy partitioned to growth. This emphasizes the need to conduct research on the implications of environmental temperature for broiler breeder feed allocation decisions.

1.6. EFFECTS OF HOUSING SYSTEMS ON ENERGY REQUIREMENT FOR MAINTENANCE

Chickens are housed either in cages or free-run systems. Peterman (2003) reported that cage housing systems account for approximately 90% of all commercial layer farms in the world. Traditionally, broiler breeders are reared in free-range housing to allow natural mating for fertile eggs (Fuquay and Renden, 1980) to reduce labor cost. It will be interesting to note the effects of different housing systems on energy requirement for maintenance in broiler breeders to maintain the target BW. Energy intake for free-run laying hens was higher than those of caged laying hens. Sakomura (2004) reported that the energy requirement for maintenance in free-run broiler breeder hens was above 70% of total ME intake. Li et al. (1991) suggested that 19% of total ME intake was used for activities in laying hens; whereas Rabello et al. (2004) reported that a free-run broiler breeder hen required 21.8% higher ME intake for activities than a caged broiler breeder hen. Energy required for normal activities of birds are integral part of maintenance. Feed allocation decisions need to be adjusted to meet the energy requirement for maintenance according to the housing system for maintaining a target BW in broiler breeder hens.

1.7. IMPLICATIONS FOR EFFICIENCY

1.7.1. The concept of efficiency

In general terms, efficiency can be defined as the ratio of the output to the input of any system (Wang and Kim, 2011). Generally, biological efficiency and energetic efficiency are used in the evaluation of livestock production.

1.7.1.1. Biological efficiency

Biological efficiency is the degree to which a conversion takes place to change physical inputs (feed) into saleable product (meat, egg or both) under a particular production environment (Wang and Kim, 2011). The definition of biological efficiency can be applied at both the individual animal level and at the industry level. Feed efficiency could be an evaluation criterion for the performance of an individual animal and as a whole flock.

1.7.1.2. Energetic efficiency

The current research compared the input-output relationships using chickens from an efficiency perspective. The chemical energy of feed is used by a biological unit to do work (Leeson and Summers, 2001). The transfer of heat and work in thermodynamic processes is governed by thermodynamic laws that were determined in the 19th century (Ebeling et al., 2005). The first law of thermodynamics states that the total amount of energy in a system always remains constant (Lehninger, 1971). It cannot be created or destroyed. This law allows for an accounting of the flow of energy within any energetic system, including chicken production, in which energy inputs and outputs are equal. The second law of thermodynamics states that the total entropy will increase over time when energy is transferred from beginning to the end of the process (Lehninger, 1971). Living organisms like chickens preserve their internal order by taking in chemical energy (useful energy) of nutrients or sunlight and returning to their surroundings an equal amount of energy into a less usable form (Lehninger, 1982). Birds lose more heat to the environment and they need more energy to maintain a relatively constant CBT, when the environmental temperature drops below the lower critical temperature (National Research Council, 1981). The amount of energy required based on the rate of heat lost to the environment. Energetic efficiency in chickens will decrease where environmental temperature drops below the lower critical temperature and it will seriously affect feed restricted broiler breeders.

1.7.1.3. Measuring energetic efficiency in broiler breeder hens

A relationship between input and output (feed efficiency) is a direct measure of energetic efficiency in animals (Skinner-Noble and Teeter, 2004; Orejano-Dirain et al., 2004). The energy requirement for maintenance in animals is an important measure of energetic efficiency; a metabolic BW is considered as a scaling factor determining part of the heat expenditure. The approach may be taken to assess energetic efficiency in poultry: quantification of residual variability in energy balance models (Romero et al., 2009a). The approach is generally used, and is known as residual feed intake (RFI). The RFI is defined as the difference between observed and predicted ME intakes. Bordas and Merat (1981), Johnson et al. (1999), and Herd et al. (2003) reported that RFI has been used to determine energetic efficiency in different species since the 1980s. An efficient animal is one that consumes less energy than the theoretical requirement (Romero et al., 2009a). Estimations of ME requirements in RFI calculations have incorporated some of the assumptions of ME models of energy partitioning. The following equation was used to determine the RFI of broiler breeders (Romero et al., 2009a):

$$\mathcal{E}=MEI-\{(a-bT)\ BW^{0.75} + cADG + dEM\}$$

where $\mathcal{E}$ is the residual feed (energy) intake, MEI is ME intake kcal/d, $BW^{0.75}$ is metabolic BW in Kg, T is temperature in ˚C, ADG is average daily gain (g/d), EM is daily egg mass production (g/d) and a, b, c and d are the coefficient of body weight, temperature, growth and egg mass respectively. The ME requirement for maintenance (ME_m) is generally considered to be dependent on environmental temperature, activity, BW, and includes heat increment of feeding.

1.8. PROBLEM STATEMENT

Management of genotype, nutrition and environmental temperature are key factors for the productivity and sustainability of broiler breeders (Renema et al, 2008). Feed alone accounts for approximately 60 to 70% of total costs of poultry production (Steiner et al., 2008). Feed allocation and maintenance energy requirements for the broiler breeder are big challenges when attempting to maximize production and increase efficiency under different environmental temperatures. The energy requirement for maintenance is the first priority for an animal especially in broiler breeders because they are feed restricted. Environmental temperature significantly affects the ME_m and thus efficiency (Zuidhof et al., 2012). Researchers have observed that for laying hens in cold environments (environmental temperature is below the lower critical temperature), the difference between the surface body temperature and environmental temperature increases, and the birds dissipate an increasing amount of heat to the environment (McDonald, 1978). They may eat more to increase the rate of metabolic heat production to maintain a relatively constant CBT (National Research Council, 1981). In hot environments (environmental temperature goes above the upper critical temperature but not exceeds the surface body temperature), when the difference between the surface body temperature and the environmental temperature decreases birds are unable to dissipate necessary heat to the environment resulting in a decreased the dependency on diet-induced thermogenesis and they reduce feed intake. The larger proportion of ME intake is used for maintenance (70 to 85%; Sakomura, 2004; Romero et al., 2009b) and the remaining very small proportion of ME intake is used for growth and production. When the energy requirement for maintenance increases, then the energy available for growth and production becomes severely deficit resulting in a decreased growth and production in broiler breeder females because they are supplied a limited amount of feed. Thus, cold or hot environments decrease efficiency in broiler breeder hens. Feed allocation needs to be adjusted with changing environmental temperature. However, the effects of environmental temperature vary the energy requirement in broiler breeder hens to maintain a relatively constant CBT. The relationship among the diurnal CBT pattern and different dietary energy levels needs to be more precisely quantified for broiler breeder hens. Therefore, to address the problem of an accurate estimation of feed allocation for the energy requirement for maintenance with respect to change in environmental temperatures the current research was conducted.

1.9. OBJECTIVES

1.9.1. General objective

The main purpose of the current research was to investigate the effects of environmental temperature and dietary ME level on core body temperature dynamics and efficiency in broiler breeder females.

1.9.2. Specific objectives

- To determine the relationship between environmental temperatures, core body temperature dynamics and growth efficiency in broiler breeder pullets (Chapter 2).

- To investigate the effects of environmental temperatures and dietary energy levels on core body temperature dynamics and reproductive efficiency in broiler breeder hens (Chapter 3).
- To identify the impacts of feeding time, photoperiod, and dietary ME level on core body temperature dynamics and oviposition time in broiler breeder hens (Chapter 4).
- To assess the maintenance energy requirement, core body temperature dynamics and efficiency of broiler breeder hens in cage versus free run housing systems (Chapter 5).

1.10. HYPOTHESES

Birds in low environmental temperature will increase heat loss to the environment leading to increased feed intake to maintain core body temperature and reduced efficiency.

A low energy diet will increase feed intake resulting in an increased core body temperature led to greater heat loss to the environment and decreased efficiency.

1.11. APPROACH

Four studies using Ross 708 broiler breeders were conducted to investigate

i).Effects of four different environmental temperatures (15, 19, 23 and 27˚C) on core body temperature dynamics and performance of broiler breeder pullets (4 to 20 wk);

ii). Impacts of four different environmental temperatures and two dietary energy (High:2,912 ME kcal/kg; Low: 2,872 ME kcal/kg) levels on core body temperature dynamics and performance of broiler breeder hens (25 to 41 wk);

iii) Effects of four feeding times (07:30, 11:30, 15:30 and Split: 07:30 and 15:30) with two photoperiods (16L:8D and 24L:0D) and two dietary energy levels on core body temperature dynamics and oviposition times of broiler breeder hens (44 wk); and

iv) Effects of cage versus free run housing systems on the energy requirement for maintenance, core body temperature dynamics, and performance in broiler breeder hens (25 to 41 wk). Feed allocation was readjusted with changing environmental temperature to achieve the target BW of broiler breeder females at chamber level. Data on core body temperature, ADFI, egg production, and egg weight were collected. This offered a better understanding of core body temperature dynamics, the energy requirement for maintenance and efficiency in broiler breeder females.

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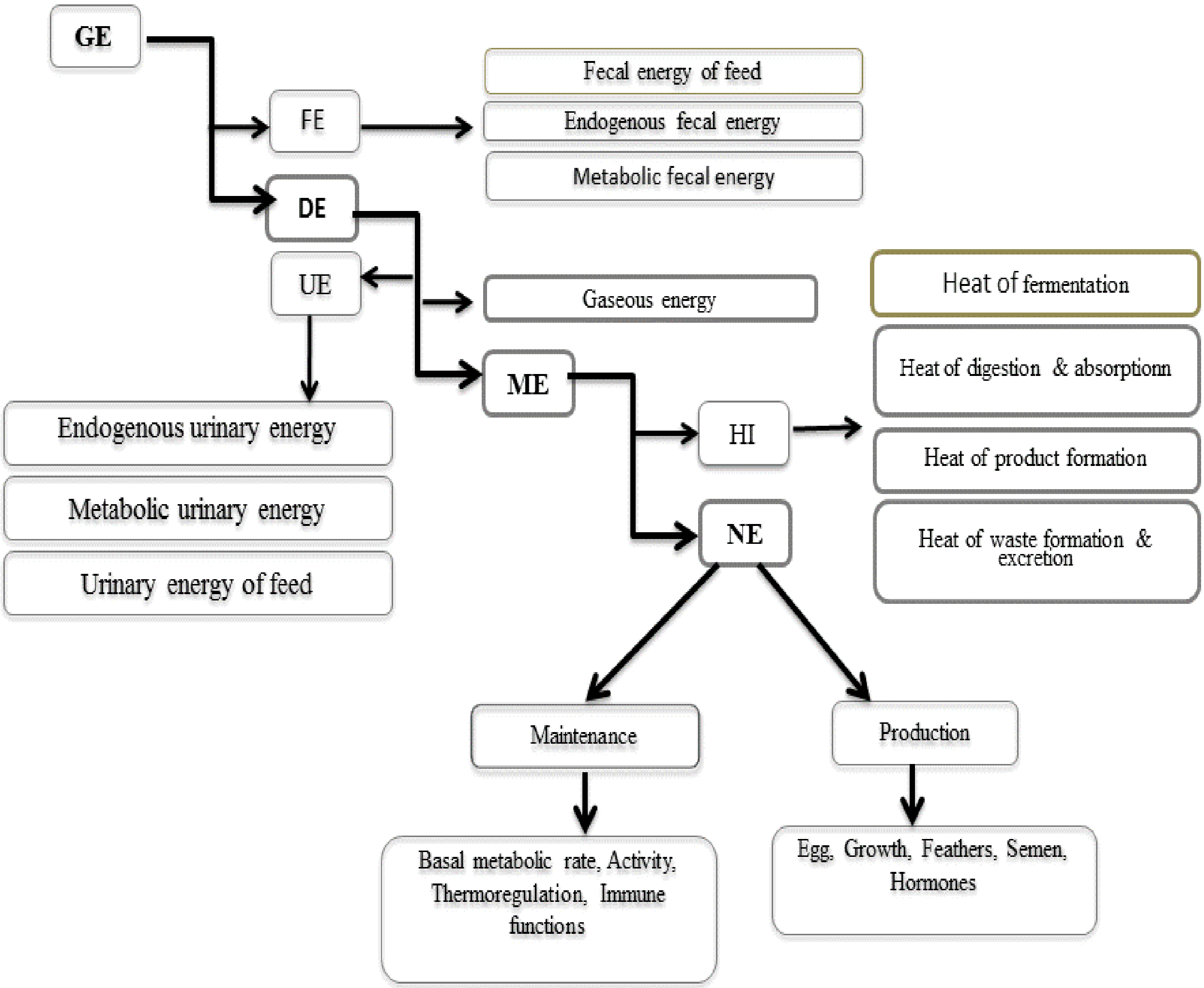

Figure 1.1 Partition of feed energy in animals
Adapted from Leeson and Summers (2001) and Teeter et al. (2005).
GE=Gross Energy; FE=Fecal Energy; DE=Digestible Energy; UE=Urinary Energy; ME=Metabolizable Energy; HI=Heat Increment; NE=Net Energy.

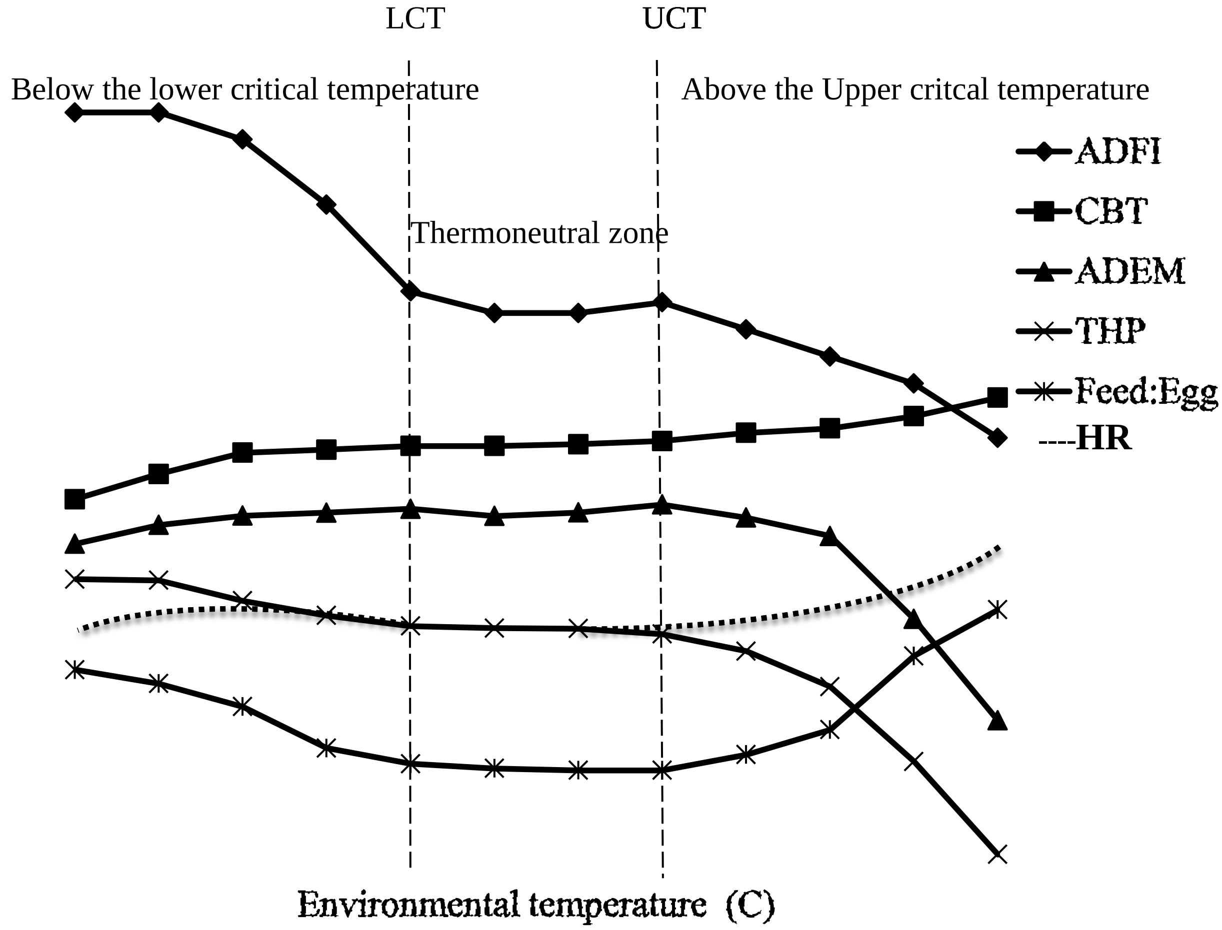

Figure 1.2 Theoretical effects of environmental temperature on core body temperature (CBT), average daily feed intake (ADFI), total heat production (THP) , heat retention (HR), average daily egg mass output (ADEM) and efficiency in broiler breeder hens.

In the thermoneutral zone, heat production and heal loss are balanced. ADFI= average daily feed intake; CBT= core body temperature; ADEM= average daily egg mass production; THP= total heat production; HR= heat retention; Feed: egg (g/g) = feed to egg conversion ratio; LCT= lower critical temperature; UCT= upper critical temperature.

CHAPTER 2: EFFECTS OF ENVIRONMENTAL TEMPERATURE ON PERFORMANCE AND CORE BODY TEMPERATURE IN BROILER BREEDER PULLETS

ABSTRACT: An experiment was conducted to investigate the effects of environmental temperature on average daily feed intake, average daily gain, feed efficiency, and core body temperature (**CBT**) dynamics in 800 feed restricted Ross 708 broiler breeder pullets from 4 to 20 wk of age. Pullets were housed in 8 climate-controlled environmental chambers, each containing 4 pens. Standard breeder BW targets were achieved using feed restriction (daily) from 14 d of age. Every 14 d, temperature treatments (15, 19, 23, or 27˚C) were randomly reassigned to the chambers. Telemetric devices that transmitted CBT data every 10 min were surgically implanted in the right abdominal cavity of 64 pullets (n=2/pen) at 13 wk of age. Average daily feed intake was the highest in the 15˚C treatment followed in decreasing order by the 19, 27, and 23˚C treatments. Average daily gain was 0.91 g higher in the 27˚C than in the 15˚C treatment. Feed, ME and CP conversion rates were higher in the 15˚C than in the 23 and 27˚C groups. Average CBT was lower in the 19˚C treatment group than in the 23 and 27˚C treatment groups. Feed restricted pullets had a clear diurnal CBT pattern, with a range of approximately 2.47˚C regardless of environmental temperature. The birds maintained a steady low CBT of 40.27˚C at night, the CBT increased gradually from 1 h pre-dawn, pre-feed and reached a peak of 41.90˚C at 0-1 h post-feed. After a postprandial CBT peak, CBT decreased gradually to 1 h pre-dusk. Pullet CBT quickly dropped in the hour after the lights were turned off. Birds maintained a relatively constant CBT in different environmental temperatures. In colder environments, the difference between body temperature and the environmental temperature was greater and birds lost more heat to the environment. Therefore, they needed more energy to maintain homeostasis. Accurate broiler breeder pullet feed allocation decisions need to accommodate effects of environmental temperature on

maintenance requirement because the expected growth rate can be affected by changes in environmental temperature.

Keywords: Environmental temperature, core body temperature, feed allocation, efficiency.

2.1. **INTRODUCTION**

Feed restriction is a common practice used with broiler breeders to achieve the target BW and maximize reproductive efficiency (Robinson and Wilson, 1996). The target BW, feed allocation and environmental temperature are crucial factors in the performance of broiler breeders. A target BW is recommended for each strain by the breeding companies and established based on field results and supported by experimental observations (Renema et al., 2007). Feed allocation is a key factor for controlling intake over time to achieve target BW in feed-restricted broiler breeders. The relationship between BW and reproduction is a very complex one in feed restricted broiler breeder females (Bornstein et al., 1984; Hocking and Robertson, 2000; Joseph et al., 2002; de Beer and Coon, 2007). Excess energy consumption makes broiler breeders obese (Renema et al., 1994; Romero et al., 2009). In particular, researchers have noted a negative relationship between growth and reproductive performance in broiler breeder hens (Maloney et al., 1967; Jaap and Muir, 1968; Yu et al., 1992). Hocking (2004) reported that the maintaining a target BW led to a uniformity in the birds for the age at onset of lay and egg weight. However, broiler breeder obesity leads to decreased production, fertility, hatchability, liveability and feed efficiency (Wilson and Harms, 1984), and erratic ovulations, abnormal eggs and irregular oviposition times (Jaap and Muir, 1968; Yu et al., 1992). Indeed, Hocking (2004) reported that severely feed restricted (25% of ad libitum) breeders produced underweight conditions relative to their recommended BW targets, which resulted in delayed sexual maturity, poor egg production and low egg weight. So achieving the target BW in broiler breeder females through accurate feed allocation is of primary concern in optimising reproductive efficiency.

Feed allocation should decide depend upon the environmental temperature. Temperature is one of the major environmental factors that influences the efficiency of energy use by poultry (National Research Council, 1981). The energy requirement for maintenance in broiler breeder pullets is about 80% of total ME intake (Sakomura, 2004). The CBT in feed restricted broiler breeder hens ranged from 39.0 to 41.2˚C (Savory et al., 2006; de Jong et al., 2002). In cold environments, the difference between the surface body temperature and environmental temperature increases, birds dissipate more body heat to the environment, and they use higher proportion of ME intake to maintain core body temperature. Since the first priority for nutrient utilization is maintenance (Reyes et al., 2011), the amounts of nutrients available for growth diminish at lower environmental temperatures. In other words, cold thermogenesis increases maintenance energy requirements, as an animal must increase its feed intake and rate of metabolic heat production in order to maintain CBT (Green et al., 2009). This may result in a reduced BW gain because feed-restricted broiler breeders cannot voluntary feed intake. Conversely, birds show symptoms of heat stress above the upper critical temperature (above thermoneutral temperature; approximately 30˚C); when the difference between the surface body temperature and environmental temperature decreases (< 10˚C). Under this condition, birds are unable to dissipate adequate heat to the environment resulting in a rise of CBT. They may reduce the rate of metabolic heat production by eating less, resulting in a decrease of nutrient intake (National Research Council, 1981). Thus, poultry BW gain and egg production efficiency is adversely affected by high environmental temperature. The relationship between environmental temperature and CBT affects the amount of energy used for thermoregulation (Geraert et al., 1996). The energy requirement for maintenance of birds changes under high or low environmental temperature such that birds require more feed in cold environmental temperature than hot environmental temperature. In addition, Howlider and Rose (1987) reported that heat stressed broiler chickens became lighter but fatter with an increase in total and abdominal fat by 0.8% and 1.6% respectively with each degree of environmental temperature over 21˚C. As broiler breeders' CBT rise, feed consumption, growth rate, feed efficiency, and survivability decrease (Wilson and Harms, 1984). Therefore, environmental temperature is a critical factor for chicken rearing in terms of maintaining CBT, body weight gain, feed intake, and reproductive efficiency.

The present study was carried out to explore the effects of different environmental temperatures on CBT dynamics, ADFI, ADG, and feed efficiency in feed restricted broiler breeder pullets. This information can be useful for understanding maintenance energy requirements, and is important for feed allocation decisions for broiler breeder pullets in varying environmental temperatures.

2.2. MATERIALS AND METHODS

2.2.1. Animal Care Approval

This study was carried out in compliance with the guideline of the Care and Use of Experimental Animals (Canadian Council on Animal Care, 1993) and was approved by the Animal Care and Use Committee for Livestock at the University of Alberta.

2.2.2. Experimental Design

A completely randomized design was used to evaluate the effects of environmental temperatures on ADFI, ADG, feed efficiency and core body temperature dynamics in broiler breeder pullets. Each of four temperature treatments (15, 19, 23, and 27˚C) was assigned to 2 environmentally controlled chambers for 8 consecutive 14 d period from 4 to 20 wk of age. The temperature treatments were randomly preassigned using the PLAN procedure of SAS.

2.2.3. Stocks and Management

A total of 800 Ross 708 (Aviagen Inc., Huntsville, AL) 1 d old broiler breeder pullets were individually identified by bar-coded neck tags (Heartland Animal Health, Fair Play, MO) and placed randomly into eight climate controlled chambers. Each chamber was divided into four floor pens with 25 chicks per pen (5 chicks/m^2) under the recommended brooding temperature (Aviagen, 2007). At 7 d of age, individual chicks were identified using bar coded wing bands with the same digits in both wings. Feed was provided *ad libitum* for the first 14 d. At 15 d of age, daily feed restriction was imposed to maintain the target BW according to the primary breeder's guidelines (Aviagen, 2007). Group feed allocation decisions were made twice per week, based on the mean BW of each pen. Pullets within each pen received the same amount of feed on any given day based on different environmental temperature treatments. Environmental temperature treatments (15, 19, 23, and 27˚C) were randomly assigned every 14 d period after 28 d of age. Each temperature treatment was replicated twice in each of 8 time periods. Pullets were reared in the floor pens until 20 wk of age. The photoperiod was 23L:1D for the first 3 d and 8L:16D from 4 d to 20 wk of age. They were fed wheat- and soybean-based mash diets (Appendix A): Starter (2,900 kcal ME, 19% CP) from 0 to 2 wk and Grower (2,700 kcal ME, 15.0% CP) from 3 to 20 wk of age.

2.2.4. Surgical Implantation of Temperature Sensors

Surgical procedure for implanting telemetry sensor in the abdominal cavity of chickens was performed according to Nain (2011). A total of 64, 13-wk old pullets were randomly selected (two pullets from each of 32 pens) for surgical implantation of CBT sensors (ATS, Inc., Isanti, MN) into the right side of the abdomen. The CBT sensors had an accuracy rating of ± 0.1˚C, and were calibrated using a water bath procedure. Prior to surgery, the pullets were moved to individual cages and were fasted overnight. Each pullet was anaesthetized with 0.75% isoflurane at a rate of 1.5 L/min through an inhalation mask just before surgery. The right ventral abdominal area was plucked and cleaned for surgery with Hibitane TM antiseptic (Chlorhexidine 2%, Ayerst Veterinary Laboratories). The CBT implants were placed in the right abdominal cavity after a 3 cm incision was made in the right ventral abdominal flank. After implantation, the muscle layers and skin were sutured using synthetic absorbable material (3/0 Polydioxone Suture). A long term acting analgesic (meloxicam: 0.1 mg/kg; Metacam, Boehringer Ingelheim) and a short term acting analgesic (buprenorphine: 0.01 mg/kg: Buprenex®, Norwich Eaton) were injected subcutaneously to prevent pain and discomfort during and after surgery. A broad spectrum antibiotic (Ampicillin: 50 mg/kg) was administered intramuscularly to prevent infection. Birds were returned to their respective cages after surgery and feed and water was provided ad libitum. Each bird was observed for 15 to 20 minutes to ensure that they were able to stand up and had normal appetite. Pullets were returned to their original pens 24 h after surgery.

2.2.5. Data Collection

Average daily feed intake and average daily BW gain, based on twice per week group weights, was recorded throughout the experiment. Abdominally-implanted temperature sensors transmitted the CBT of each bird every 10 min from 13 to 20 wk of age. The following terminologies were used: Maximum CBT was the average of the highest daily body temperature of individual chickens. Mean CBT was the daily average of all recorded body temperatures of individual chickens. Minimum CBT was the average daily lowest body temperature of individual chickens. Range of CBT was the average of the difference between the daily maximum and minimum body temperatures of individual chickens. Night was defined as the time when lights were turned off (15:00), excluding 1 h post-dusk and 1 h pre-dawn; 1 h pre-dawn was the one hour time period before lights were turned on (07:00); pre-feed was the time period from lights on to feeding time; 0-1 h post-feed was the first hour after feeding; 1-2 h post-feed was the second hour after feeding; 2-3 h post feed was the third hour after feeding; 3-4 h post-feed was the fourth hour after feeding; >4 h post-feed was the remainder of time that the lights were on following the fourth hour post-feed, excluding pre-dusk; 1 h pre-dusk was the one hour time period before lights were turned off; 1 h post-dusk was the one hour time period after lights were turned off.

2.2.6. Statistical Analysis

Data were analyzed using the Mixed procedure of SAS 9.2 (SAS Institute, Cary, NC) and the treatment means were differentiated using Tukey's test. Environmental temperature treatments were considered fixed effects. The individual pen was the experimental unit for feed intake, body weight, and efficiency data. Correlated repeated measures of CBT were accounted for using age as a random effect with hen as a subject. Unless otherwise noted, differences between means were considered significant at $P \leq 0.05$.

2.3. RESULTS AND DISCUSSION

2.3.1. Feed intake and BW gain

An increase in environmental temperature led to a stepwise decrease in ADFI from 15 to 23˚C treatment groups (Table 2.1). The target body weight was similar among the treatments throughout experimental period. However, the ADFI of the 27˚C treatment was not different from the 23 and 19˚C treatments. Theoretically, the rate at which birds dissipated heat to the environment was directly proportional to the difference between the surface body temperature and environmental temperature. Therefore, at cold temperatures birds require more feed to maintain body temperature (National Research Council. 1981). When the environmental temperature drops below the lower critical temperature; the temperature difference between the surface body and the environment increases, birds dissipate more heat to the environment and they eat more to increase the rate of metabolic heat production for maintaining a relatively constant CBT. When the environmental temperature is above the upper critical temperature, the temperature difference between the surface body and the environment decreases, birds are unable to dissipate adequate heat to the environment and they try to dissipate heat through panting (evaporative cooling) in the primary phase of the upper critical temperature (National Research Council, 1981). In both scenarios, birds expend more energy to maintain their CBT. The ADFI was lower in the 23˚C treatment compared to the 15 and 19˚C treatments. This might be due to less body heat being lost to the environment, therefore requiring a lower metabolic rate of heat production. Conversely, ADFI was highest in the 15˚C treatment group; probably because birds lost more heat to the environment and they required more energy for maintaining CBT. In hot environments, birds spend energy for cooling themselves, through activities such as panting (Brody, 1945; Mack et al., 2013). This is consistent with the observation in the current study that pullets in the 27˚C group did not eat less feed than birds in the 23˚C treatment group. In the current study, ADG was higher in the 27˚C treatment group (P = 0.06) compared to the 15˚C treatment group. The ADG was similar in the 19, 23, and 27˚C treatment groups and in the 15, 19, and 23˚C treatment groups. By design, average daily gains were expected to be the same in each treatment. This observation is likely the result of birds growing more quickly and efficiently than expected at higher environmental temperatures. Feed, CP and ME conversion rates were higher in the 15˚C treatment compared to the 23 and 27˚C treatments. This is consistent with the hypothesis that birds in the 15˚C treatment lost more energy as heat to the colder environment.

2.3.2. Core body temperature dynamics

Average daily maximum CBT was higher by approximately 0.12˚C in the 23 and 27˚C environmental temperature treatments than in the 15 and 19˚C treatments (Table 2.2). The mean CBT was similar when environmental temperature increased from 15 to 19˚C. The CBT increased by 0.03˚C with each subsequent environmental temperature increase. The mean CBT was significantly lower in the 19˚C, compared to the 23 and 27˚C treatment groups. Kadono and Besch (1978) recorded similar mean CBT in full-fed chickens under environmental temperatures within the range of 23 to 32˚C. However, the birds were feed restricted in the current study, and therefore would have less of a continuous source of heat available from the processes associated with feed intake and digestion. Thus feed restricted birds must be more active in the physiological regulation of CBT. In the current study, average daily minimum CBT increased with each subsequent increase in environmental temperature from 15 to 27˚C treatment group, indicating that the minimum CBT may be the most sensitive to environmental influence. Being homoeothermic, birds may be conserving energy by maintaining a slightly lower CBT in cooler environment (15 to 19˚C), and slightly higher CBT in warmer environment (23 to 27˚C). This was in agreement with Zuidhof et al., (2012). This response would reduce heat loss to the environment by reducing the temperature differential between body and environment. Although we did not measure surface temperature, it would seem reasonable that in an attempt to thermoregulate (control the rate of heat loss to the environment) the difference in bird skin temperatures between treatments would have been greater than the 0.03°C difference observed in CBT. For example, Richards (1971) reported shank skin temperatures of 34.1, 39.2 and 40.2˚C in 20, 30 and 40˚C environmental temperature, respectively. A similar range of CBT (2.47˚C) was observed in all temperature treatment groups. Energy efficiency could be reduced in cold temperatures because of increased heat loss to the environment.

2.3.3. Diurnal CBT Rhythms

In all treatments, the CBT followed a clear diurnal rhythm (Figure 2.1; Table 2.3). The CBT started increasing before dawn, peaked at feeding time (0-1 h post-feed), and then slowly declined during the remainder of the day. There was a rapid post-dusk drop in CBT (1 h after lights were turned off), and CBT remained relatively low during the night (Table. 2.3; Figure. 2.1). The CBT was likely the highest after feeding because of the combined effects of the feeding activity of birds and feed metabolism (Kadono et al., 1981; Khalil et al., 2004). The CBT increased about by 0.61˚C 1 h pre-dawn (one hour before lights on), probably in relation to changes from a state of sleep to wakefulness and activity. This may be associated with heat generated by muscle movement during activity (Khalil et al., 2004). In the pre-feed period (lights on to feeding time), CBT increased about by 0.67˚C compared to 1 h pre-dawn, which might be due to continued general increases in activity, as well as sudden visual due to lights on and auditory stimuli (Richards, 1971) such as the sound of a door opening. Other factors might have influenced CBT 1 h pre-dawn and pre-feed, including habituation to the lights coming on, and to feeding which was done fairly consistently about an hour after the lights were turned on. Just after feeding (0-1 h), CBT peaked. This was probably due to a combination of diet-induced thermogenesis and increased feeding-related activity. After feeding (1-2 h), the gradual decline in CBT reflected a rate of metabolic heat production that presumably decreased gradually after feeding. However, during the day time (from pre-feed to 1 h post-dusk), the CBT was higher than at night, likely due to a higher activity level. Khalil et al. (2004) reported activities such as body shaking, litter pecking, beak wiping, head scratching and preening during the day. In the 1 h pre-dusk period (one hour before lights off), CBT decreased by 0.02˚C from daytime CBT. In the 1 h post-dusk period, CBT dropped by about 0.76˚C. This was likely because of drastically reduced activity levels, resting and sleeping (Blokhuis, 1984; Khalil et al., 2004). This was in agreement with de Jong et al. (2002), who reported that higher activity level increased CBT in the day time compared to night time. Similarly, Kadono and Besch (1978) reported that for full-fed broiler chickens, CBT started to increase 2 to 4 h before lights were turned on and decreased 2-4 h before lights were turned off. The CBT was higher in the day time and lower at night time in all treatment groups. These results were in agreement with those of others (Fronda, 1921; Heywang, 1938; Winget et al. 1965). In the current study, a strong diurnal rhythm was observed in CBT of broiler breeder pullets, responding to feeding activities and photoperiod. Environmental temperature within the range from 15 to 27˚C did not dramatically affect diurnal CBT rhythm in feed restricted broiler breeder pullets. There is some evidence, however, from slight reductions in CBT in cooler environments that broiler breeder pullets may be actively conserving energy to dissipate less heat to the environment by reducing the temperature difference between the body surface and the environment.

2.3.4. Economic evaluation of pullets feed

Assuming a feed cost of $380/T, the feed cost increased by $0.02, $0.09 and $0.22 per pullet from 4 to 20 wk of age in the 23, 19 and 15˚C treatment respectively relative to the 27˚C treatment. The average feed intake was increased by decreasing environmental temperature from 27 to 15˚C.

Colder environmental temperatures (15˚C) decreased feed efficiency, CP and ME utilization efficiency, and increased feed intake considerably compared to warmer environmental temperatures (27˚C) in feed restricted broiler breeder pullets. Though there were subtle differences, CBT was maintained relatively constant across environmental temperatures, suggesting that heat loss from broiler breeder pullets, and therefore energy requirements for maintenance, were higher at low environmental temperatures. Zuidhof et al. (2012) suggested that feed allocations for target growth rates would be expected to be about 5% lower at environmental temperatures of 27˚C compared to 15˚C. To achieve a uniform rate of growth in broiler breeder pullets, feed allocation decisions should consider environmental temperature because the energy requirement for maintenance increases with decreasing temperature.

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Table 2.1 Average daily feed intake, average daily gain, and feed conversion rates of broiler breeder pullets (4 to 20 wk) in different environmental temperature treatments.

Environmental Temperature (˚C)		ADFI	ADG	Feed:Gain	ME:Gain	CP:Gain
Set	Actual ± SD	(g/d)	(g/d)	(g/g)	(kcal/g)	(g/g)
15	17.3 ± 2.2	52.70^{a}	13.28^{b}	3.99^{a}	11.15^{a}	0.69^{a}
19	20.4 ± 1.1	52.03^{b}	13.81^{ab}	3.77^{ab}	10.52^{ab}	0.64^{ab}
23	23.9 ± 1.0	51.14^{c}	13.92^{ab}	3.65^{b}	10.20^{b}	0.62^{b}
27	26.7 ± 2.2	51.51^{bc}	14.19^{a}	3.61^{b}	10.09^{b}	0.61^{b}
SEM	-	0.17	0.25	0.08	0.23	0.01
Probability	-	0.0001	0.0626	0.0048	0.0048	0.0048

$^{a\text{-}c}$Means within column with no common superscript are significantly different ($P \leq 0.05$)

Set environmental temperature= designated temperature to each chamber through computer programing

Actual environmental temperature= actual chamber temperature was recorded by data loggers

Table 2.2. Average daily maximum, mean, minimum, and range of core body temperature (CBT) of broiler breeder pullets (13 to 20 wk) in different environmental temperature treatments.

Environmental Temperature					
Set	Actual ± SD	Maximum	Mean	Minimum	Range
(˚C)		CBT (˚C)			
15	17.3 ± 2.2	42.36^{b}	40.75^{bc}	39.87^{d}	2.48
19	20.4 ± 1.1	42.39^{b}	40.74^{c}	39.94^{c}	2.44
23	23.9 ± 1.0	42.47^{a}	40.77^{ab}	39.99^{b}	2.48
27	26.7 ± 2.2	42.52^{a}	40.80^{a}	40.03^{a}	2.49
SEM	-	0.029	0.023	0.029	0.032
Probability	-	<0.0001	<0.0001	<0.0001	0.2616

$^{a-d}$Means within column with no common superscript are significant different ($P \leq 0.05$)

Set environmental temperature= designated temperature to each chamber through computer

Actual environmental temperature= actual chamber temperature was recorded by data loggers

Maximum = average of daily highest CBT of individual hens during the study period

Mean = average of daily mean CBT of individual hens during the study period

Minimum = average of daily lowest CBT of individual hens during the study period

Range = average of difference between daily highest and lowest CBT of individual hens during the study period

Table 2.3. Core body temperatures of broiler breeder pullets (13 to 20 wk) at different times of day under different environmental temperature treatments.

Time of day[1]	Environmental temperature (˚C)				
	15	19	23	27	overall
	----------------------------------CBT(˚C)--------------------------------------				
Night	40.24^{hC}	40.21^{hD}	40.28^{jB}	40.37^{jA}	40.27^{j}
1 h pre-dawn	40.87^{f}	40.90^{f}	40.88^{h}	40.89^{h}	40.88^{h}
Pre-feed	41.49^{dD}	41.54^{cC}	41.57^{cB}	41.60^{cA}	41.55^{c}
0-1 h post-feed	41.88^{aBC}	41.86^{aC}	41.89^{aB}	41.98^{aA}	41.90^{a}
1-2 h post feed	41.64^{bAB}	41.61^{bB}	41.61^{bB}	41.65^{bA}	41.63^{b}
2-3 h post feed	41.54^{cAB}	41.53^{cAB}	41.52^{dB}	41.57^{dA}	41.54^{d}
3-4 h post feed	41.48^{d}	41.46^{d}	41.46^{e}	41.49^{e}	41.47^{e}
>4 h post-feed	41.44^{eA}	41.42^{eAB}	41.40^{fB}	41.43^{fA}	41.42^{f}
1 h pre-dusk	41.42^{eA}	41.40^{eAB}	41.37^{gC}	41.39^{gBC}	41.40^{g}
1 h post-dusk	40.63^{gB}	40.65^{gAB}	40.63^{iB}	40.67^{iA}	40.64^{i}
SEM	0.006	0.006	0.006	0.006	0.005
Source of variation	-----------------------------------Probability------------------------------------				
Temperature	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Diurnal	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Diurnal*Temperature	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[A-D] Means within row with no common superscript are significantly different ($P\leq 0.05$)

[a-j] Means within column with no common superscript are significantly different ($P\leq 0.05$)

[1] Night= lights off time period (16:00 to 06:00; excluding 1 h post-dusk and 1 h pre-dawn); 1 h pre-dawn= one hour time period before lights on (at 07:00); Pre-feed= time period from lights on to feeding time; 0-1 h post-feed= first hour after feed; 1-2 h post-feed= second hour after feed; 2-3 h post feed= third hour after feed; 3-4 h post-feed= fourth hour after feed; >4 h post-feed= remainder of the lights on period following the fourth hour post-feed, excluding pre-dusk; 1 h pre-dusk= one hour time period before lights off; 1 h post-dusk= one hour time period after lights off (at 15:00).

Note: Normally, feeds were supplied to the birds at 07:30 and it little delayed at weighing days.

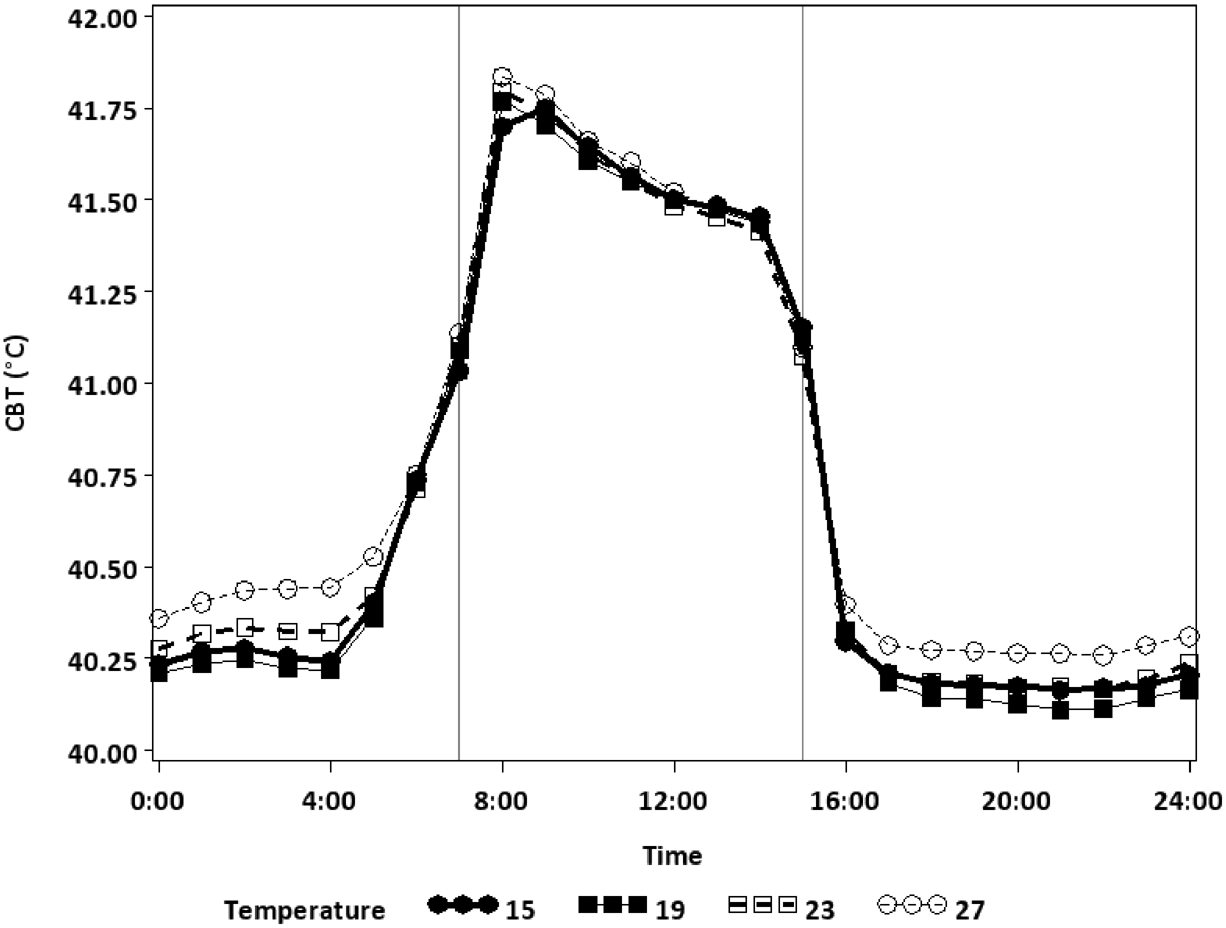

Figure 2.1 Diurnal core body temperature (CBT) pattern of broiler breeder pullets (13 to 20 wk) in 15, 19, 23 and 27˚C environmental temperature treatment. Vertical reference lines in the graph indicate lights on at 07:00 and lights off at 15:00

CHAPTER 3: IMPACT OF ENVIRONMENTAL TEMPERATURE AND DIETARY ENERGY ON CORE BODY TEMPERATURE AND REPRODUCTIVE PERFORMANCE OF BROILER BREEDER HENS

ABSTRACT: An experiment was conducted using 192 Ross 708 broiler breeder females from 25 to 41 wk of age to evaluate the effects of environmental temperatures and dietary ME levels on core body temperature (CBT) and reproductive performance. At 22 wk of age, pullets were randomly distributed among six climate-controlled environmental chambers (n=32/chamber) including 48 temperature sensor-implanted birds to measure the CBT. The experiment was a 4 x 2 factorial arrangement, with four environmental temperatures (15, 19, 23, and 27˚C) and two dietary ME levels (high: 2,912; or low: 2,786 kcal/kg). For every 2 wk period, environmental temperatures were randomly reassigned to the chambers with the constraint that each treatment was represented at least once per period and each chamber had equal exposure to each temperature treatment by the end of the experiment. The CBT dynamics, ADFI, ADG, feed efficiency, egg production, and egg weight were determined. The highest maximum, mean and minimum CBT occurred in the 27˚C treatment, followed by the 23˚C treatment, and then the 19 and 15˚C treatments, which did not differ. Dietary energy levels had a little effect on maximum, minimum, or mean CBT. A higher CBT range (1.88˚C) was recorded in the 15 and 19˚C than in the 23 and 27˚C (1.83˚C) treatments. The CBT increased gradually from 1 h pre-dawn and peaked at 1 h after feeding. After peaking, CBT decreased gradually for the rest of the day. The CBT quickly dropped in anticipation of the lights turning off and was lowest during the night. Average daily feed intake was higher at 15˚C than at 19 or 23˚C. Feed intake was 6% higher in the low energy treatment than in the high energy treatment, resulting in a higher intake of CP, which contributed to higher egg weight in the low energy treatment. Efficiency (Feed, ME or

CP) was lower in the low energy diet than in the high energy diet. Egg production was not affected by temperature or dietary energy treatments. In feed restricted broiler breeder hens, the feed allocation needs to increase with decreasing environmental temperature to maintain CBT and the target BW for maximizing reproductive output.

KEYWORDS: Environmental temperature, core body temperature, dietary energy, performance.

3.1. INTRODUCTION

Accurate feed allocation for broiler breeders to achieve target BW is a key to maximize reproductive output (Yu et al., 1992; Renema et al., 2007). Excess feed intake makes breeders obese resulting in multiple ovulations, deformed eggs, decreased egg production and increased irregular oviposition (Jaap and Muir, 1968; Renema and Robinson, 2004). Conversely, severe feed restriction made birds underweight, delayed sexual maturity and also decreased egg production (Hocking, 2004). Excessive or insufficient feed allocation results in sub-optimal production in broiler breeder hens.

Excess dietary protein must be deaminated prior to being used as an energy source and therefore the heat increment from dietary protein is greater compared to dietary fat or carbohydrates (Musharaf and Latshaw, 1999). Excess dietary protein may increase CBT and birds are unable to dissipate required heat to a hot environment. As a result, birds reduce feed intakes in warm environments (Mack et al., 2013), which is detrimental for production and product quality. Reducing the protein content in broiler diets may reduce heat production that helps to reduce heat stress-related mortality and increase performance, especially in hot environmental conditions (Furlan et al., 2004). However, Spratt and Leeson (1987) reported that high dietary protein contributed to increased egg production, egg weight, hatchability, and offspring performance in broiler breeders.

Homoeothermic animals maintain a relatively constant core body temperature (CBT) over a wide range of thermoneutral temperatures (Deeb and Cahaner, 1999; Lacey et al., 2000a). Birds' ability to maintain their CBT depends on the difference between the internally produced heat and the rate of heat dissipation to the environment. Romero et al. (2009) reported that in broiler breeder hens about 70% of ME intake was used for maintenance. The energy requirement for maintenance in birds increases with decreasing environmental temperature below the critical temperature approximately less than 16˚C because birds lose energy in the form of heat to the environment; they need more feed to increase the rate of metabolic heat production to maintain their CBT (National Research Council, 1981) and this increased feed intakes decrease efficiency. In addition, in colder weather, concentrations of Thyroxin (T_3) and active forms of uncoupling proteins (UCPs) in the blood increased, which increased heat production resulting in increased CBT in homoeothermic animals (Collin et al., 2005). When environmental temperature is above the upper critical temperature, the difference between the surface body temperature and the environmental temperature decreases, and birds are unable to dissipate adequate heat to the environment (National Research Council, 1981). As a result, CBT may increase. At the primary stage of the upper critical temperature, birds try to dissipate heat to the environment though evaporative cooling (Mack et al., 2013) to maintain a relatively constant CBT and thus they increase the energy requirement for maintenance. Wilson and Harms (1984) observed that such an increase in CBT reduced dependency on diet-induced metabolic heat production and birds reduce their feed intake. The reduced feed intake resulted in a decrease of available nutrients, which causes poor production and product quality (National Research Council, 1981).

In broiler breeders, feed allocation decisions need to be readjusted based on environmental temperature specially, at above the upper and below the lower critical environmental temperature to maintain a relatively constant CBT for maximizing reproductive output. Birds need more energy for maintenance in a colder environment than in a thermoneutral zone because they lose more heat (energy) to the environment (Geraert et al., 1988). The maintenance requirement is the first energy partitioning priority, which is to regulate the vital physiological functions including normal activities and thermoregulation (Reyes et al., 2011). Thereafter, the remaining energy is used for growth and production. Pishnamazi et al. (unpublished data) found a quadratic relationship of environmental temperature on maintenance energy requirements in feed restricted broiler breeder hens: the ME requirement for maintenance decreased with increasing temperatures from 15 to 24˚C, and increased above 24˚C. In broiler breeder hens, a large proportion of total ME intake is used for maintenance (more than 70%) and the remaining small proportion of ME intake is used for growth and production (Romero et al., 2009). The energy requirement for maintenance increases in colder environmental temperatures and that could seriously affect growth and production, especially when birds are feed restricted. Therefore, the feed allocation needs to be readjusted accurately with the change in environmental temperature to maintain CBT, the target BW and reproduction.

The objective of the current research was to investigate the effects of environmental temperatures and dietary energy on CBT, feed intake, egg production, egg weight, and efficiency of broiler breeder hens.

3.2. MATERIALS AND METHODS

3.2.1. Animal Care Approval

The chickens in this research project were managed according to the Guide to the Care and Use of Experimental Animals (Canadian Council on Animal Care, 1993). The experimental protocol was approved by the Animal Care and Use Committee for Livestock of the University of Alberta.

3.2.2. Experimental Design

A 4 x 2 factorial experiment was conducted using four temperature treatments and two dietary energy levels (low: 2,786 kcal/kg; and high: 2,912 kcal/kg) in wheat and soybean based diets (Appendix A). Both diets contained 15% CP and were provided in mash form from 21 to 41 wk. Four environmental temperature treatments (15, 19, 23, and 27˚C) were randomly assigned to 6 chambers for consecutive 2 wk periods from 25 to 41 wk of age. Each treatment was represented in at least one chamber per period, and over the entire experiment each chamber had equal exposure to all treatments. The individual hen was the experimental unit and age was used as a random effect.

3.2.3. Stocks and Management

A total of 192 Ross 708 (Aviagen Inc., Huntsville, AL) broiler breeders were selected randomly from a population of 800 birds, and housed in individual laying cages at 23 wk of age in six climate-controlled environmental chambers. Feed allocations were provided to achieve the standard BW target recommended by the primary breeder (Aviagen, 2007). Individual hen BW, egg production, egg weights and CBT data were collected from 25 to 41 wk to investigate production performance of broiler breeder hens under different temperature and dietary treatments. The photoperiod was 12L:12D at 21 wk, and it was increased by one additional h/wk to 16L:8D by 25 wk.

3.2.4 Core Body Temperature Sensors

A total of 48 hens with a surgically implanted telemetric core body temperature sensor in its right abdomen were equally distributed among the 6 chambers, with 16 on each experimental diet. A detailed surgical procedure for sensor implantation was described in Chapter 2.

3.2.5. Data Collection

Body weight data were recorded twice per week throughout the experiment using an electronic balance (BW-1050, Weltech Agri Data, Charlotte, NC). Average BW, feed intake and daily BW gain were recorded. Eggs were collected daily at 15:00, individually weighed and categorized as total, normal, abnormal or settable eggs. Abnormal eggs included membranous, soft shell, broken shells, and double yolked eggs. Total eggs was defined as all eggs including abnormal eggs; normal eggs included the total eggs minus abnormal eggs; and settable eggs were normal egg minus eggs that weighed less than 52 g. The incidence of broken eggs was recorded and missing egg weight values were replaced by an estimate of egg weight on an individual hen basis by fitting a nonlinear regression of egg weight as a function of the hen age (wk) in the form: $EggWt = a\text{-}be^{-c*age}$ Where a= weight asymptote; b and c were estimated coefficients. Egg mass (EM) was defined on a hen basis as the sum of all eggs weights per 2 wk period divided by the number of days in the period. Average egg weight was calculated per hen per period from 25 to 41 wk.

Forty eight temperature-humidity loggers with a resolution of 0.1˚C and an accuracy of ±0.06˚C (Microlog EC650, Fourier Systems, New Albany, IN) were equally distributed and uniformly placed on birds level in the six chambers and were used to log environmental temperature every half hour. Core body temperature measurements were recorded every 10 min**.** The first day of lay was recorded as the age of sexual maturity.

Average daily maximum CBT was the average of the highest daily body temperature of individual chickens. Daily mean CBT was the daily average of all recorded body temperatures of individual chickens. Average daily minimum CBT was the average daily lowest body temperature of individual chickens. Average daily range of CBT was the average of the difference between the daily maximum and minimum body temperatures of an individual chicken. The diurnal CBT pattern was classified as 1 h pre-dawn, pre-feed, 0-1 h post-feed, 1-2 h post-feed, 2-3 h post-feed, 3-4 h post-feed, >4 h post-feed, 1 h pre-dusk, 1 h post-dusk and night, and classified captions were described in detail in Chapter 2.

3.2.6. Statistical Analysis

The Mixed Procedure of SAS 9.2 (SAS Institute, Cary, NC) was used to analyze data and unless otherwise noted, differences between treatment means were at $P \leq 0.05$. Each individually caged bird was an experimental unit. Treatments (environmental temperature and dietary energy level) were considered fixed effects, while age was a random effect. LS-mean separation was conducted using Tukey's test.

3.3. RESULTS AND DISCUSSION

3.3.1. Body weights, sexual maturity and egg production

The average BW, age at sexual maturity and age at 52 g eggs were similar between high and low energy diets (Table 3.1). This was in agreement with Bennett and Leeson (1990) who reported that high (3081 kcal/kg) or low (2550 kcal/kg) energy diets did not affect age at sexual maturity in broiler breeder hens. First egg weight was also similar between the diets. This was expected according to the experimental design since birds were maintained on the target BW recommended by the primary breeder (Aviagen, 2007). Egg production (total, normal and settable) was similar among the temperature treatments (Table 3.2). However, total egg production was higher in the interaction of high energy diet and high environmental temperature (27˚C; Table 3.2) compared to any other interactions. Within the 27˚C temperature treatment, birds fed high energy diet had higher total egg production. There was no difference in total egg production in the low energy diet. However, in the high energy diet, birds in the 27˚C had greater total egg production than the 23˚C temperature treatment group. Normal egg production was 2.1 eggs higher in the high energy treatment group than in the low energy treatment group. Egg production was expected to be similar because individual hens were not allowed to acclimatize to temperature treatments, since the treatments rotated every 14 d. This prevented any confounding effects of body composition changes due to long-term exposure to specific temperatures, and is likely the reason we did not observe temperature treatment differences in egg production rates.

3.3.2. Feed intake, body weight gain, egg weight and feed efficiency

Feed intake was higher in the 15˚C treatment group than those of 19 and 23˚C treatment groups (Table 3.3). Presumably, birds dissipate more heat to lower environmental temperatures because the difference between the surface body temperature and environmental temperature increases (National Research Council, 1981). In this case, birds need more feed to increase the rate of metabolic heat production to maintain their CBT. Environmental temperature ranging from 15 to 27˚C in broiler breeder hens had a quadratic effect on feed intakes (Pishnamazi et al., unpublished data). However, feed intake was similar among the 19, 23 and 27˚C treatment groups. It means total heat production could be similar as well as heat retention within the range of 19 to 27˚C environmental temperature. Feed intake was also similar between the 15˚C and 27˚C temperature treatment groups. The ADG was higher in the 15 and 23˚C than the 19 and 27˚C treatment groups. This observation is consistent with the theory that birds in the 23˚C treatment had dissipated less body heat to the environment compared to the 19˚C treatment.

At 15˚C, presumably, birds raised feed intake to meet the maintenance requirement because they dissipate more heat to environment compared to other temperature treatments. De Andrade et al. (1977) reported that egg weight decreased by 8% when environmental temperature increased from 21 to 31˚C in full-fed laying hens due to decreased feed intake. In contrast, birds were not eating ad libitum in the current experiment. A precise feed allocation decision was made to maintain the target BW in broiler breeder hens within the range of environmental temperature from 15 to 27˚C and that similar BW of hens could be the possible reason to produce similar egg weight. Egg production and egg weights were similar regardless of temperature treatments. Environmental temperatures in broiler breeder hens within the range of 15 to 27˚C had no effect on feed, ME and CP efficiency, and egg weight.

Dietary energy levels were negatively correlated (R^2= -.69) with feed intake, as well as the indices of efficiency: ME, CP, and feed per gram of egg weight. The average daily feed intake was 6% higher in the low energy diet than in the high energy diet group. This higher amount of feed intake did not affect daily BW gain but it did result in higher egg weight in low energy birds. The low energy treatment decreased feed, ME and CP efficiency, and birds required a higher amount of feed (0.27 g), ME (0.26 kcal) and CP (0.03 g) for producing a one g of egg compared to the high energy treatment (Table 3.3).The low energy birds ate more. Presumably, they spent more energy to digest the higher amount of intake feed compared to high energy birds and the efficiency may decrease in the low energy birds.

In the current study, average daily feed intake was 135 g and 143 g in high (2,912 ME kcal/kg) and low (2,786 ME kcal/kg) energy treatments, respectively, which was equivalent to 393 kcal ME and 22 g CP and 398 kcal ME and 23 g CP per day in the high and low energy treatments, respectively. Spratt and Leeson (1987) reported that 385 kcal ME and 19 g CP were required by individually-caged broiler breeder hens for maintaining normal egg production. Average egg weight (58.0 g) was higher in the low energy diet group compared to the egg weight (57.3 g) in the high energy diet group. Presumably, higher amount of CP intake contributes a heavier egg in low energy diet group than high energy diet group. This was in agreement with Spratt and Leeson (1987) who suggested that egg weight increased in broiler breeder hens due to higher amount of protein intake per day.

In the current study, the feed cost for a broiler breeder hen from 25 to 41 wk of age increased by $0.14 per hen with decreasing environmental temperature from 27 to 15˚C assuming a feed cost of $380/T. However, feed costs did not decrease in the 23˚C but decreased by $0.04 per hen in the 19˚C treatment based on feed to egg mass ratio relative to the 27˚C treatment group.

3.3.3. Relationship between environmental temperature, dietary energy and CBT

Birds maintained a minimum CBT (39.77˚C) among treatments regardless of the environmental temperature to which they were exposed (Table 3.4). The daily average maximum, minimum and mean CBT was similar among the 15 and 19˚C treatments. The daily average maximum, minimum and mean CBT in broiler breeder hens increased significantly with each subsequent increase in environmental temperature from 19 to 27˚C (Table 3.4). Compared to the 19˚C treatment, the maximum CBT increased at 23 and 27˚C by 0.15 and 0.40˚C, respectively; mean CBT increased by 0.11 and 0.32˚C; and minimum CBT increased by 0.19 and 0.47˚C, respectively. The average range of CBT (1.88˚C) was higher in the lower environmental temperature (15 and 19˚C) compared to the higher environmental temperature (23 and 27˚C; 1.83˚C) but only in the low energy treatment. Presumably, birds maintained lower body temperature in the lower environmental temperature because they try to decrease the temperature difference between the body and the environment, to dissipate less heat to the environment, thus conserving heat in the body.

Overall, CBT were similar between the high and low energy treatments, suggesting that presumably, heat production was higher in the low energy treatment due to higher feed and protein intake (Musharaf and Latshaw, 1999). However, birds were likely able to cope with the change in heat production within the environmental temperature ranging from 15 to 27˚C. The daily average maximum, minimum and mean CBT were high in the 27˚C treatment group regardless of high and low energy diets. The current study revealed that the trend of increases in CBT was in a linear fashion with the increase of environmental temperatures ranging from 19 to 27˚C in feed restricted broiler breeder hens. Presumably, birds reduce heat dissipation with increasing environmental temperature from 19˚C onward. This was in agreement with Teeter et al. (1992), who reported that the CBT in broiler chickens increased linearly with increasing environmental temperature from 24 to 35˚C. The CBT increased linearly with increasing environmental temperature from 19 to 27˚C regardless of dietary energy in feed restricted broiler breeder hens.

3.3.4. Diurnal core body temperature pattern in broiler breeder hens

Overall, CBT increased by 0.15˚C suddenly in the pre-dawn period (one hour before lights on), because chickens woke up from sleep and were active (Cain and Wilson, 1974). The CBT increased by about 0.47˚C after lights on in the current study (Table 3.5). This was in agreement with Richards (1971), who reported that CBT in chickens rose by about 0.42˚C with a sudden response to visual stimuli of light in the morning. The CBT was highest during the first hour of feeding due to the higher rate of metabolism and heat increment increase due to the feeding activity (van Kampen, 1976; Cain and Wilson, 1974). Thereafter, the CBT gradually decreased over time, possibly because of a reduced rate of metabolism and lower activities (Kadono and Besch, 1978). The CBT decreased 1 h pre-dusk (one hour before lights off) and quickly dropped 1 h post-dusk (one hour after lights off), probably due to reduced locomotors activities. de Jong et al. (2002) also reported that the CBT of broiler breeder dropped suddenly after lights turned off. The CBT was higher in the day time because of diet-induced thermogenesis (Khalil et al., 2004), feeding related activities and behavioural activities (body shaking, head shaking, preening, cage pecking, beak wiping, crouching; de Jong et al., 2002). The CBT was lower at night time because of rest, sleep, minimal metabolic rate and a reduction in other physiological activities in the absence of light (Cain and Wilson, 1974; Khalil et al., 2004). In the current study, CBT was higher by 0.70˚C in the day than at night in feed restricted broiler breeder hens (Table 3.5). Similarly, Lacey et al., (2000b); Kadono and Besch, (1978); Cain and Wilson, (1974) reported that CBT was higher in day time than in night time in full-fed chickens. The CBT peaked in the first hour after feeding in feed-restricted broiler breeder hens.

Diurnal CBT patterns in broiler breeder hens were similar trend in different environmental temperatures (Figure 3.1). The difference in CBT between day and night increased linearly with decreasing environmental temperature from 27 to 15˚C. The CBT in the 0-1 h post-feed, 1-2 h post-feed, 2-3 h post-feed, 3-4 h post-feed, over 4 h post- feed, 1 h pre-dusk, 1 h pre-dawn, pre-feed, 1 h post-dusk, and night were higher in the 27˚C treatment group (Table 3.5). The CBT was highest in the 27˚C, intermediate in the 23˚C and lowest in the 19 and 15˚C temperature treatment (Table 3.4; Figure 3.1). Presumably, birds in the 27˚C treatment group dissipated less heat to the environment compared to other treatments. However, postprandial CBT was higher at 0-1 h post feed regardless of treatments but higher in 23 and 27˚C treatments. In the current study, average CBT was 41.08 and 40.15˚C in the day and the night time respectively. These results were in agreement with those of others researchers who found higher CBT in the day time compared to night time in full fed layer chickens (Fronda, 1921; Heywang, 1938; Winget et al., 1965). Similar diurnal CBT pattern in broiler breeder hens was recorded in day and night time between the high and low energy diets (Figure 3.2). However, the CBT in night time was higher in the low energy diet than in the high energy diet (Table 3.5). Possibly, birds conserved more body heat due to higher feed intake.

The present study indicated that the CBT peaked in the first hour after feeding, suggesting a strategy for feeding time. If birds will be fed in the warmer time of day, they might be unable to dissipate adequate heat to the environment leading less dependency on diet induced thermogenesis. As a consequence, birds may reduce feed intake, including other nutrients such as protein, amino acids, minerals and vitamins that will negatively affect the egg production and egg size (National Research Council.1981). Generally, in a hot summer, mid-morning to mid-afternoon is a warmer period of day. Shifting feeding time in the cooler period of day likes early-morning or late afternoon or a half meal in the early morning and a half meal in the late afternoon could be a better approach to avoid heat stress in the hot summer. Birds can take enough feed for requirement and thus, they sustain their production.

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Table 3.1 Impacts of dietary energy level on BW, age at sexual maturity, first egg weight, and age at 52 g egg weight in broiler breeder females.

Dietary ME (kcal/kg)	BW at sexual maturity (g)	Age at sexual maturity (d)	First egg weight (g)	BW at 52 g egg (g)	Age at 52 g eggs (d)
2,912	2,891	186.8	48.2	2,944	192.4
2,786	2,864	186.3	48.1	2,919	191.1
SEM	23.84	0.67	0.46	18.7	0.66
Probability	0.4351	0.6038	0.8573	0.3466	0.1475

Table 3.2 Impacts of environmental temperature and dietary energy level on total, normal and settable egg production in broiler breeder females from 25 to 41 wk of age.

Environmental temperature (˚C) Set	Actual ± SD	Dietary ME (kcal/kg)	Total Egg Production[1] (%)	Normal Egg Production (%)	Settable Egg Production[3] (%)
15	17.5 ± 1.3		76.1	75.5	68.2
19	20.4 ± 1.0		76.5	75.1	66.6
23	23.5 ± 0.8		75.0	73.1	66.4
27	27.3 ± 1.0		78.1	73.0	64.3
SEM			1.01	1.01	1.22
		2,912	77.3	75.3^{a}	66.6
		2,786	75.6	73.2^{b}	66.1
SEM			0.71	0.70	0.86
15		2,912	76.5^{ab}	76.1	68.7
19		2,912	77.8^{ab}	75.6	66.1
23		2,912	73.6^{b}	73.2	65.3
27		2,912	81.2^{a}	75.8	66.4
15		2,786	75.7^{ab}	74.9	67.7
19		2,786	75.2^{ab}	74.6	67.1
23		2,786	76.3^{ab}	73.0	67.4
27		2,786	75.0^{b}	70.1	62.2
SEM			1.73	1.43	1.72
Sources of variation		--------------------------------Probability--------------------------------			
Environmental temperature			0.1794	0.1564	0.1708
Dietary energy			0.0885	0.0446	0.6715
Interaction			0.0198	0.1905	0.2828

[a-b]Means within column and main effect with no common superscript are significantly different ($P < 0.05$)

[1]Total eggs= all eggs, including abnormal eggs

[2]Normal eggs= all eggs minus abnormal eggs

[3]Settable eggs= normal eggs < 52 g

Table 3.3 Impacts of environmental temperature and dietary energy level on average daily feed intake (ADFI), average daily gain (ADG), and feed efficiency in broiler breeder females from 25 to 41 wk of age.

Environmental temperature (˚C)		Dietary energy (ME, kcal/kg)	ADFI (g)	ADG (g)	Egg wt (g)	Feed:Egg[1] (g/g)	ME:Egg[2] (kcal/g)	CP:Egg[3] (g/g)
Set	Actual ± SD							
15	17.5 ± 1.3		141.87^{a}	7.73^{a}	57.74	3.23	9.20	0.53
19	20.4 ± 1.0		137.83^{b}	5.67^{b}	57.74	3.18	9.06	0.52
23	23.5 ± 0.8		137.82^{b}	8.48^{a}	57.59	3.16	9.00	0.51
27	27.3 ± 1.0		139.78^{ab}	6.03^{b}	57.51	3.16	8.99	0.51
SEM			0.73	0.45	0.12	0.04	0.12	0.01
		2,912	135.30^{b}	6.95	57.32^{b}	3.07^{b}	8.93^{b}	0.50^{b}
		2,786	143.35^{a}	7.01	57.97^{a}	3.30^{a}	9.19^{a}	0.53^{a}
SEM			0.52	0.32	0.12	0.03	0.09	0.01
Source of variation		--Probability--						
Environmental temperature			0.0001	<0.0001	0.1450	0.5919	0.5900	0.5900
Dietary energy			< 0.0001	0.8890	0.0002	<0.0001	0.0377	0.0002
Interaction			0.1304	0.9520	0.7696	0.6237	0.6259	0.6245

[a-b] Means within column and main effect with no common superscript are significantly different ($P < 0.05$)

[1] Feed:Egg (g/g) = ADFI divided average daily egg mass

[2] ME:Egg (kcal/g of egg) = average daily ME intake divided by average daily egg mass

[3] CP:Egg (g/g of egg) = average daily CP intake divided by average daily egg mass

Table 3.4 Effects of environmental temperature and dietary energy level on core body temperature (CBT) in broiler breeder hens from 25 to 41 wk of age.

Environmental temperature (˚C)	Dietary energy	Maximum	Mean	Minimum	Range
		CBT(C)			
15		41.65^{c}	40.54^{c}	39.77^{c}	1.89^{a}
19		41.66^{c}	40.54^{c}	39.78^{c}	1.87^{a}
23		41.81^{b}	40.65^{b}	39.97^{b}	1.84^{b}
27		42.06^{a}	40.86^{a}	40.25^{a}	1.81^{b}
SEM		0.02	0.02	0.03	0.03
	2,912	41.80	40.65	39.93	1.88
	2,786	41.78	40.65	39.96	1.83
SEM		0.03	0.04	0.05	0.04
15	2,912	41.61^{e}	40.53^{de}	39.73^{d}	1.88^{ab}
19	2,912	41.64^{de}	40.53^{de}	39.76^{d}	1.88^{ab}
23	2,912	41.84^{bc}	40.66^{bc}	39.96^{bc}	1.88^{ab}
27	2,912	42.12^{a}	40.87^{a}	40.24^{a}	1.88^{ab}
15	2,786	41.70^{ce}	40.56^{ce}	39.80^{cd}	1.90^{a}
19	2,786	41.67^{e}	40.54^{ce}	39.80^{cd}	1.87^{ab}
23	2,786	41.77^{bd}	40.65^{bd}	39.98^{b}	1.79^{b}
27	2,786	42.00^{a}	40.85^{a}	40.25^{a}	1.74^{b}
SEM		0.04	0.04	0.05	0.04
Source of variation		Probability			
Temperature		<.0001	<.0001	<.0001	<.0001
Dietary energy		0.6786	0.9150	0.6497	0.3560
Interaction		<.0001	0.0118	0.0388	<.0001

$^{a-d}$Means within column and main effect with no common superscript are significantly different ($P < 0.05$)

Maximum= daily highest CBT of individual hens

Mean= average of daily CBT of individual hens

Minimum= average of daily lowest CBT of individual hens

Range= average of daily range of difference between the highest and lowest in CBT of individual hens

Table 3.5 Effects of environmental temperature and dietary energy level on diurnal core body temperature (CBT) in broiler breeder hens from 25 to 41 wk of age.

Time of day[1]	Temperature (˚C)				Dietary energy[2]		Overall
	15	19	23	27	HE	LE	
	--------------------	--------------------	--------------------	CBT(˚C)	--------------------	--------------------	--------------------
Night	40.02^{iD}	40.07^{iC}	40.20^{hB}	40.36^{iA}	40.15^{hB}	40.18^{hA}	40.16^{i}
1h pre-dawn	40.19^{hD}	40.24^{hC}	40.37^{fB}	40.46^{gA}	40.30^{fB}	40.33^{fA}	40.31^{g}
Pre-feed	40.77^{eB}	40.75^{fC}	40.81^{dA}	40.81^{fA}	40.77^{dB}	40.80^{dA}	40.78^{e}
0-1 h post-feed	41.28^{aB}	41.26^{aB}	41.36^{aA}	41.37^{bA}	41.33^{aA}	41.30^{aB}	41.32^{a}
1-2 h post-feed	41.23^{bC}	41.21^{bC}	41.35^{aB}	41.43^{aA}	41.32^{aA}	41.29^{aB}	41.31^{b}
2-3 h post-feed	41.16^{cC}	41.12^{cD}	41.21^{bB}	41.32^{cA}	41.21^{b}	41.19^{b}	41.20^{c}
3-4 h post-feed	41.05d^{C}	41.03^{dD}	41.08^{cB}	41.20^{dA}	41.09^{c}	41.09^{c}	41.09^{d}
>4 h post-feed	40.72^{fC}	40.76^{eB}	40.77^{eB}	40.85^{eA}	40.76^{e}	40.79^{e}	40.77^{f}
1 h pre-dusk	40.22^{gD}	40.26^{gC}	40.29^{gB}	40.43^{hA}	40.29^{g}	40.31^{g}	40.30^{h}
1 h post-dusk	39.97^{jD}	40.05^{jC}	40.17^{iB}	40.34^{jA}	40.12^{iB}	40.15^{iA}	40.13^{j}
SEM	0.005	0.005	0.005	0.005	0.004	0.005	0.003
Source of variation	--------------------	--------------------	--------------------	Probability	--------------------	--------------------	--------------------
Time of day		<0.0001			<0.0001		<0.0001

$^{A-C}$Means across the row within each treatment with no common letters are significantly different at $P \leq 0.05$.

$^{a-j}$Means within column within each treatment with no common letters are significantly different at $P \leq 0.05$.

[1] Night= lights off time period (22:30 to 04:30; excluding post-dusk and pre-dawn); 1 h pre-dawn= one hour time period before lights on (at 05:30); Pre-feed= time period from lights on to feeding time; 0-1 h post-feed= first hour after feed, 1-2 h post-feed= second hour after feed, 2-3 h post feed= third hour after feed, 3-4 h post-feed= fourth hour after feed, >4 h post-feed= remainder of the lights on period following the fourth hour post-feed, excluding pre-dusk 1 h pre-dusk= one hour time period before lights off, 1 h post-dusk= one hour time period after lights off (at 21:30). Note: Normally, feeds were supplied to the birds at 07:30 and it little delayed at weighing days.

[2] HE= High energy: 2,912 kca/kg; LE= Low energy: 2,786 kcal/kg

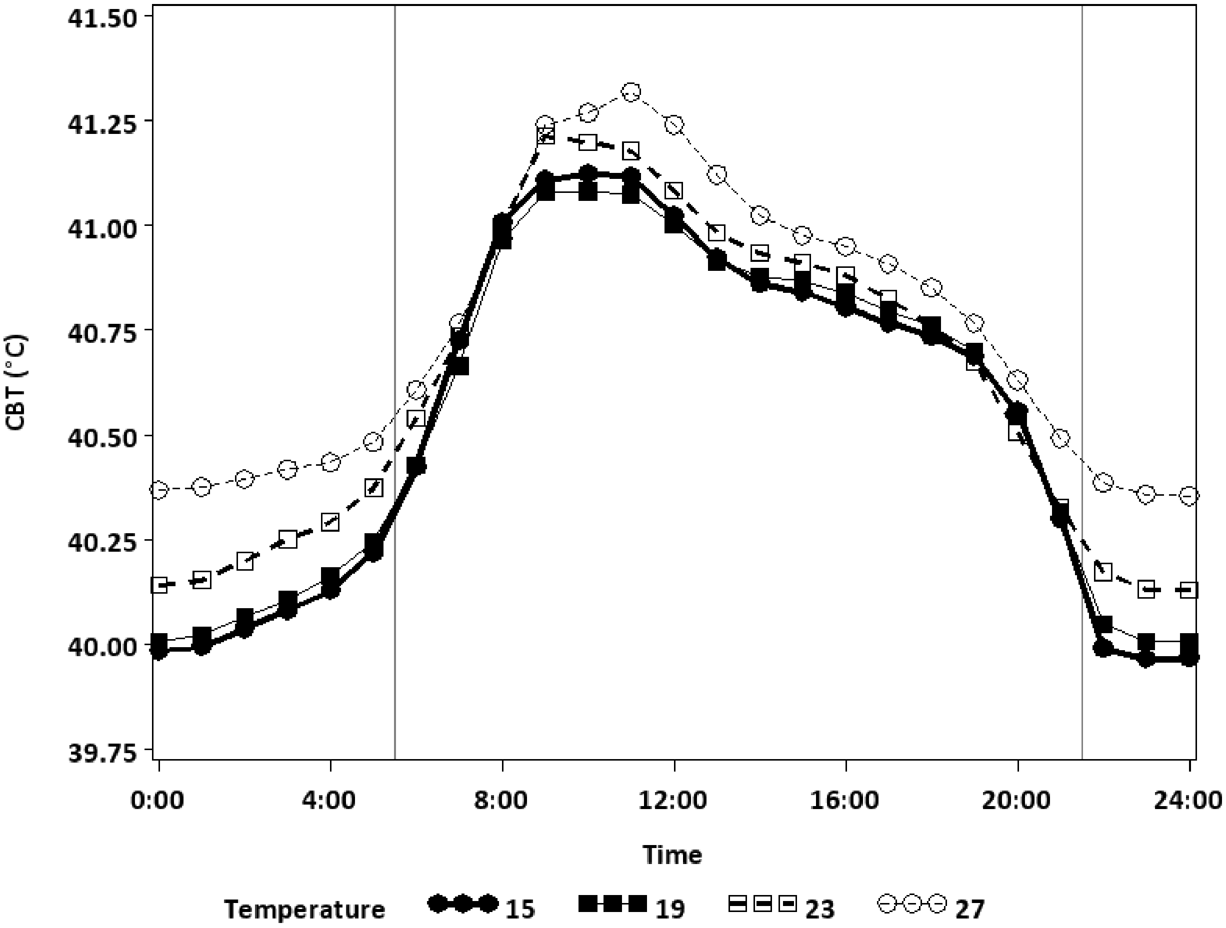

Figure 3.1 Diurnal core body temperature (CBT) pattern of broiler breeder hens (25 to 41 wk of age) in different environmental temperatures. Vertical reference lines in the graph indicate lights on at 05:30 and lights off at 21:30 (Y axis indicates CBT in degree Celsius and X axis indicates time in hour).

Night= lights off time period (22:30 to 04:30; excluding post-dusk and pre-dawn); 1 h pre-dawn= one hour time period before lights on (at 05:30); Pre-feed= time period from lights on to feeding time; 0-1 h post-feed= first hour after feed, 1-2 h post-feed= second hour after feed, 2-3 h post feed= third hour after feed, 3-4 h post-feed= fourth hour after feed, >4 h post-feed= remainder of the lights on period following the fourth hour post-feed, excluding pre-dusk 1 h pre-dusk= one hour time period before lights off, 1 h post-dusk= one hour time period after lights off (at 21:30).

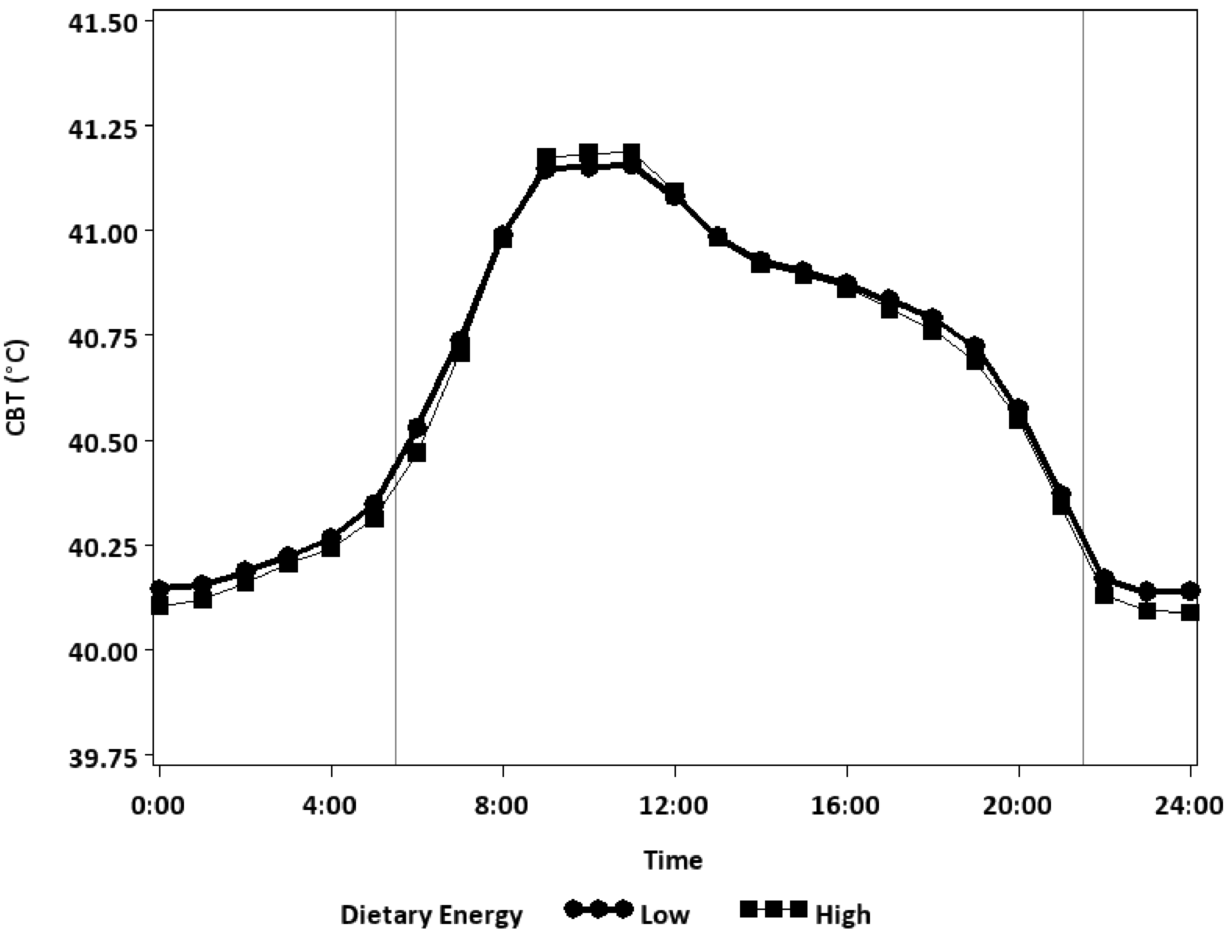

Figure 3.2 Diurnal core body temperature pattern (CBT) of broiler breeder hens (25 to 41 wk of age) in high and low dietary energy level. Vertical reference lines in the graph indicate lights on at 05:30 and lights off at 21:30 (Y axis indicates CBT in degree Celsius and X axis indicates time in hour).

Night= lights off time period (22:30 to 04:30; excluding post-dusk and pre-dawn); 1 h pre-dawn= one hour time period before lights on (at 05:30); Pre-feed= time period from lights on to feeding time; 0-1 h post-feed= first hour after feed, 1-2 h post-feed= second hour after feed, 2-3 h post feed= third hour after feed, 3-4 h post-feed= fourth hour after feed, >4 h post-feed= remainder of the lights on period following the fourth hour post-feed, excluding pre-dusk 1 h pre-dusk= one hour time period before lights off, 1 h post-dusk= one hour time period after lights off (at 21:30).

CHAPTER 4: IMPACT OF FEEDING TIMES, PHOTOPERIODS AND DIETARY ENERGY LEVELS ON CORE BODY TEMPERATURE AND OVIPOSITION IN BROILER BREEDER HENS

ABSTRACT: The effects of feeding time, photoperiod, and dietary energy level on core body temperature (CBT) and oviposition time were investigated using Ross 708 broiler breeder hens at 44 wk (7 d) of age. A total of 192 hens, including 48 CBT temperature sensor-implanted hens, were equally and randomly distributed over six climate-controlled environmental chambers (n=32/chamber). The experiment was a 4 x 2 x 2 factorial arrangement, with four feeding times (07:30; 11:30; 15:30; or split feeding: 07:30 and 15:30); two dietary ME levels (high, 2,912 or low, 2,786 kcal/kg) and two photoperiods (standard, 16L:8D or continuous, 24L:0D). Oviposition time was recorded at 10 min intervals using video cameras. Mean (39.73 ± 0.08˚C) and minimum (40.38 ± 0.05˚C) CBT was higher in the low energy fed chickens than in the high energy fed chickens. In general, CBT were low at night, and increased anticipatorily prior to the lights turning on. The CBT of breeder hens peaked within 2 h after feeding, after which CBT gradually decreased in anticipation of lights turning off. Diurnal CBT patterns were similar between the photoperiod treatments, but CBT of birds on the continuous photoperiod did not drop as much at night as birds on the standard photoperiod. Feeding time, dietary energy level and photoperiod had no influence on egg production and egg weight. Average daily feed intake was similar among feeding time and photoperiod treatments. Oviposition time was later in split fed hens than in morning fed hens. Dietary energy level and photoperiod did not

affect oviposition times. Shifting feeding time in the early morning or late afternoon especially colder part of day may be a strategy to mitigate heat stress.

Keywords: Feeding time, photoperiod, core body temperature dynamics, oviposition, broiler breeder hens

4.1. INTRODUCTION

Control of feed intake and lighting are important practices for optimizing broiler breeder management at the industry level (Renema and Robinson, 2004; Backhouse and Gous, 2005; Gibson et al., 2008; Romero et al., 2009). Feed is normally provided to birds once daily, in the morning. However, this practice does not supply nutrients at peak demand times that coincide with the timing of requirements for egg shell development, and may reduce shell quality (Bootwalla et al., 1983). Cave (1981) observed that feeding later in the day or splitting the single feed allocation across more frequent feeding throughout the day decreased weight gain and increased egg mass, suggesting that this strategy enhanced nutrient availability for egg production and regulated excessive body tissue deposition. Taherkhani et al. (2010) likewise reported that split feeding broiler breeder hens increased egg production. Moreover, Spradley et al. (2008) suggested that egg production was higher in split-fed broiler breeder hens than in one meal fed broiler breeder hens. Afternoon feeding in cage reared broiler breeder hens increased the shell quality of eggs (Backhouse and Gous, 2005). Harms (1991) reported that medium and light BW hens had increased egg weight and egg production when they were fed in the afternoon instead of morning. This finding was not supported by Brake (1988). It appears clear, meanwhile, that restricted-fed broiler breeders experienced hunger and frustration due to high motivation for feeding (Hocking et al., 1996; de Jong et al., 2002). Split feeding thus offers a potential method of reducing frustration and hunger because birds get feed two times a day, increasing the duration of nutrient metabolism. However, two time feedings may also increase labour costs and delay oviposition resulting in increased management hazard.

Feeding time may change the oviposition time, though the conclusions of researchers in this respect appear inconsistent. Wilson and Keeling (1991) and Backhouse and Gous (2005) reported that oviposition time was delayed due to feeding broiler breeder hens in the afternoon (16:00 to 18:00) due to late ovulation or prolonged egg formation time in the oviduct. Conversely, Samara et al. (1996) noted no difference in the oviposition time between morning- and afternoon-fed broiler breeder hens. Similarly, Lewis and Perry (1988) reported no difference in oviposition time between broiler breeder hens fed a single allocation of feed in the morning or half the daily feed allocation twice each day.

Photoperiod can also affect oviposition patterns. Oviposition time was delayed by 30 min per hour of photoperiod increase, with no difference after 14 h of photoperiod (Lewis et al., 2004). Full fed hens under 24L:0D photoperiod had a clear diurnal CBT rhythm. Presumably, the CBT increased due to feeding activity and feed metabolism. This was in agreement with Kadono et al. (1983). They reported that CBT in full fed layer chickens was higher during the waking phase (feeding and drinking time) than during the sleeping phase (decreased feeding and drinking time).

Environmental temperature can change feed intake, weight gain, egg production, egg quality, and CBT dynamics in chickens. Core body temperature patterns follow diurnal patterns, increased by photoperiod (Fronda, 1921; Heywang, 1938) and physiological events such as oviposition and ovulation (Winget et al. 1965). The CBT ranged from 39.0 to 41.2 ˚C in feed-restricted broiler breeder hens (Savory et al., 2006). The CBT was increased due to feeding activity and feed metabolism during the photoperiod and decreased following feed removal (Skinner-Noble and Teeter, 2003). Variation in core body temperature is likely an adaptation to regulate the rate of heat transfer from the body of chickens to their environment, and influences production efficiency (NRC, 1981). Previous studies (Chapter 2 and 3) suggest that the diurnal CBT pattern is mostly similar between pullets and hens under a standard photoperiod. The current experiment was designed to compare the diurnal CBT pattern between a standard and continuous photoperiod, between dietary energy levels, and to systematically determine whether feeding-related CBT dynamics could be detected by observing CBT patterns following feeding at different times in the day. Limited research exists comparing the combined effects of feeding time, photoperiod and dietary energy level on CBT dynamics and oviposition time in broiler breeder hens. This information can help us to understand the mechanisms of efficiency in response to management.

4.2. MATERIALS AND METHODS

4.2.1. Animal Care Approval

This research project was managed in compliance with the Guide to the Care and Use of Experimental Animals (Canadian Council on Animal Care, 1993) and the experimental protocol was approved by the Animal Care and Use Committee for Livestock of the University of Alberta.

4.2.2. Experimental Design

A 4 x 2 x 2 factorial experiment in a Completely Randomized Design was performed using four feeding times in which 100% of the daily feed allotment was provided at either 07:30, 11:30, or 15:30, or split, in which 50% of the daily feed allotment at both 07:30 and 15:30; two photoperiods (16L:8D and 24L:0D) and two dietary energy levels (2,912 kcal/kg and 2,786 kcal/kg; Appendix A).

4.2.3. Stocks and Management

At 44 wk (7 d; 308 to 316 d) of age, 192 Ross 708 broiler breeder hens (Aviagen Inc., Huntsville, AL) in individual laying cages in six climate-controlled environmental chambers were used for seven days. Photoperiod in 3 of the chambers was 24L:0D, and 16L:8D in the remaining 3 chambers. Half of the birds in each chamber were fed the high energy diet, and half the low energy diet. The feeding time treatments were applied to equal numbers of birds in all treatments in all chambers.

4.2.4 Surgical Implantation Temperature Sensors

A total of 64 broiler breeder females were implanted at 13 wk of age with temperature sensor transmitters in their right abdominal cavity. Details of the surgical procedures are provided in Chapter 2 of the current thesis. A total of 48 of these implanted hens were randomly and equally distributed among the treatments in the six environmental chambers in this experiment. Core body temperature measurements were recorded every 10 min**.**

4.2.5. Data Collection

Body weight of hen was recorded at the beginning and the end of the experiment and daily feed allocation was made according to the primary breeder's management guide line based on target BW and production rate. Eggs were collected daily at 15:00, and individually weighed using a digital balance. The average daily maximum, mean, minimum, and range of individual CBT were determined according to the procedure described in Chapter 2 of the current thesis. Temporal diurnal CBT categories were classified as; Night was defined as the time when lights were turned off at 21:30 only in 16L:8D treatment, excluding 1 h post-dusk and 1 h pre-dawn; 1 h pre-dawn was the one hour time period before lights on; pre-feed was the time period from lights turned on at 05:30 only in 16L:8D to feeding time; 0-1 h post-feed was the first hour after feeding; 1-2 h post-feed was the second hour after feeding; 2-3 h post feed was the third hour after feeding; >3 h post-feed was the remainder of time that the lights were on following the third hour post-feed, excluding pre-dusk; 1 h pre-dusk was the one hour time period before lights turned off; 1 h post-dusk was the one hour time period after lights were turned off. These categories were based on the lights turning on at 05:30 and off at 21:30 in both photoperiod treatments; this was an arbitrary classification for the 24L:0D treatment.

4.2.6. Webcam Video Camera

All hens were monitored by webcam for determination of oviposition time. Time-stamped images were taken at 10 min intervals for groups of 16 caged hens to determine oviposition time. Daily oviposition times for each hen were determined by video observation.

4.2.7. Statistical Analysis

The Mixed Procedure of SAS 9.2 (SAS Institute, Cary, NC) was used for analysis and treatment means were differentiated using Tukey's test with a critical value of $P \leq 0.05$. Feeding times, photoperiods and dietary energy levels were treated as main effects and age as a random effect. Each individually-caged bird was considered an experimental unit.

4.3. RESULTS AND DISCUSSION

4.3.1. Relationship of feeding time, photoperiods, dietary energy, and CBT

The maximum, mean and minimum CBT in broiler breeder hens were not different according to feeding time (Table 4.1). Mean and minimum CBT were higher in the low energy diet-fed broiler breeder hens than the high energy diet-fed broiler breeder hens. Possibly, heat increment increased due to a higher amount of total feed intake (and therefore protein intake), and protein metabolism (Musharaf and Latshaw, 1999). The high energy treatment had a greater range in CBT (1.87˚C) than that of the low energy treatment (1.57˚C). The intake of larger amount feed in low energy diet-fed birds might have produced more metabolic heat and required longer time for metabolism (Almirall and Steve-Garcia, 1994) and thus heat increment prolonged resulting in a narrow range of CBT.

Photoperiod treatment had no effect on the maximum, mean, and minimum CBT in broiler breeder hens. The 16L:8D photoperiod had a greater range in CBT (1.82˚C) than the continuous photoperiod (1.61˚C). This was likely due to decreased activity after lights were turned off at night (Khalil et al., 2004) in the 16L:8D treatment. However, CBT was higher likely due to increased activity level in the 24L:0D treatment against night period (from 21:30 to 05:30) in the 16:8D treatment.

4.3.2. Diurnal core body temperature pattern

Across treatments, CBT was lowest (39.97 ± 0.01°C) at night, increased in anticipation of the lights coming on (by 0.16˚C one hour before lights on) and peaked at 40.87˚C within 2 hours of feeding (Table 4.2). The CBT gradually decreased after 2 h of feeding, and dropped substantially before lights were turned off (1 h pre-dusk), dropping quickly to night time CBT in the hour after lights were turned off (Figure 4.1). The CBT peaked after feeding regardless of feeding time (Figure 4.1). The post-prandial CBT peak was likely due to heat increment related to feeding activity (Khalil et al., 2004), and feed metabolism and absorption (Wilson et al., 1989). Interestingly, van Kampen (1976) observed that heat production increased during eating by an average of 37% due to the physical activities related to eating. Core body temperature increased in the current experiment because the heat generated by the flurry of eating activity built up in the body, and took several hours to dissipate fully. The low CBT observed at night was likely due to reduced activity level after lights were turned off, although activity level was not measured in the current experiment. Lacey et al. (2000);

Khalil et al. (2004), and Savory et al. (2006) reported similar diurnal CBT patterns in broiler and broiler breeder chickens. However, CBT fluctuation was higher in broiler breeder chickens than in broilers due to feed restriction.

Night-time CBT were approximately 0.22°C lower in morning- and split-fed hens compared to noon- and afternoon-fed hens. The highest CBT was observed in the noon-fed treatment. This would suggest that noon feeding may cause heat stress in breeders in hot environment; in this condition, the temperature difference between birds and the environment decreases. Birds are unable to dissipate adequate amounts of heat to the environment and they reduce their dependency on diet-induced thermogenesis to maintain their CBT (Swennen et al., 2007) resulting in a decreased feed intake; decreased production and efficiency. Conversely, morning- and split-feeding may be an appropriate way for keeping CBT control because morning is cooler than noon of a day and split-feeding may produce comparatively less heat than one meal feeding. At cold environment like in the morning, birds can dissipate adequate amount of heat to the environment for energy balance in open housing management.

Day and night time CBT were 0.12˚C and 0.28˚C higher respectively in the low energy treatment than in the high energy treatment (Table 4.2; Figure 4.2). Feed intake was also higher in the low energy treatment (Table 4.3). The increase in CBT during day was likely due to a combination of increased feeding behaviour (van Kampen, 1976) and heat increment associated with digestion, absorption, and protein metabolism (Musharaf and Latshaw, 1999). Intakes of feed as well as protein and other nutrients were higher in the low energy group resulting in higher heat increment during metabolism compared to the high energy group. Presumably, the higher heat production resulting from the low energy diet may increase CBT in both day and night time period.

Interestingly, in spite of the absence of a day/night cue in the continuous photoperiod, the diurnal CBT pattern was similar to the 16L:8D photoperiod (Figure 4.3). The CBT likely decreased during resting and sleeping time in feed-restricted broiler breeders in the continuous photoperiod, this was in agreement with Kadono et al. (1981) who reported that CBT decreased during the sleeping phase in full-fed laying hens in the continuous photoperiod (24L:0D). Activity levels in breeder hens that could be stimulated by human activity, including feeding and egg collecting, which occurred during the day, but they were absent during the night. During the night (21:30 to 05:30), CBT was 0.20˚C higher in the continuous photoperiod group compared to the standard photoperiod group (Table 4.2). This difference may be due to a smaller drop in night-time activity levels in the continuous photoperiod than in the standard photoperiod. Birds used in the continuous photoperiod treatment group could have been influenced by the pre-established diurnal pattern, sleeping pattern and other activity of the standard photoperiod (Birds were reared under the standard photoperiod (16L:8D) before starting this experiment). In addition, similar morning feeding cycle, feeding related activity and feed metabolism resulted in a similar trend of diurnal CBT patterns in the standard and in the continuous photoperiod.

However, feed-associated increases in CBT were lower (approximately 0.1˚C) in the continuous photoperiod compared to the standard photoperiod

(Table 4.2), likely due to higher activity level increased CBT in standard photoperiod. In the standard photoperiod after lights were turned on, birds increased activity in addition to feeding activity and diet induced thermogenesis increased CBT, which was higher than the CBT in the continuous photoperiod.

4.3.3. Feeding times, photoperiods and dietary energy levels on egg production

Feeding times did not significantly affect average daily feed intake (P=0.0508), egg production, and egg weight (P=0.0860) in the feed restricted broiler breeder hens (Table 4.3). This was consistent with Backhouse and Gous (2005), who reported that feeding time had no effect on egg production and egg weight. However, Lewis and Perry (1988) and Wilson and Keeling (1991) suggested that egg production decreased with split feeding. In addition, de Avila et al. (2003) reported that feeding in the afternoon reduced egg production in chickens. Bootwalla et al. (1983) suggested that feeding times did not affect egg weight. Conversely, Farmer et al. (1983) observed that egg weight was higher with afternoon feeding than with morning feeding in caged broiler breeder hens. In afternoon feeding, birds may directly use feed energy for egg formation, whereas in morning feeding, birds store energy first and thereafter birds use stored energy for egg formation. Presumably, birds lose energy through this process. As a result, egg weight decreases in feed restricted broiler breeder hens.

In the current study, ADFI was 3.5 g higher in the low energy diet fed broiler breeder hens than in the high energy diet fed broiler breeder hens. Dietary energy had no effects on daily BW gain, egg production and egg weight (Table

4.3). Photoperiods did not affect ADFI, ADG, egg production, and egg weight in broiler breeder hens.

4.3.4. Feeding time, photoperiod and dietary energy level on oviposition time

Oviposition time in broiler breeder hens was similar across the morning, noon and afternoon feeding treatments. This was in agreement with the results of Samara et al. (1996). However, the morning feeding resulted in oviposition occurring over one hour earlier than split feeding. Several researchers have reported that split feeding delayed oviposition time in broiler breeder hens (Wilson and Keeling, 1991; Harms 1991; Samara et al., 1996; Backhouse and Gous, 2005). The reasons may be associated with the effects of feeding time on the timing of the open period for LH release (Backhouse and Gous, 2005). Birds may have rest after a second time feeding that may increase release of LH for ovulation within the open period and that may be the reason for the delay in oviposition time in split fed hens. In the current study, the continuous photoperiod delayed oviposition time (P = 0.0673; nearly significant) compared to the standard photoperiod. However, Lewis et al. (2004) observed that oviposition time was advanced in a shorter photoperiod.

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Table 4.1 Core body temperature (CBT) of broiler breeder hens (44 wk of age) fed two dietary energy levels at different times, and subjected to standard and continuous photoperiods.

Feeding time[1]	Dietary Energy[2]	Photoperiod[3]	Core body temperature (˚C)			
			Maximum	Minimum	Mean	Range
Morning			41.26	39.47	40.25	1.79
Noon			41.36	39.73	40.37	1.63
Split			41.27	39.41	40.24	1.86
Afternoon			41.34	39.74	40.35	1.60
SEM			0.07	0.11	0.07	0.10
	2,912		41.32	39.45^{b}	40.23^{b}	1.87^{a}
	2,786		41.30	39.73^{a}	40.38^{a}	1.57^{b}
SEM			0.05	0.08	0.05	0.07
		16L:8D	41.31	39.49	40.29	1.82^{a}
		24L:0D	41.30	39.69	40.32	1.61^{b}
SEM			0.05	0.08	0.05	0.07
Source of variation			--------------------Probability---------------------			
Feeding time			0.6765	0.0522	0.4166	0.2249
Dietary energy			0.7928	0.0110	0.0198	0.0042
Photoperiod			0.9093	0.0526	0.6981	0.0395
Feeding time* Dietary energy			0.2990	0.8075	0.2949	0.9864
Feeding time* Photoperiod			0.6880	0.3835	0.3609	0.5374
Dietary energy* Photoperiod			0.9379	0.2744	0.4369	0.2604
Feeding time* Dietary energy* Photoperiod			0.2823	0.3555	0.1963	0.6947

[a,b] Means within column with no common superscript are significantly different ($P \leq 0.05$),

[1] Morning feeding: birds fed entire daily feed allocation at 7:30; Noon feeding: birds fed entire daily feed allocation at 11:30; Split feeding: birds fed 50% daily feed allocation at 7:30 and 50% at 15:30; Afternoon feeding: birds fed entire daily feed allocation at 15:30.

[2] High energy= 2,912 kcal/kg; Low energy= 2,786 kcal/kg.

[3] 16L:8D=standard photoperiod; 24L:0D=continuous photoperiod.

Table 4.2 Diurnal core body temperature (CBT) patterns of broiler breeder hens (44 wk of age) fed two dietary energy levels at different times, and subjected to standard and continuous photoperiods.

Time of day[1]	Feeding time[2]				Photoperiod		Dietary energy level		Overall
	Morning (07:30)	Noon (11:30)	Afternoon (15:30)	Split (07:30 & 15:30)	Standard (16L:8D)	Continuous (24L:0D)	High (2,912 kcal/kg)	Low 2,786 kcal/kg	
	CBT (°C)								
Night	39.73^{fB}	39.94^{fA}	39.95^{hA}	39.70^{hB}	39.73^{hB}	39.93^{gA}	39.69^{gB}	39.97^{hA}	39.83^{h}
1 h pre-dawn	39.90^{eB}	40.10^{eA}	40.11^{fA}	39.84^{gB}	39.93^{gB}	40.05^{eA}	39.88^{fB}	40.09^{gA}	39.99^{g}
Pre-feed	40.18^{dB}	40.40^{dA}	40.45^{dA}	40.15^{eB}	40.34^{eA}	40.24^{dB}	40.21^{eB}	40.37^{eA}	40.29^{e}
0-1 h post-feed	40.74^{bB}	40.78^{bB}	40.93^{aA}	40.84^{aAB}	40.88^{bA}	40.78^{aB}	40.80^{b}	40.85^{b}	40.83^{b}
1-2 h post-feed	40.83^{aB}	40.98^{aA}	40.88^{bAB}	40.78^{bB}	40.93^{aA}	40.81^{aB}	40.84^{a}	40.90^{a}	40.87^{a}
2-3 h post-feed	40.78^{bB}	40.93^{aA}	40.65^{cBC}	40.59^{cC}	40.78^{c}	40.69^{b}	40.69^{cB}	40.79^{cA}	40.74^{c}
>3 h post-feed	40.47^{cB}	40.62^{cA}	40.36^{eB}	40.43^{dB}	40.50^{d}	40.44^{c}	40.37^{dB}	40.57^{dA}	40.47^{d}
1 h pre-dusk	39.96^{eB}	40.12^{eA}	40.12^{fA}	39.93^{fB}	40.01^{f}	40.05^{e}	39.92^{fB}	40.14^{fA}	40.03^{f}
1 h post-dusk	39.70^{fB}	39.98^{fA}	40.01^{gA}	39.66^{hB}	39.72^{hB}	39.96^{fA}	39.70^{gB}	39.97^{hA}	39.84^{h}
SEM	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.01
Source of variation	Probability								
Time of day	<0.0001				<0.0001		<0.0001		<0.0001

$^{A-C}$Means across rows within treatment with no common superscript are significantly different (P≤ 0.05).

$^{a-h}$Means within column with no common superscript are significantly different (P≤ 0.05).

[1] Night= time when lights were off (22:30 to 04:30: excluding post-dusk and pre-dawn); 1 h pre-dawn= one hour time period before lights on (at 05:30); Pre-feed= time period from lights on to feeding time; 0 to 1 h post-feed= first hour after feed; 1 to 2 h post-feed= second hour after feed; 2 to 3 h post feed= third hour after feed; >3 h post-feed= remainder of the light period following the third hour post-feeding; excluding pre-dusk; 1 h pre-dusk= one hour time period before lights off (at 21:30); 1 h post-dusk= first hour of darkness after lights off.

[2] Morning feeding: birds fed entire daily feed allocation at 07:30; Noon feeding: birds fed entire daily feed allocation at 11:30; Split feeding: birds fed 50% daily feed allocation at 07:30 and 50% at 15:30; Afternoon feeding: birds fed entire daily feed allocation at 15:30.

Table 4.3 Oviposition time and production performance of broiler breeder hens (44 wk of age) fed two dietary energy levels at different times, and subjected to standard and continuous photoperiods.

Feeding time[1]	Dietary energy[2]	Photoperiod[3]	ADFI (g/d)	ADG (g/d)	Egg production (%)	Egg wt (g)	Oviposition (h)
Morning			138.13	-16.51	69.79	64.36	10:55^{b}
Noon			138.13	1.99	69.79	63.52	11:32^{ab}
Split			137.98	-3.93	70.31	65.60	12:00^{a}
Afternoon			138.17	5.60	72.92	64.67	11:26^{ab}
SEM			0.70	5.98	3.47	0.77	0:15
	2,912		136.38^{b}	-8.97	70.31	64.20	11:29
	2,786		139.83^{a}	2.54	71.09	64.87	11:24
SEM			0.51	4.22	2.45	0.66	0:10
		16L:8D	137.46	-0.40	72.92	64.33	11:13
		24L:0D	138.75	-6.02	68.49	64.75	11:41
SEM			0.54	4.22	2.45	0.85	0:10
Source of variation			---------------------------------Probability--------------------------				
Feeding time			0.9973	0.0508	0.9058	0.0860	0.0405
Dietary energy			0.0001	0.3483	0.8220	0.2421	0.7436
Photoperiod			0.1611	0.0559	0.2035	0.7484	0.0673
Feeding time*Dietary energy			0.9973	0.2634	0.8532	0.5259	0.8164
Feeding time*Photoperiod			0.9983	0.6118	0.2302	0.5042	0.4210
Dietary energy*Photoperiod			0.7367	0.4338	0.7078	0.9994	0.4442
Feeding time*Dietary energy*Photoperiod			0.9983	0.5302	0.5826	0.3287	0.8154

^{a,b}Means within column with no common superscript are significantly different ($P \leq 0.05$),

[1] Morning feeding: birds fed entire daily feed allocation at 07:30; Noon feeding: birds fed entire daily feed allocation at 11:30; Split feeding: birds fed 50% daily feed allocation at 07:30 and 50% at 15:30; Afternoon feeding: birds fed entire daily feed allocation at 15:30.

[2] High energy= 2,912 kcal/kg; Low energy= 2,786 kcal/kg

[3] 16L:8D=standard photoperiod; 24L:0D=continuous photoperiod

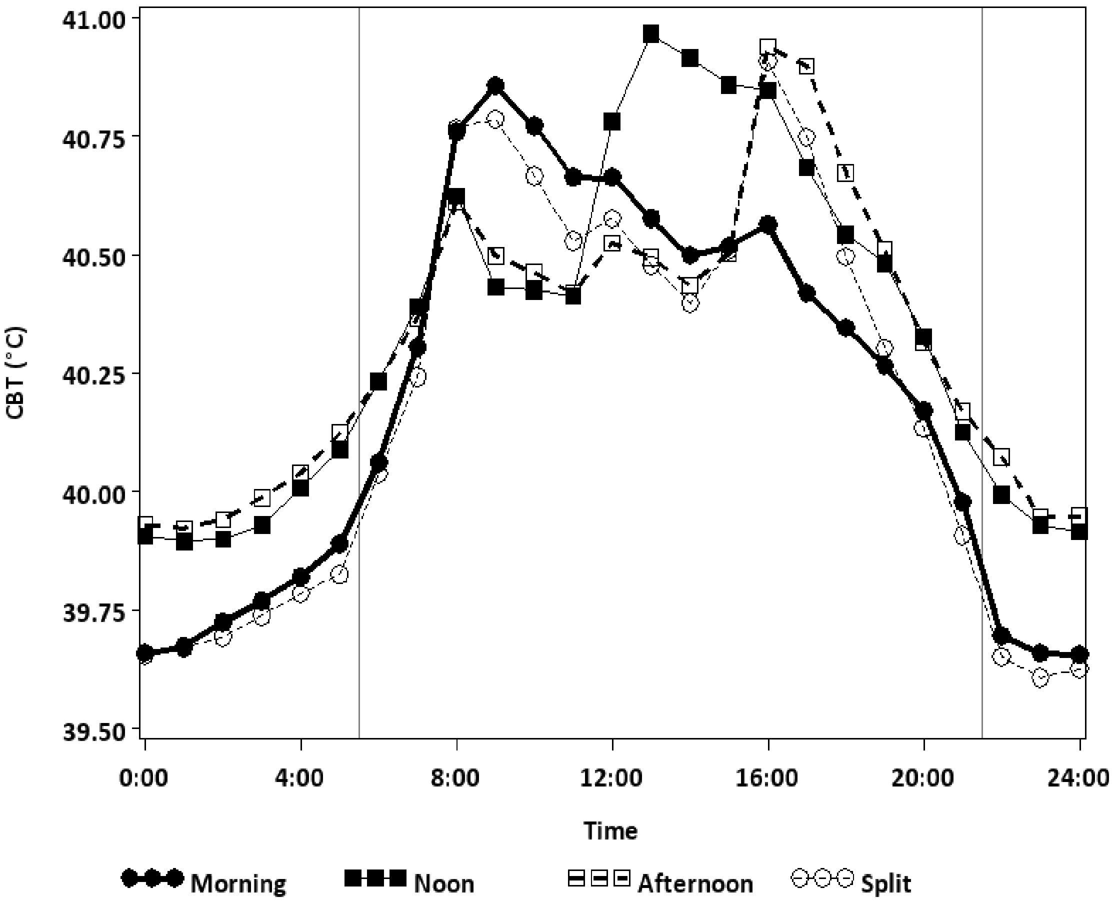

Figure 4.1 Diurnal core body temperature (CBT) patterns of broiler breeder hens (44 wk of age: 7 d) in different feeding times. Y axis indicates CBT in degree Celsius and X axis indicates time in hour.

Morning feeding: birds fed entire daily feed allocation at 07:30; Noon feeding: birds fed entire daily feed allocation at 11:30; Split feeding: birds fed 50% daily feed allocation at 07:30 and 50% at 15:30; Afternoon feeding: birds fed entire daily feed allocation at 15:30. Vertical reference lines in the graph indicate lights on at 05:30 and lights off at 21:30.

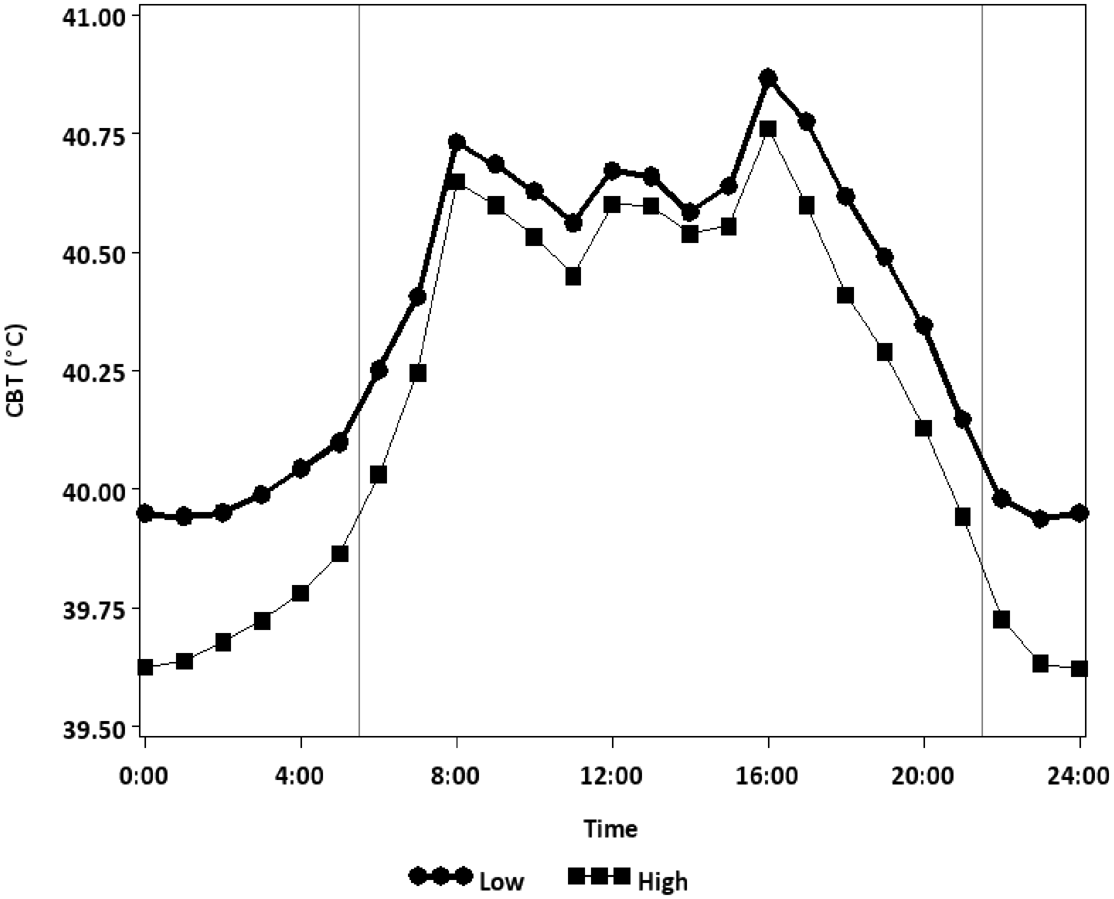

Figure 4.2 Diurnal core body temperature (CBT) patterns of broiler breeder hens (44 wk of age: 7 d) fed high and low energy diets. Y axis indicates CBT in degree Celsius and X axis indicates time in hour. Vertical reference lines in the graph indicate lights on at 05:30 and lights off at 21:30.

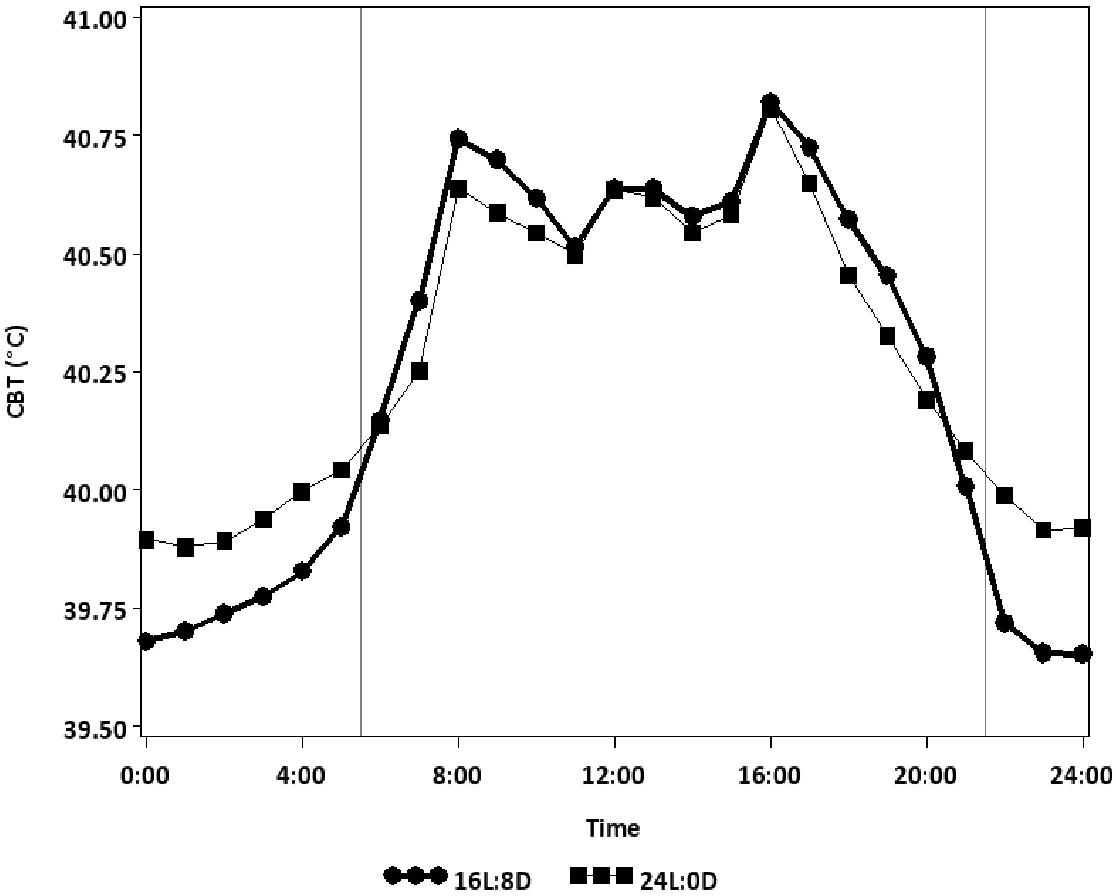

Figure 4.3 Diurnal core body temperature (CBT) patterns of broiler breeder hens (44 wk of age: 7 d) in standard (16L:8D) and continuous (24L:0D) photoperiods. Y axis indicates CBT in degree Celsius and X axis indicates time in hour. Vertical reference lines in the graph indicate lights on at 05:30 and lights off at 21:30.

CHAPTER 5: ENERGETIC EFFICIENCY, PRODUCTION PERFORMANCE AND CORE BODY TEMPERATURE DYNAMICS OF BROILER BREEDER HENS IN CAGE VERSUS FREE-RUN HOUSING SYSTEMS

ABSTRACT: A study was conducted using 172 Ross 708 broiler breeder hens from 25 to 41 wk of age to determine the ADFI, ADG, egg production, egg weight, feed efficiency, and core body temperature (**CBT**) dynamics in cage versus free-run housing systems. A total of 140 hens were randomly distributed among 4 free-run pens within two chambers (n=35 birds per pen). The remaining 32 birds were randomly allocated to individual cages in two chambers (n=16 birds per chamber). Twenty-four temperature sensor-implanted broiler breeder hens were equally distributed among six locations (two chambers and four pens), which transmitted CBT every 10 min. Birds were provided the same diet under a constant housing temperature (19˚C) and relative humidity (60%). Egg production did not differ between the cage and free-run housed broiler breeder hens. However, egg weight and daily feed intake was higher in free-run housed hens than in caged hens. The maximum and minimum CBT were also higher in the free-run hens. The highest diurnal CBT was recorded in the first hour after feeding, averaging 41.2˚C and 41.4˚C in caged and free-run hens, respectively. In free-run hens, CBT at night was 0.3˚C higher than in the caged hens. Free-run birds expended 17.2% more energy for maintenance than cage housed birds, translating into a 17.0% higher feed intake. The current study provides information about feed consumption and energy requirements that can contribute

to appropriate interpretation of cage based breeder nutrition research to free-run birds.

Keywords: Productive traits, energy requirement, diurnal CBT pattern, ADFI, housing systems, broiler breeders.

5.1. INTRODUCTION

Commercially, free-run housing systems are popular for broiler breeders because these systems allow chickens to mate naturally and reduce the cost of managing reproduction. Broiler breeder research is often done in cages. Application of cage housed broiler breeder research to commercial free-run housing, therefore, may not translate directly. In free-run housing, broiler breeders are feed restricted and usually feed is supplied daily in the morning. Competition for a limited amount of feed results in poor BW uniformity, contributing to poor production and egg quality (Petitte et al., 1982). In laying hens, cages facilitate even feed distribution, easier determination of sick chickens through individual observation, clean egg collection, less feed consumption and the maintenance of BW uniformity (Farooq et al., 2002).

Hatching egg weight is important because it increases subsequent broiler weight (Vieira and Moran, 1998). Many researchers (Petitte et al., 1982; Mohan et al., 1991; Anderson and Adams, 1994; Leyendecker et al., 2001) noted that egg weight was higher in cage housing systems than in free-run housing systems. In contrast to those studies, Tumova and Ebeid (2005); Singh et al. (2009) recorded higher egg weight with higher feed intake in free-run housed layer chickens than in caged layers. Other researchers (Basmacioglu and Ergul, 2005; Thomas and

Ravindran, 2005) reported that egg weight was not influenced by the housing system. The energy requirement for maintenance was higher in free-run hens than in caged hens, and therefore feed intake being higher in free-run systems, and CP being consumed at higher rates that may contribute to increase egg weight.

Fertility and hatchability are also indicators of breeder performance, and very important for sustainable production systems. Several researchers (Fuquay and Radden, 1980; Petitte et al., 1982; Petitte et al., 1983; Leeson and Summers, 1985) have reported inconsistent fertility and hatchability rates due to housing type. High rates of fertility and hatchability can be achieved in both systems, but good management practice for both natural mating and artificial insemination are important for success. In addition, efficient technical know-how of artificial insemination is an important for success.

The energy requirement for maintenance in birds is also an important difference related to housing systems for broiler breeders. Anderson and Adams (1994); Muthusamy and Viswanathan (1998); Farooq et al. (2002) reported that daily energy intake was 25 kcal/bird higher in full-fed, free-run commercial layers than in caged layers. In broiler breeders, Rabello et al. (2004) suggested that free-run hens required more energy, likely for increased activity level, than caged hens. A substantial amount of research has been conducted to investigate the effects of cage versus free-run housing systems on egg production, egg weight, and energy requirement of birds, but inconsistent conclusions were drawn. The CBT dynamics of feed restricted broiler breeder hens has not been studied in cage versus free-run housing systems, but could be a tool for better understanding of physiological or metabolic status of feed restricted broiler breeder hens.

The objective of the current study was to determine the effect of cage versus free-run housing systems on energy requirements, CBT dynamics, and production efficiency in broiler breeder hens.

5.2. MATERIALS AND METHODS

5.2.1. Animal Care and Approval

The current experiment was compliant with the Guide to the Care and Use of Experimental Animals (Canadian Council on Animal Care, 1993) and was approved by the Animal Care and Use Committee for Livestock of the University of Alberta.

5.2.2. Experimental Design

The effect of cage and free-run housing systems on average daily feed intake, egg production, egg weight, feed efficiency, energetic efficiency, and CBT dynamics in broiler breeder hens was examined using two treatments (caged and free-run) in a completely randomized design. For all variables except CBT where the experimental unit was the individual hen in all treatments, the experimental units were the individual hen in the cage housing system and the pen in the free-run housing system.

5.2.3. Stocks and Management

At hatch, a total of 800 Ross 708 pullets were individually identified by bar-coded neck tags (Heartland Animal Health, Fair Play, MO), weighed and randomly allocated to 1 of 8 environmental chambers. Each chamber was divided into four floor pens with 25 pullets per pen (5 pullets/m^2) in a climate controlled facility under recommended brooding temperature. At 7 d of age, each pullet was also tagged with matching bar coded wing bands on each wing. Feed was provided *ad libitum* for the first 14 d of age. From 15 d, pullets were feed restricted to maintain breeder recommended BW target (Aviagen, 2007). Pullets were reared in the pens until 20 wk of age. The photoperiod was 23L:1D for the first 3 d and 8L:16D from 4 d to 20 wk of age. The photoperiod was changed to 12L:12D at 21 wk, and the light was increased by one hour per week until 16L:8D at 25 wk of age. The light intensity was 60 lux. At 21 wk of age, 32 pullets were placed in individual laying cages (0.135 m^2/hen) in temperature-controlled environmental chambers, and 140 pullets were placed in 4 free-run pens within 2 chambers (35 hens/pen; 0.2025 m^2/hen). Environmental temperature and relative humidity in the chambers were set at 19˚C and 60 %, respectively, during the experimental period. Photoperiod was 16L:8D with lights on at 05:30. Water was supplied *ad libitum* using nipple drinkers. Feed was supplied to birds at 07:30 except weighing days. The time of feeding was recorded daily. Data loggers (Microlog EC650, Fourier Systems, New Albany, IN) were used to record actual room temperature at feeder height. Wheat-and soybean-based diets in mash form were given: Starter (2,900 kcal ME, 19% CP) from 0 to 2 wk; Grower (2,700 kcal ME, 15% CP) from 3 to 20 wk; Breeder (2,912 kcal ME, 16.4% CP) from 25 to 41 wk of age (Appendix A).

5.2.4 Surgical Implantation Temperature Sensors

At 13 wk of age, 24 birds had temperature telemetry devices surgically implanted into the abdominal cavity (see chapter 2 for details). The implants were approximately the size of an ‘AA’ battery. Implanted birds were randomly distributed among the four pens and two chambers (4 birds each).

5.2.5. Data Collection

Feed allocation, egg production, and egg weight were recorded from 25 to 41 wk of age. Individual (caged) or group (free-run) BW were recorded twice per week. Average daily gain (ADG) was calculated from the difference between initial and final BW for each weighing interval. The temperature sensors transmitted CBT of implanted birds at approximately 10 min intervals. Eggs were collected daily at 15:00, and weighed individually. The total eggs variable was defined as all eggs including broken, double yolk and deformed; normal eggs as total eggs minus broken, double yolked and deformed eggs; and settable eggs as normal eggs 52 g or greater in weight. Feed efficiency was measured based on the ratio of average daily feed intake per hen and average daily egg mass per hen (Flock, 1998). The following terminologies were used in this thesis: Maximum CBT was the average highest daily body temperature of individual hens. Mean CBT was the average daily body temperature of individual hens. Minimum CBT was the average daily lowest body temperature of individual hens. Range of CBT was the average difference between the daily highest and lowest body temperatures of an individual hen. Night was defined as the time period when lights turned off excluding post-dusk and pre-dawn (22:30 to 04:30), 1 h pre-dawn was the one hour time period before lights turned on; pre-feed was the time period from lights on to feeding time; 0-1 h post-feed was the first hour time period after feeding; 1-2 h post-feed was the second hour time period after feeding; 2-3 h post feed was the third hour time period after feeding; 3-4 h post-feed was the fourth hour time period after feeding; >4 h post-feed was the remainder of time period that the lights were on following the fourth hour post-feed, excluding pre-dusk; 1 h pre-dusk was the one hour time period before lights turned off; 1 h post-dusk was the one hour time period after lights were turned off.

5.2.6. Statistical Analysis

The Mixed procedure of SAS 9.2 (SAS Institute, Cary, NC) was used to compare the treatment means using Tukey's test with a significance level of $P \leq$ 05. Housing system was considered as a fixed effect within all dependable variables and date was used as a random effect. Nonlinear mixed procedure of SAS 9.2 was used to develop an energy partitioning (energetic efficiency) model for caged and free-run broiler breeder hens. The model was in the form of;

$$MEI = ((a+u) + c*Te)*BW^{0.35} + g*padg - (ng)*nadg + e*eggmass + \varepsilon,$$

Expected energy requirement for maintenance $(a + u)$; where $u \sim N(0,Vu)$ associated with each hen in cage and each pen in free-run housing system was estimated from 25 to 41 wk of age using a mixed nonlinear model, Te = environmental temperature; padg= positive average daily gain; nadg= negative average daily gain; eggmass= average daily eggmass; ε= error.

5.3. RESULTS AND DISCUSSION

5.3.1. Feed Efficiency

Average daily feed intake and ADG were higher in free-run housed broiler breeder hens compared to caged hens (Table 5.1). This was in agreement with Farooq et al. (2002) who reported that feed intake was higher in full-fed layers in a free-run system than caged hens. The higher feed intake in free-run housed broiler breeder hens did not affect egg production (Table 5.2). The higher feed intake might be due to increased activity level of hens in the spacious free-run housing system compared to caged hens (Rabello et al 2004). Egg weight was heavier in free-run hens than in caged hens, higher intake of feed as well as CP may have contributed to increased egg weight in free-run hens (Singh et al., 2009). Feed, ME, and CP efficiency decreased in free-run hens compared to caged hens. Possibly because free-run hens required higher energy for higher activity level in large floor area compared to caged hens. Farooq et al. (2002) reported that feed efficiency increased as egg production was higher with lower feed intake in caged hens than in free-run hens. The ADFI increased by 17% in free-run hens compared to caged hens in maintaining target BW. Some of this feed contributed to higher ADG, but most was used to fuel activity.

5.3.2. Egg Production in Cage versus Free-run Housing Systems

Total, normal and settable egg production was similar between cage and free-run housed broiler breeder hens (Table 5.2). This was in agreement with Petitte et al. (1982); Roll et al. (2009), who also reported a similar egg production in cage and free-run housed commercial hens. However, Anderson and Adams

(1994) stated that the normal egg production was higher in caged hens compared to free-run housed broiler breeder hens. In commercial layers, Yousaf and Ahmed (2006) also reported higher egg production in caged hens compared to free-run hens. Good management systems were provided to both caged and free-run hens. There is no biological reason that housing types (cage vs free-run) should influence egg production.

Egg weight was higher in free-run hens than in caged hens (Table 5.1). This result was in agreement with Petitte et al. (1982); Anderson and Adams (1994); Pistekova et al. (2006), who reported that egg weight was heavier in free-run housed layer chickens compared to caged layer chickens. Conversely, Yakubu et al. (2007) reported that egg weight was higher in caged hens than in free-run hens. Several researchers (Basmacioglu and Ergul, 2005; Yousaf and Ahmed, 2006; Thomas and Ravindran, 2005; Zemkova et al., 2007; Roll et al., 2009) indicated that the housing system did not affect egg weight in layer chickens. In the current study, BW of broiler breeder hens was higher in free-run hens than caged hens. In addition, ADFI as well as other nutrients intake including CP was higher in free-run hens than in caged hens and those excess nutrients may contribute to heavier eggs. This was in agreement with the result of Halaj et al. (1998); Basmacioglu and Ergul (2005), who reported that egg weight was influenced by nutrition and age.

5.3.3. CBT of Broiler Breeder Hens in Different Housing Systems

The daily average maximum and minimum CBT were higher in free-run broiler breeder hens than in caged hens (Table 5.3), which might be increased by higher daily feed intake (feed metabolism) and possibly, due to increased activity level. The mean CBT and the range of CBT were similar in both cage and free-run housed broiler breeder hens. The range of CBT in caged and free-run broiler breeder hens was from 39.8 to 41.6˚C and 40.0 to 41.8˚C respectively. Similarly, Savory et al. (2006) reported that CBT in broiler breeder hens ranged from 39.6 to 41.2˚C. However, Deeb and Cahaner (1999) reported the CBT ranged from 40.4 to 41.6˚C in full fed chickens. In the current study, the result may indicate that heat increment in broiler breeder hens did not differ in various housing systems to maintain a relatively constant CBT. However, when the temperature difference between the surface body and the environment increases, birds dissipate heat to the environment and they require more feed to increase the rate of metabolic heat production to maintain CBT (National Research Council, 1981).

5.3.4. Diurnal CBT Patterns

Diurnal CBT patterns were closely related between caged and free-run hens. The CBT increased by 0.2˚C one hour before lights on and it continued increasing after lights on until 1-2 h post-feeding time (Table 5.4). This increased CBT may be associated with the increased activity level 1 h prior to lights on possibly due to biological response of birds and after lights turned on, birds' response to sudden visual and auditory stimuli of lights on and sounds by attendants respectively (Richards, 1971). This was in agreement with the results of Lacey et al. (2000), who reported CBT increased before lights on, rising till noon in full fed birds. Moreover, Kadono and Besch (1978) reported that CBT started to increase 2 to 4 h before lights on in full fed chickens. The highest diurnal CBT was recorded at the 0-1 h post-feed (one hour after feeding) followed by 1-2 h post-feed, 2-3 h post-feed, 3-4 h post-feed, > 4 h post-feed, pre-feed, 1 h pre-dusk,1 h pre-dawn, night and 1 h post-dusk of day (Table 5.4). The overall highest CBT (41.3˚C) was recorded at the feeding time (0-1 h post feed) and the lowest CBT (40.1˚C) was at the 1 h post-dusk (Table 5.4). In the current study, the CBT increased at the day time due to light, activity and feed metabolism (Khalil et al., 2004). The CBT gradually decreased in both caged and free-run broiler breeder hens from 1-2 h post-feed until lights off. Presumably, it may be due to reduced rate of metabolic heat production. Kadono and Besch (1978) suggested that CBT decreased 2 to 4 h before lights off in full-fed chickens. The CBT dropped quickly after lights turned off, possibly due to sharply reduced activity level (Cain and Wilson, 1974; Khalil et al., 2004). The diurnal CBT was higher in the day time period than in the night time period in both caged and free-run broiler breeder hens. These results were supported by several researchers (Lacey et al., 2000; Fronda, 1921; Heywang, 1938; Winget et al. 1965); they reported that CBT was higher at day time periods than at night time periods. In the current study, the peak CBT of broiler breeder hens during 0-1 h post-feed (feeding time) may be the combined effects of nutrients metabolism and feeding activity. Therefore, feed intake and activity levels played a major role for diurnal CBT dynamics in broiler breeder hens.

The diurnal CBT was higher at night, 1 h pre-dawn, 0-1 h post-feed, 1-2 h post-feed, 1 h pre-dusk, and 1 h post-dusk in free-run hens compared to caged hens (Table 5.4). In the current study, CBT patterns were similar between cage and free-run housed broiler breeder hens. However, the diurnal CBT was very close between free-run and caged hens during the day time period, and CBT was higher during night time period in free-run hens than in caged hens (Figure 5.1). It may be due to extra activity of broiler breeder hens at night in the free-run housing system. This activity possibly increases the rate of basal metabolism resulting in higher heat increment in the body (Boshouwers and Nicaise, 1985) Free-run hens also increased insulation by sleeping together on the floor resulting in reduced heat dissipation to the environment. However, caged birds may lose more heat through convection (air flow surrounding the bird) and conduction (birds contact with metal wires of the cage), and that could be the reason of lower CBT at night.

5.3.5. Energetic Efficiency

The energy requirement for maintenance was determined for caged and free-run broiler breeder hens. Body weights of broiler breeder hens were higher in free-run hens than in caged hens (Table 5.1). The mean residual feed intake (RFI) did not differ between cage and free-run broiler breeder hens (Table 5.5). Swennen et al. (2007) suggested that a high RFI indicated less efficient resulting in a higher feed intake in cockrels and a greater postprandial thermogenesis. The RME_m was higher in the free-run hens compared to cage hens. This result demonstrates that broiler breeder hens in the free-run housing system were less efficient than in cage housing system. The concept of RME_m was defined as the residual of estimated maintenance requirement, and RFI as the residual of predicted feed intake (Romero et al., 2009). In the current study, the energy requirement for maintenance in free-run housed broiler breeder hens was 17.2% ($kgBW^{0.35}$) higher than in cage housed broiler breeder hens (Table 5.5). This higher energy expenditure was possibly due to extra activitiy level in the large floor area in the free-run housing system. This was in agreement with Rabello et al. (2004), who reported that the requirement for ME_m was 21.8 % higher in free-run hens compared to caged breeder hens. BW of broiler breeder hens was slightly higher in free-run hens compared to caged hens. However, in the current study, free-run broiler breeder hens were less efficient than caged hens, possibly free-run hens expended more energy for activity level.

A similar range of CBT in both cage and free-run housing system may indicate that broiler breeder hens were energy balanced (total heat production=total heat loss) in either cage or free-run housing systems. In addition, diurnal CBT pattern was closely related in both the cage and the free-run housed broiler breeder hens. The ADFI and the ME_m was 17.0 % and 17.2 % higher in free-run housed broiler breeder hens compared to cage housed broiler breeder hens due to higher activity levels in spacious free-run housing systems. Egg production was similar in both the cage and the free-run housing system. Heavier egg weight and lower feed efficiency was observed in free-run hens compared to caged hens. Birds raised in cages were more efficient than free-run hens. Feed allocation decision needs to be readjusted, when cage research data is applied to commercial free run housing systems.

5.5. REFERENCES

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Table 5.1 Body weight, average daily feed intake, average daily gain and feed efficiency of broiler breeders (25 to 41 wk) in cage and free-run housing systems.

Housing system	Body weight (kg)	Average daily feed intake (g)	Average daily gain (g)	Average egg weight (g)	Feed:Egg (g/g)	ME:Egg (kcal/g)	CP:Egg (g/g)
Cage	3.31^{b}	133.42^{b}	5.68^{b}	57.38^{b}	3.05^{b}	8.89^{b}	0.50^{b}
Free-run	3.37^{a}	156.06^{a}	9.71^{a}	59.00^{a}	3.77^{a}	10.98^{a}	0.62^{a}
SEM	0.07	1.75	1.28	0.53	0.13	0.38	0.02
Probability	0.0029	<.0001	0.0316	0.0275	0.0047	0.0047	0.0047

$^{a-b}$Means within column with no common letters are significantly different ($P \leq 0.05$)

Feed:Egg (g/g) = average daily feed intake divided average daily egg mass

ME:Egg (kcal/g of egg) = average daily ME intake divided by average daily egg mass

CP:Egg (g/g of egg) = average daily CP intake divided by average daily egg mass

Table 5.2 Egg production and egg weight of broiler breeders (25 to 41 wk) in cage and free-run housing systems.

Housing system	Total egg production (%)	Normal egg production (%)	Settable production (%)
Cage	76.38	73.34	67.22
Free-run	69.50	69.20	66.65
SEM	2.91	2.75	4.56
Probability	0.1071	0.1564	0.7228

$^{a-b}$Means within column with no common letters are significantly different ($P\leq 0.05$)
Total egg production = all eggs including abnormal eggs
Normal egg production = total eggs minus abnormal eggs
Settable eggs = normal eggs minus <52g eggs

Table 5.3 Core body temperature (CBT) of broiler breeders (21 to 41 wk) in cage and free-run housing systems.

Housing system	Maximum	Mean	Minimum	Range
	CBT (˚C)			
Cage	41.64^{b}	40.54	39.77^{b}	1.87
Free-run	41.82^{a}	40.62	39.99^{a}	1.83
SEM	0.04	0.04	0.06	0.05
Probability	0.0009	0.1256	0.0096	0.6522

$^{a-b}$Means within column with no common letters are significantly different ($P \leq 0.05$)
Maximum= daily highest CBT of individual hens
Mean= average of daily CBT of individual hens
Minimum= average of daily lowest CBT of individual hens
Range= average of daily range of difference between the highest and lowest CBT of individual hens

Table 5.4 Diurnal core body temperature (CBT) rhythm of broiler breeders (25 to 41 wk) in cage and free-run housing systems.

Time of day[1]	Treatment		Overall
	Cage	Free-run	
	-------------------------------CBT(˚C)------------------------------------		
Night	40.00^{iB}	40.30^{hA}	40.15^{i}
1 h pre-dawn	40.17^{hB}	40.44^{gA}	40.30^{g}
Pre-feed	40.68^{f}	40.71^{f}	40.69^{f}
0-1 h post-feed	41.20^{aB}	41.35^{aA}	41.28^{a}
1-2 h post-feed	41.18^{bB}	41.24^{bA}	41.21^{b}
2-3 h post-feed	41.09^{c}	41.08^{c}	41.09^{c}
3-4 h post-feed	41.00^{d}	41.00^{d}	41.00^{d}
>4 h post-feed	40.71^{e}	40.71^{e}	40.71^{e}
1 h pre-dusk	40.21^{gB}	40.27^{iA}	40.24^{h}
1 h post-dusk	39.97^{jB}	40.22^{jA}	40.10^{j}
SEM	0.008	0.006	0.005
Probability	<0.0001	<0.0001	<0.0001

$^{A-B}$Means across rows with no common letters are significantly different ($P \leq 0.05$).

$^{a-j}$Means within column with no common letters are significantly different ($P \leq 0.05$)

[1] Night= lights off time period (22:30 to 4:30; excluding post-dusk and pre-dawn); 1 h pre-dawn= one hour time period before lights on (at 05:30); Pre-feed= time period from lights on to feeding time; 0-1 h post-feed= first hour after feed, 1-2 h post-feed= second hour after feed, 2-3 h post feed= third hour after feed, 3-4 h post-feed= fourth hour after feed, >4 h post-feed= remainder of the lights on period following the fourth hour post-feed, excluding pre-dusk 1 h pre-dusk= one hour time period before lights off, 1 h post-dusk= one hour time period after lights off (at 21:30).

Table 5.5 Energetic efficiency and the energy requirement for maintenance of broiler breeders (25 to 41 wk) in cage and free-run housing systems.

Housing system	RFI[1]	RME$_m$[2]	ME$_m$[3]
	Kcal of ME/d	-------------kcal of ME/kg$^{0.35}$	----------------
Cage	-8.94	-1.29^{b}	234.65^{b}
Free-run	1.35	32.14^{a}	274.93^{a}
SEM	7.80	2.48	1.59
Probability	0.3796	<0.0001	<0.0001

[a-b] Means within column with no common letters are significant different ($P \leq 0.05$)

[1] Residual feed intake (RFI) was refered to the diffrence between observed and predicted ME intake. The predicted MEI was calculated for each hen in cage and each pen in free-run housing system from 25 to 41 wk of age using the mixed nonlinear model: $MEI = ((a+u) + c*Te)*BW^{0.35} + g*padg – (ng)*nadg + e*eggmass + Ɛ$, Te = environmental temperature; padg= positive average daily gain; nadg= negative average daily gain; eggmass= average daily eggmass; Ɛ= error.

[2] Residual maintenance requirement (RME$_m$). Residual of the regression between ME$_m$ and MEI for each hen in cage and each pen in free-run housing system: $MEI_m = 218.31 + 0.06*MEI + Ɛ$;

[3] ME$_m$ = predicted maintenance requirement (kcal/kg BW$^{0.35}$); MEI = average ME intake (kcal/d) from 25 to 41 wk of age. Expected maintenance requirement (a + u); where u~N(0,Vu) associated with each hen in cage and each pen in free-run housing system was estimated from 25 to 41 wk of age using a mixed nonlinear model, which is defined in the first footnote.

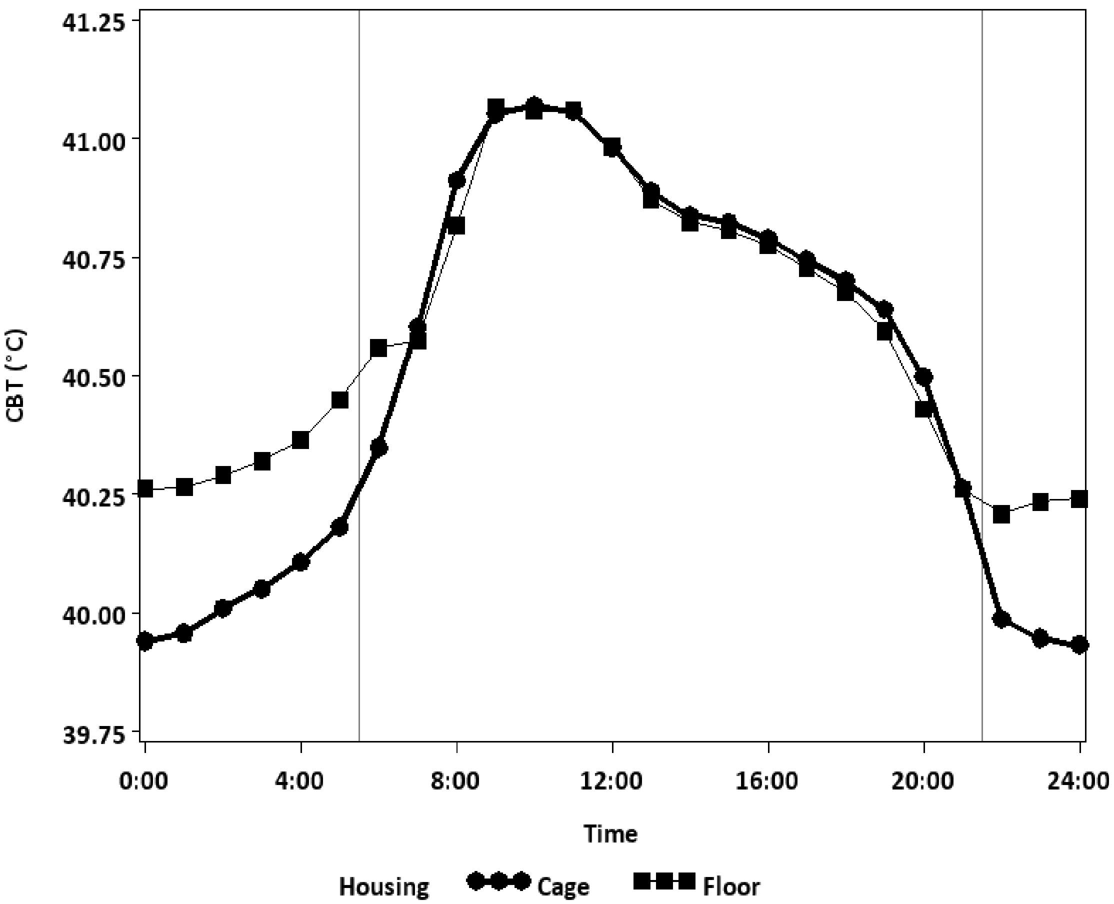

Figure 5.1 Diurnal core body temperature pattern of broiler breeder hens (25 to 41 wk) in cage and free-run housing system. Y axis indicates CBT in degree Celsius and X axis indicates time in hour. Vertical reference lines in the graph indicate lights on at 05:30 and lights off at 21:30.

CHAPTER 6: CORE BODY TEMPERATURE DYNAMICS: IMPLICATIONS FOR BROILER BREEDER PRODUCTION

6.1. INTRODUCTION

Chickens are homoeothermic animals that maintain a relatively narrow range of core body temperature (**CBT**) from 40.6 to 41.4˚C (Deeb and Cahaner, 1999). However, feed-restricted broiler breeders exhibited a range in CBT from 39.6 to 41.2˚C (Savory et al. 2006). They are capable of maintaining an energy balance between heat production and heat loss to keep a relatively constant CBT in thermoneutral conditions (18 to 27˚C; National Research Council, 1981).

When birds are housed in a cold environment (below the lower critical temperature) and the difference between the surface body temperature and the environmental temperature increases; birds lose an increasing amount of body heat to the environment. They need more feed to increase the rate of metabolic heat production to maintain their CBT. In contrast, when birds are housed in a hot environment (above the upper critical temperature), the difference between the surface body temperature and the environmental temperature decreases; they are unable to dissipate adequate body heat to the environment. Above the upper critical temperature, birds try to dissipate body heat (energy) to the environment through evaporative cooling to maintain their CBT (Richards, 1971; National Research Council, 1981). Thus, the bird's energy requirement for maintenance increases in both the lower and the upper critical temperature. Sakomura (2004) reported that the energy requirement for maintenance is around 80% of total ME intake for broiler breeder pullets. Romero et al. (2009) reported that the energy requirement for maintenance is around 70% of total ME intake for broiler breeder hens. In a cold environment, the large proportion of the energy requirement for maintenance further increases to maintain their CBT. The remaining small proportion of energy available for growth and production dramatically declines resulting in decreased growth and production, particularly in feed restricted broiler breeders, where available ME cannot increase due to increased voluntary intake. Efficiency decreases as energy requirement for maintenance to maintain CBT increases. In the current study, feed efficiency was determined by the ratio between input (feed intake) and output (BW gain or egg mass) according to Wang and Kim (2011).

Broiler breeders are feed restricted to maximize reproductive output by maintaining a target BW profile (Hocking, 2004; Aviagen, 2007; Renema et al., 2007) through an accurate feed allocation. Full-fed broiler breeders became obese, leading to multiple ovulations, deformed eggs and irregular oviposition (Renema and Robinson, 2004). Severely feed-restricted (25% of ad libitum*)* broiler breeders led to delayed onset of lay and decreased egg production and egg weight (Hocking, 2004). Both full-feeding and severely feed-restricted broiler breeders had reduced reproductive output. An accurate feed allocation decision is a big challenge which depends on the energy requirement of chickens, and that in turn depends on BW, age, rate of lay and environmental temperature (Sibbald, 1980).

Feed cost per bird increases in a cold environment depending on desired barn temperature. Heating costs may be reduced if birds are placed at lower environmental temperature. In the current study, birds were reared in four environmental temperatures (15, 19, 23 and 27˚C). Feed cost, heating cost and savings were calculated relative to 27˚C of barn temperature (Appendix B).

This thesis examined ways in which environmental temperature, dietary energy levels, feeding times, photoperiods and housing systems influence CBT dynamics and efficiency. Real time CBT was recorded using telemetry devices at 10-min intervals in broiler breeders to determine the CBT dynamics suggesting a feeding program to avoid heat stress. In addition, financial savings were assessed based on feed costs and heating costs of broiler breeder females reared in different barn temperatures.

6.2. CORE BODY TEMPERATURE IN CHICKENS RELATIVE TO ENVIRONMENTAL TEMPERATURE.

In general, when environmental temperature is above or below the thermoneutral point, birds initially apply physiological mechanisms and physical posture changes to maintain their CBT. The temperature difference increases between the surface body and environment, when the environmental temperature drops below the lower critical temperature. Birds then dissipate an increasing amount of heat to the environment and they eat more to increase the rate of metabolic heat production to maintain their CBT (National Research Council, 1981). In addition, birds conserve body heat to increase insulation by sitting, huddling, reducing body surface area, and adjusting feathers. Birds also try to dissipate less heat to the environment by reducing blood flow to the skin through vasoconstriction. Initially, birds can regulate all physiological functions but when environmental temperature continuously decreases below the lower critical temperature, then birds increase feed intake as much as possible. When the energy requirement for maintenance increases in feed restricted broiler breeders; a reduced proportion of energy is left for growth and production. This decreases growth, production and efficiency.

Conversely, when an environmental temperature is above the upper critical temperature, the temperature difference between the surface body and the environment decreases, and birds cannot lose adequate heat to the environment. Birds change physical posture to increase heat dissipation including separating from each other, increasing surface area by standing, trying to stay near window (presumably looking for a colder area or finding a way to lose heat through convection (air movement) and shadow, wing drooping and spreading, and eventually dissipating excess heat by panting (a faster rate of breathing promotes evaporative water loss; Freeman, 1965). They also try to maintain their CBT by increasing blood flow to extremities resulting in body heat loss through vasodilation in hot environments. When they cannot dissipate adequate heat, CBT increases and birds decrease the rate of metabolic heat production by decreasing feed consumption. Sufficiently reduced feed consumption results in reduced productive outputs such as growth or egg production or both resulting in decreased efficiency. Heat stress has a greater negative impact on efficiency than cold stress.

6.3. DIURNAL CORE BODY TEMPERATURE PATTERNS

Feed-restricted broiler breeder females had a distinct diurnal CBT pattern. The CBT peaked within 1 h after feeding in both broiler breeder pullets and hens regardless of environmental temperature, feeding time, photoperiod and housing system. This was likely due to feeding activity and feed metabolism (Khalil et al., 2004). The CBT decreased in the remainder of day and was minimum at night during sleep and rest (Chapter 2: Figure 2.1; Chapter 3: Figure 3.1; Chapter 4: Figure 4.1; Chapter 5: Figure 5.1). Feeding activity, feed metabolism and normal activity could increase day time CBT compared to night time CBT.

The CBT in birds was lower at night time in the standard photoperiod due to sleep and rest (Cain and Wilson, 1974; Khalil et al., 2004) compared to day time. However, CBT was lower in the continuous photoperiod during same time period against night time compared to day time of standard photoperiod. The CBT in broiler breeder hens dropped (0.3˚C) quickly after lights turned off in the 16L:8D treatment group and slightly dropped (0.1˚C) in the 24L:0D at the same time, and remained similar in the next 8 h light period in both the 24L:0D and 16L:8D treatment groups. It might be due to synchronized feeding times; birds in both photoperiods were fed in the morning every day. Possibly, birds developed a biological habit due to repetitive feeding cycle resulting in activity prior to feeding leading to increased CBT. The CBT patterns were similar in the common 16 h light period in both treatments. The CBT was higher during the hours from 21:30 to 05:30, which corresponded to dark period in the 16L:8D treatment, because birds were likely more active when exposed to continuous lighting. This was a short study (7 d) and birds in the 24L:0D treatment group could be influenced by the pre-established diurnal pattern of the standard photoperiod

(Birds were reared under the standard photoperiod (16L:8D) before starting this experiment), and regular morning feeding cycle.

The CBT at night was higher in free run hens than caged hens. Presumably, activity levels of broiler breeder hens in the spacious free run housing system could contribute to a residual higher rate of metabolic activity, leading in turn to higher CBT at night compared to caged hens. In addition, free-run hens sleep together and sit on the floor resulting in increased insulation that could reduce heat dissipation to the environment. Conversely, caged birds may lose more heat through convection (air flow surrounding the bird) and conduction (birds contact with metal wires of the cage) than free-run hens. Increased feed intake in free run hens is mainly used for activity level and activity increases heat production in the body. Possibly, vasomotor activity (vasodilation) could increase peripheral blood flow and expanded blood vessel especially in comb, wattles, and feet resulting in heat dissipation to environment at a higher rate to maintain a homeostatic CBT in free run hens. However, the CBT peaked due to feeding related activity and diet induced thermogenesis within 1 h after feeding, and CBT was lower at night than at day regardless of environmental temperature and housing systems.

Breeder hens consumed about 6% more feed in the low energy diet compared to the high energy diet as their CP intake was 1 g higher per day in the low energy diet than in the high energy diet. Theoretically, heat production was higher in low energy diet-fed birds because of higher volume of feed and a higher amount of CP intake. When birds use CP as an energy source, heat production would be higher about 30% compared to fat or carbohydrate (Geraert et al., 1996). Low energy diet-fed birds likely lose heat as soon as possible through vasodilation (Mustaf et al., 2009); presumably, birds expand blood vessels, resulting in increasing temperature difference between surface body and environmental temperature, and increase heat loss to the environment.

A significant rise in CBT was observed within 1 h after feeding. In the hot summer, mid-morning to mid-afternoon is the hottest time of the day. If birds were fed at hot times of day, the difference between the surface body temperature and the environmental temperature would decrease. Birds would be unable to dissipate adequate heat to the environment resulting in a rise of CBT. In such conditions, birds decrease feed intake resulting in a decrease in growth, egg production and egg quality (National Research Council.1981; Randall and Hiestand, 1939). As a consequence, birds decrease the rate of metabolic heat production to maintain CBT. Shifting feeding time from a hot time to a cooler time of day, like early morning or late night or late afternoon just before the sun sets or a half meal early morning and another half meal in the late afternoon, could be an appropriate approach to mitigate heat stress of birds in the hot summer.

6.4. MAINTENANCE ENERGY REQUIREMENTS

The metabolizable energy requirement for maintenance (ME_m) includes the total heat of digestion and absorption, product formation, fermentation, and waste formation and excretion. Heat production and heat loss are balanced based on the difference between the surface body temperature and environmental temperature (Monteith, 1974). The energy requirement for maintenance in chickens increased with decreasing environmental temperature below the lower critical temperature (National Research Council, 1981). Thus, ME_m in chickens can vary depending on environmental temperatures. The net energy for maintenance (NE_m) is the energy used by animal after subtracting the total heat increment from the ME_m. Thus, NE_m is not affected by environmental temperature or feed intake.

Feed intake was decreased linearly in feed-restricted breeder pullets with increasing environmental temperature from 15 to 27˚C. Zuidhof et al. (2012) demonstrated a 5% decrease feed intake in broiler breeder pullets when changing the environmental temperature from 15 to 27˚C, possibly due to severe feed restriction resulting in less heat production in a higher environmental temperature. The degree of feed restriction is higher in pullets than in hens due to their higher growth potential (de Beer and Coon, 2007). Theoretically, the energy requirement for maintenance would decrease linearly with increasing environmental temperature (Figure 6.1) because breeder pullets would eat less feed due to higher feed restriction and they would have less diet induced thermogenesis. Pishnamazi et al., (unpublished) reported that environmental temperature ranging of 15 to 27˚C had a quadratic effect on the energy requirement for maintenance in broiler breeder hens (Figure 6.2). The energy requirement for maintenance increased with decreasing the environmental temperature from 24 to 15˚C and with increasing the environmental temperature from 24 to 27˚C. The energy requirement for maintenance was minimal at 24˚C, likely heat production and heat loss is comparatively balanced than other environmental temperatures. Above 24˚C, the energy requirement for maintenance increases because birds expend energy to cool themselves (Pishnamazi et al., unpublished). Presumably, pullets produce less heat depending on severity of feed restriction, ME_m in relaxed feed restriction pullets would decrease linearly until 27˚C (Figure 6.1) and this linear relationship could be extended beyond a 27˚C environmental temperature with a severe feed restriction. Severe feed restricted breeder pullets consume less feed than relaxed feed restricted pullets. The ME_m in severe feed restricted pullets would decrease linearly until a higher environmental temperature (Figure 6.1). This gradual decreasing of ME_m indicates that the thermal point could further extend in severely feed restricted pullets than in relaxed feed restriction pullets. As a result, we could hypothesize that the thermoneutral zone could be wider in pullets than broiler breeder hens.

6.5. APPLICATION TO COMMERCIAL BROILER BREEDER FARMING (RECOMMENDATION)

According to the law of thermodynamics, heat production (H_p) and heat loss (H_l) will be equal in the poultry barn. That is, $H_p = H_l$ within a barn. Heaters and animals are two sources of heat production. The sources of heat loss are ventilation, walls, ceiling and floor of the building. Where, H_p = heat production, H_l = heat loss; $H_p = f(\text{heater, birds})$, $H_l = f(\text{celling, floor, ventilation, wall})$; $f(\text{heater}) = f(\text{celling, floor, ventilation, wall}) - f(\text{birds})$. Heat loss through the building depends on the difference $\{\Delta T = (\text{inside} - \text{outside temperature})\}$ between the inside and outside temperature and the insulation status of the building. We assumed an outside temperature was -15˚C. Total and sensible heat productions were calculated for an individual bird in different environmental temperatures (15, 19, 23 and 27˚C) with the following equation developed by Pedersen and Thomsen (2000);

$q_t = 9.84*m_a^{0.75}(4*10^{-5}(20 - T_{ts})^3 + 1)$; $q_s = 0.83q_t\ (0.8 - 1.85*10^{-7}(T_{ts} + 10)^4)$; where: q_t= Total heat production, J s^{-1}; q_s= Sensible heat produced, J s^{-1}; m_a = Mass per animal, live animal kg; T_{ts} = Dry bulb temperature, ˚C.

Heat production from heaters was calculated as follows:

f(heater) = f(ceiling + floor + ventilation + walls) – f(birds) (Appendix B). Feed cost was calculated for individual birds in different environmental temperatures during the rearing period (4 to 20 wk) and the breeding period (25 to 41 wk).

We assumed feed cost was \$380/T and natural gas cost was \$3.25/GJ (Equal Energy, 2010). The effects of changes in environmental temperature on feed intake and heating cost was applied to calculate saving cost for broiler breeder females. Feed cost, heat cost and savings were calculated relative to 27˚C scenario. Feed cost increased by \$0.02, \$0.09 and \$0.22 per pullet; \$0.00, \$0.04, \$0.14 per hen) and heat cost decreased by \$0.11, \$0.21 and \$0.30 per pullet; \$0.23, \$0.43 and \$0.62 per hen in the 23, 19 and 15˚C treatment respectively, compared to 27˚C treatment (Figure 6. 3; Figure 6. 4). Net savings for each pullet from 4 to 20 wk of age were \$0.08, \$0.12, and \$0.09 in the 15, 19 and 23˚C respectively relative to 27˚C. Net savings for each hen from 25 to 41 wk of age were \$0.48, \$0.39 and \$0.23 in the 15, 19 and 23˚C respectively. The highest savings were $0.12 per pullet in the 19˚C and $0.48 per hen in the 15˚C relative to 27˚C.

Feed intakes increased as well as feed costs increased and heating cost decreased with decreasing barn temperature from 27 to 15˚C, when outside temperature was -15˚C. Birds increased feed intake because they lose energy to the lower environmental temperature. On the other side, heating costs decreased with decreasing barn temperature because the temperature difference decreases between the barn and outside. Thus, less heat was lost to outside environment. Decreased heat costs of broiler breeders were higher than increased feed costs in the 15˚C relative to 27˚C.

Feed allocation would increase to maintain core body temperature in broiler breeder females in cold environmental temperature (below the lower critical temperature). Consequently, birds could increase the rate of metabolic heat production. Inadequate feed allocations in feed restricted broiler breeders, particularly in a cold environment, would leave a small proportion of energy for growth and production. A precise feed allocation decision based on environmental temperature is a big challenge to optimize growth and production in feed restricted breeders.

Adjustment of feed allocation with the change of environmental temperature is recommended. For each 1˚C decrease in barn temperature from 23 to 15˚C, feed consumption increased around 0.2 g and 0.5 g for each broiler breeder pullet and hen respectively. This extra feed allocation is mostly utilized for maintenance requirements of birds, particularly to keep a relatively constant CBT in lower environmental temperatures.

A 17.0 % increase in feed allocation would be needed to compensate the energy lost by activity in free-run hens, when research outcomes from caged broiler breeders are applied to the industry level.

High energy diet-fed breeders were more energy efficient than low energy diet-fed breeders. High energy diet-fed birds had lower maintenance energy than low energy diet-fed birds because birds on a high energy diet required less quantity of feed and possibly use less energy to digest this feed. Feed volume was 18% higher in the low energy diet than in the high energy diet. When dietary CP is used as an energy source, heat production increased by 30% compared to fat and carbohydrate (Geraert et al., 1996). Thus, lower CP:ME ratio (0.055) diet fed birds can avoid heat stress.

Heat production in chickens was influenced by several factors like activity, feeding time, light intensity, dietary crude protein, housing system, and day length. Feeding related activity and feed metabolism in broiler breeders increased CBT in peak within 1 h after feeding. Heat production in chickens would increase with increasing intake of dietary CP, at higher environmental temperature, birds are unable to lose adequate amount of heat (National Research Council, 1981). Then, they would reduce the dependency on diet induced thermogenesis to maintain their CBT resulting in decreased feed intake. This results in decreased production and efficiency.

Reducing CP:ME ratio in the diet, birds could decrease heat production with reduced intake of CP, and birds can avoid heat stress in hot environment (Zuidhof et al., 2012). In general, birds increase activity level in the larger area in the free run housing system. This increased activity level in birds result in high heat production compared to caged hens because caged hens were allowed a limited area and they cannot increase activity like free run hens. Intake of small amount of dietary CP in caged hens could produce less heat, which could avoid heat stress in a high environmental temperature (above the upper critical temperature).

Environmental temperature generally increases with increasing day length and this temperature decreases at the end of day. If birds are fed in the early morning of day when environmental temperature is normally lower than at noon time or at the end of day (late afternoon), when environmental temperature cools down, birds also can avoid heat stress because they can lose adequate heat to the cold environment of day. Birds increase activity level with increasing light intensity resulting in increased heat production and they decrease heat production with decreasing light intensity (Boshouwers and Nicaise, 1987). So, birds with lower light intensity also can mitigate heat stress in hot summer.

Reducing rearing space, light intensity, less intake of CP and decreasing CP:ME ratio in diet, shifting feeding time from a hot period to a cold period of day, likely early morning or late night or late afternoon just before the sun sets or a half meal early morning and another half meal in the late afternoon, could be an appropriate management approach to mitigate heat stress in the hot summer.

6.6. SOME BASIC FINDINGS OF THE RESEARCH

- Core body temperature ranged from 39.99 to 42.47˚C in the 23˚C treatment groups which seems to be normal CBT in broiler breeder pullets. Because, breeder pullets are more efficient in the 23˚C than other environmental temperatures.
- Core body temperature in broiler breeder hen ranged from 39.77 to 41.06˚C within the range of environmental temperature from 15 to 27˚C. Because, broiler breeders are similar efficient within environmental temperature from 15 to 27˚C.

6.7. FUTURE RESEARCH

Production, feed efficiency and efficient use of resources as well as fundamental information are key issues to make the poultry industry sustainable and profitable. Feed consumption was linearly decreased in broiler breeder pullets and it had a quadratic relationship in broiler breeder hens with increasing environmental temperature from 15 to 27˚C. The energy requirement for pullet maintenance linearly decreased until 27˚C environmental temperature; possibly, due to a higher feed restriction in broiler breeder pullets than in broiler breeder hens. This may indicate that the thermoneutral zone for broiler breeder pullets could extend above 27˚C. However, further experimentation is needed to identify the upper and lower critical environmental temperature and CBT for broiler breeder females' performance under dietary and housing conditions. The CBT may act as an indicator of heat stress when CBT goes above the normal range and cold stress when CBT drops below the normal range. This could help broiler breeder industry to setup guidelines for management in different environmental temperatures.

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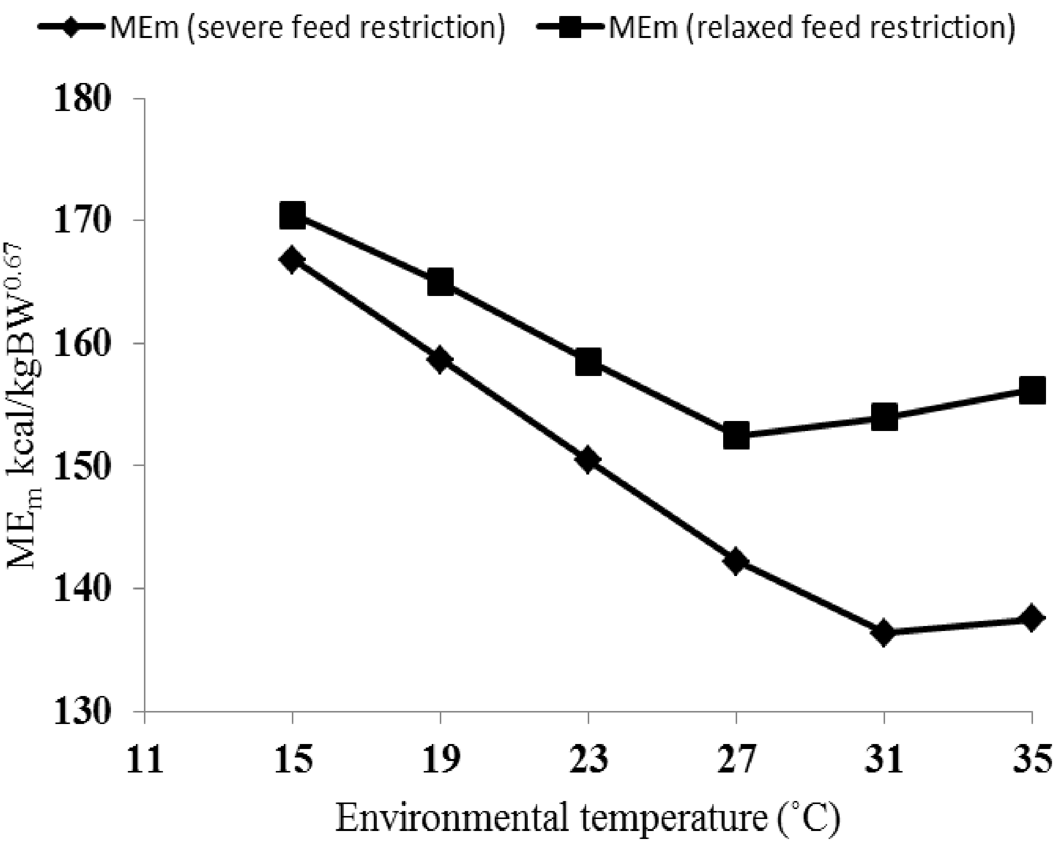


Figure 6.1 Theoretical ME requirements for maintenance (severe feed restriction and relaxed feed restriction) in broiler breeder pullets (4 to 20 wk of age) in different environmental temperatures. Y axis indicates the energy requirement for maintenance kcal per kg metabolic BW and X axis indicates environmental temperature in degree Celsius.

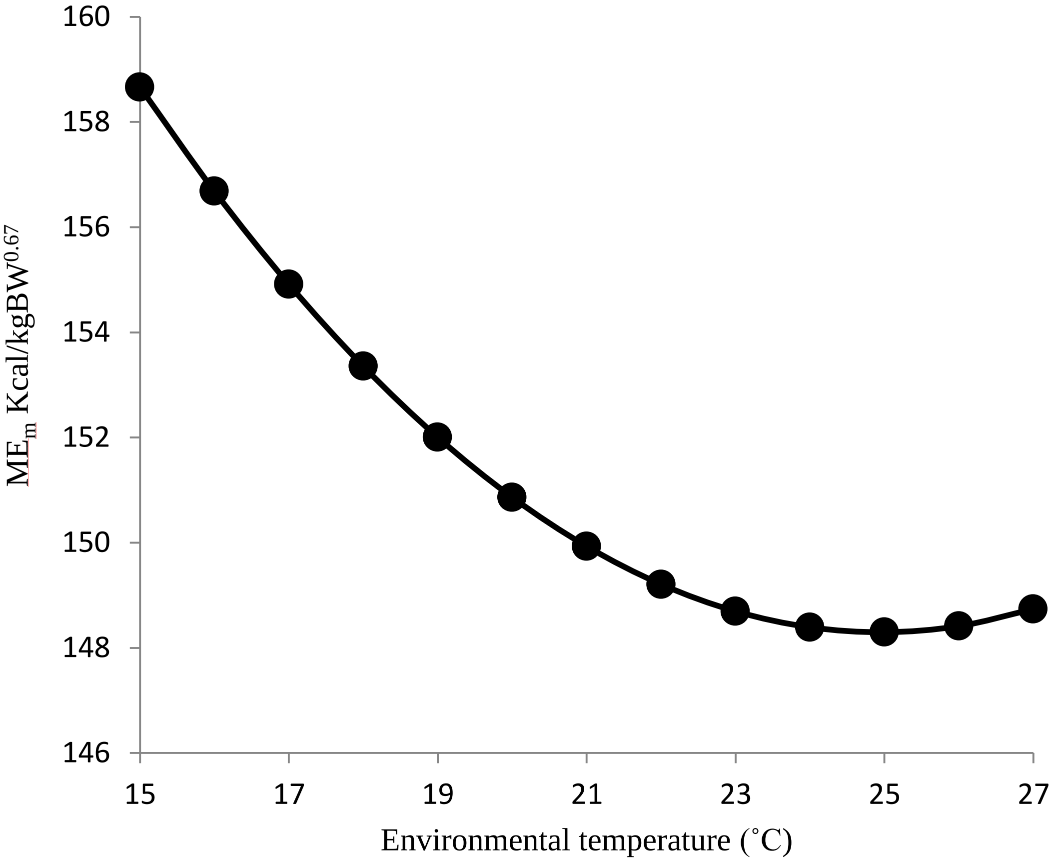


Figure 6.2 Predicted ME requirements for maintenance of broiler breeder hens (25 to 41 wk of age) in different environmental temperatures**.** Y axis indicates the energy requirement for maintenance kcal per kg metabolic BW and X axis indicates environmental temperature in degree Celsius.

Source: Pishnamazi et al. (unpublished)

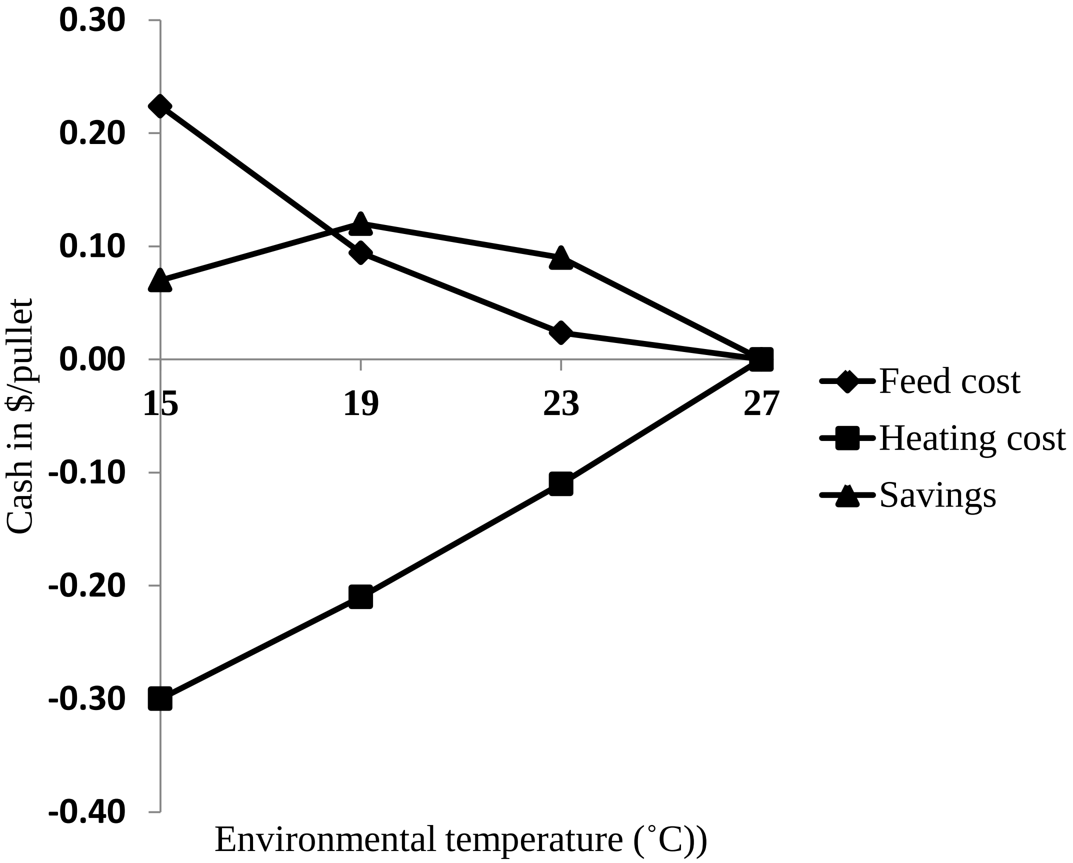


Figure 6.3 Relative feed and heating costs of broiler breeder hens reared in environmental temperatures of 15, 19, 23, and 27˚C from 25 to 41 wk of age. All costs and savings relative to 27˚C scenario, and assume that the outdoor temperature was 15˚C. Y axis indicates cash in $ per pullet and X axis indicates environmental temperature in degree Celsius.

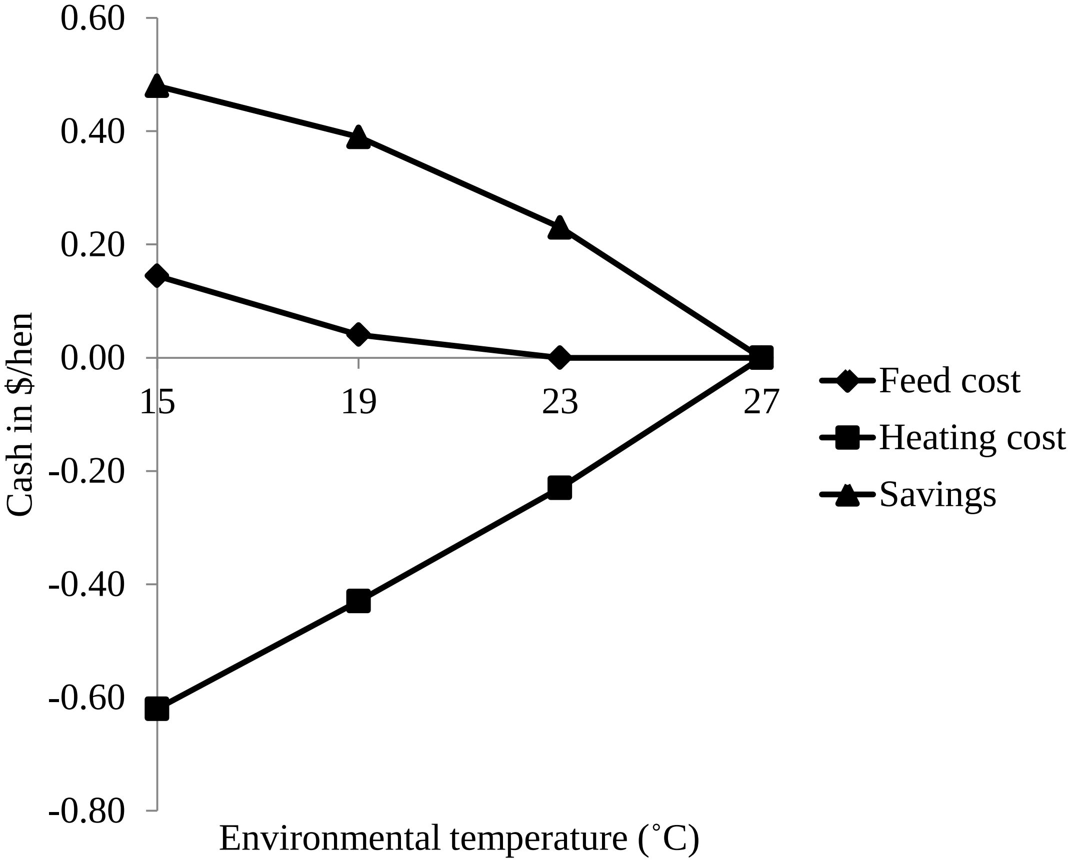


Figure 6.4 Relative feed and heating costs of broiler breeder hens reared in environmental temperatures of 15, 19, 23, and 27˚C from 25 to 41 wk of age. All costs and savings relative to 27˚C scenario, and assume that the outdoor temperature was -15˚C. Y axis indicates cash in $ per hen and X axis indicates environmental temperature in degree Celsius.

Appendix A: Broiler Breeder diets

Table A.1 Starter and grower diet of broiler breeder (Ross 708)

Items	Starter diet	Grower diet
Ingredients%		
Corn	15.000	33.450
Wheat	39.410	35.000
Soybean meal (SBM)	17.590	6.660
Oats	15.000	6.190
Canola meal	5.000	5.000
Canola oil	2.380	8.000
Dical phosphate	1.980	1.000
Calcium carbonate	1.580	0.000
Ground limestone	0.000	1.520
Broiler premix[1]	0.500	0.500
Salt	0.450	0.390
Choline chloride premix[2]	0.500	0.500
L-lysine	0.355	0.122
DL-methionine	0.207	0.093
Avizyme 1302	0.050	0.050
Threonine	0.000	0.025
Total	100.002	100.000
Calculated (% unless otherwise indicated)		
ME kcal/kg	2,900.000	2,865.000
Crude Protein%	19.000	15.000
Calcium%	1.100	1.000
Analyzed (% unless otherwise indicated)		
ME kcal/kg	NA	2,792.000
Crude Protein%	NA	16.990

NA= not analyzed

[1] The premix provided the following (per kg of diet): vitamin A (retinyl acetate), 10,000 IU; cholecalciferol, 4,000 IU; vitamin E, 35 IU; vitamin K, 4.0 mg; pantothenic acid, 15 mg; riboflavin, 10 mg; folic acid, 0.2 mg; vitamin B_{12}, 0.02 mg; niacin, 65 mg; thiamine, 4.0 mg; pyridoxine, 5.0 mg; biotin, 0.2 mg; choline, 2.63 mg iodine, 1.65 mg; Mn, 120 mg; Cu, 20 mg; Zn, 100 mg, Se, 0.3 mg; and Fe, 80 mg.

[2] Provided choline chloride in the diet at a level of 100 mg/kg.

Table A.2 Layer diet of broiler breeder (Ross 708)

Items	High energy	Low energy
Ingredients%		
Corn	39.882	35.526
Wheat	30.000	30.000
Soybean meal (SBM)	17.000	15.143
Limestone	7.829	7.928
Wheat bran	0.000	7.585
Canola oil	2.295	1.000
Dical phosphate	1.414	1.212
Layer Vit/Mineral PMX[1]	0.500	0.500
Choline Chloride PMX[2]	0.500	0.500
Common salt	0.386	0.380
DL Methionine	0.143	0.147
Avizyme 1302	0.050	0.050
Lysine HCl	0.000	0.028
Total	99.999	99.999
Calculated (% unless otherwise indicated)		
ME kcal/kg	2,900.000	2700.000
Crude Protein%	15.200	15.190
Calcium%	3.300	3.300
Analyzed (% unless otherwise indicated)		
ME kcal/kg	2,912.000	2,786.000
Crude Protein%	16.400	16.100

[1] The premix contained (per kg of diet): iron, 80 mg; zinc, 100 mg; manganese, 88 mg; copper, 15 mg; iodine, 1.65 mg; selenium, 0.3 mg; vitamin A, 12,500 IU; vitamin D_3, 3,125 IU; vitamin E, 40 IU; vitamin K (menadione), 2.5 mg; niacin, 37.5 mg; D-pantothenic acid, 12.5 mg; riboflavin, 7.5 mg; pyridoxine, 5 mg; thiamine, 2.55 mg; folic acid, 0.625 mg; biotin, 0.15 mg; vitamin B_{12}, 0.01875 mg; and choline, 2.767055 mg.

[2] Provided choline chloride in the diet at a level of 100 mg/kg.

APPENDIX B: CALCULATIONS USED FOR ECONOMIC ANALYSIS.

Heat production =Heat loss
Heater + Animal= ventilation+ building
Heater = (ventilation+ building)-Animal
Assuming outside temperature= -15C
Natural gas price=3.25$/GJ

Rearer: 100birds/chamber
Breeder: 48birds/chamber

Measurement of chamber (m)
Length=4.45
Width=3.85
Height=3.00

Heat loss for ventilation (VHL)

$Qv=m*Cp*\Delta T$
Qv= heat loss for ventilation in watt/s
Cp= specific heat capacity usually given as 1
ΔT= temperature difference between inside and outside

m= air flow rate (m^3/h)

Heat loss for walls (HLW)

$Q=A\Delta T/r$
A= area of the wall
A=(length*height*2)+ (width*height*2)
ΔT= temperature difference between inside and outside
r=resistance of wall
Q= heat loss for walls in watt/s

Heat loss for ceiling (HLC)

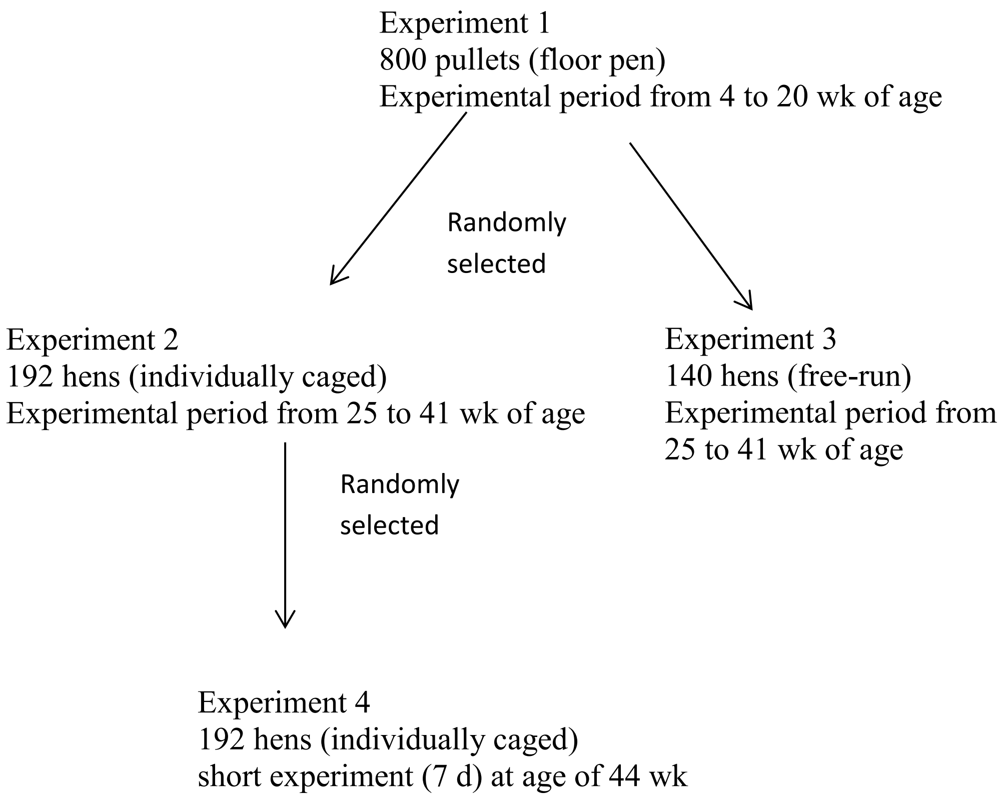
$Q=A\Delta T/r$
A= area of the ceiling
A=length*width
ΔT= temperature difference between inside and outside
r=resistance of ceiling
Q= heat loss for ceiling in watt/s

Heat loss for floor (HLF)

$Q=P\Delta TF$
P= perimeter of the room
P= 2 (length + width)
ΔT= difference of temperature between inside and outside
F=1.42 (resistance of normal concrete floor
Q= heat loss for floor in watt/s

3224 All calculations were approver by Dr. J. Feddes, Retired Professor. University of Alberta.

APPENDIX C: SCHEMATIC DIAGRAM OF CHICKENS USED IN DIFFERENT EXPERIMENTS



Experiment 1
800 pullets (floor pen)
Experimental period from 4 to 20 wk of age

Experiment 2
192 hens (individually caged)
Experimental period from 25 to 41 wk of age

Experiment 3
140 hens (free-run)
Experimental period from 25 to 41 wk of age

Experiment 4
192 hens (individually caged)
short experiment (7 d) at age of 44 wk