CLOACAE AND SURFACE TEMPERATURES OF HYBRID CONVERTER TOM TURKEYS EXPOSED TO TWO DIFFERENT TEMPERATURE REGIMES DURING THE FIRST TWELVE WEEKS OF GROWTH

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ABSTRACT

Due to genetic selection, poultry of the 21st century reach a larger final body mass compared to earlier poultry when both strains are grown using the same conditions. Increased growth rates have resulted in increased heat production, which may have caused alterations to the bird's homeostatic processes and requirements. The objective of this project was to determine the thermal responses of Hybrid Converter Tom Turkeys when exposed to either the standard recommended rearing temperature or 4°C below the standard, on a weekly basis. An infrared camera was used to measure surface temperatures of the breast (T_{breast}), drumstick (T_{drum}), head (T_{head}), shank (T_{shank}) and wing (T_{wing}) of 12 turkeys exposed individually over a 2 hour period once each week (wk) for 12 wks. A small thermal data logger (T_{logger}) was also used to measure the surface temperature of the skin beneath the wing. Cloacal temperature (T_{core}) was measured once before and after the test period. Temperatures of the feathered locations (T_{breast}, T_{drum} and T_{wing}) decreased from wks 1 – 7 and then remained constant from wks 8 - 12 ($P<0.05$). In contrast, temperatures of the featherless locations (T_{head}, T_{logger} and T_{shank}) increased from wks 1 - 3 and then decreased gradually from wks 3 - 12 as the exposure temperature decreased ($P>0.05$). The remaining featherless location (T_{core}) was found to be lower during the first week before rising and remaining constant for the last 11 weeks. A decrease of 4°C caused a decrease in the temperatures of the feathered locations ($P<0.05$). The greatest calculated difference in temperature between the two treatment groups was seen with T_{breast}, while T_{drum} and T_{wing} were less affected and had the same calculated difference. No difference in temperature was found between the treatment groups for T_{core} ($P>0.05$). The remaining featherless locations were found to have different temperatures between the treatment groups during the first few wks of growth ($P<0.05$). Control temperatures were found to be higher in temperature than the treatment temperatures for all measurement locations where a difference in temperature occurred. Exposure temperature therefore, directly influences body surface temperatures to varying degrees, depending on the location's physical parameters and whether the location is feathered or featherless.

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DEDICATION

"This thesis is dedicated to my loving parents Bonnie and David Mayes, without whom I would never have reached my current level of success. Your patience, guidance and unwavering support have helped me overcome numerous obstacles. I am eternally grateful and lucky to have two such extraordinary people in my life."

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LIST OF ABBREVIATIONS

T – Temperature

T^{con} – Control temperature curve

T^{trt} – Treatment temperature curve

T_{breast} – Breast temperature value(s)

T_{drum} – Feather temperature value(s) over the distal lateral region of the tibiotarsal bone

T_{wing} – Wing temperature value(s)

T_{core} – Cloacal temperature value(s)

T_{logger} – Skin temperature value(s) under the wing at the juncture between wing and the body

T_{head} – External ear opening temperature value(s)

T_{shank} – Skin temperature value(s) over the lateral region of the tarsometatarsus bone

T_{breast}^{con} – Breast temperature value(s) for the control group

T_{breast}^{trt} – Breast temperature value(s) for the treatment group

T_{drum}^{con} – Feather temperature value(s) over the distal lateral region of the tibiotarsal bone for the control group

T_{drum}^{trt} – Feather temperature value(s) over the distal lateral region of the tibiotarsal bone for the treatment group

T_{wing}^{con} – Wing temperature value(s) for the control group

T_{wing}^{trt} – Wing temperature value(s) for the treatment group

T_{core}^{con} – Cloacal temperature value(s) for the control group

T_{core}^{trt} – Cloacal temperature value(s) for the treatment group

T_{logger}^{con} – Skin temperature value(s) under the wing at the juncture between wing and the body for the control group

T_{logger}^{trt} – Skin temperature value(s) under the wing at the juncture between wing and the body for the treatment group

T_{head}^{con} – External ear opening temperature value(s) for the control group

T_{head}^{trt} – External ear opening temperature value(s) for the treatment group

T_{shank}^{con} – Skin temperature value(s) over the lateral region of the tarsometatarsus bone for the control group

T_{shank}^{trt} – Skin temperature value(s) over the lateral region of the tarsometatarsus bone for the treatment group

RH – Relative humidity

(week) – Comparison of the measured temperatures between the control and treatment groups during each week of study

(difference) – Comparison of the calculated temperature difference between the measured surface temperatures and their corresponding exposure temperatures.

(week-difference) – Comparison of the calculated temperature difference between the measured surface temperature and the corresponding exposure temperature, between the control and treatment groups during each week of study

CHAPTER 1: GENERAL INTRODUCITON

The Canadian retail purchase of turkey products has increased by approximately 26,000 tonnes over the past 35 years, while the number of registered turkey growers has decreased, specifically in Alberta, Manitoba, Saskatchewan and Quebec (Canadian Turkey Marketing Agency, 2011). In 2010, Saskatchewan produced 5,152 tonnes of turkey (Canadian Turkey Marketing Agency, 2011), resulting in operation expenses of, on average, over $900,000 per farm (Statistics Canada, 2011). In warm climates, such as California, turkey producers spend roughly 7.9% (Voris, 1997) of their total cost of production on energy expenses. According to the Manitoba Chicken Producer Board (1999) the per cycle electricity and propane costs of a broiler barn (5 tonnes per cycle) is around $9,000. A study by the Chicken Farmers of Saskatchewan (C. Monchuk, personal communication, Chicken Farmers of Saskatchewan, Saskatoon, SK, 2010) states that farm utility (consisting mainly of electrical energy, telephone and gas) costs, amount to approximately 3% of the total operation expenses. On a per kg basis, this calculates out to a producer spending 4.4¢ on utility costs.

Energy costs consist mainly of electricity and propane expenses, although it is not limited to these. Two demands for electricity and propane are the heating and ventilation systems within barns. There are two main ways in which barns are heated: the hydronic system and the hot air system. The hydronic system circulates hot water, heated within a boiler to between 66 and 93°C, through piping within the barn (Czarick *et al.*, 2008). Pipes are normally mounted to the walls or ceiling and can be located within the floor. Surface area of the pipe determines how much heat is released by each foot of pipe length. The larger the surface area, the more heat is released, making finned pipes the most efficient. These pipes look like miniature radiators as they contain small folds along the entire length of the pipe. The folds increase the surface area (Czarick *et al.*, 2008), allowing for increased heat transfer along the same length of pipe as a non-finned pipe of the same diameter.

Other factors influence the effectiveness of the hydronic system. Fans placed near the pipes remove the heated air from around the pipes, replacing it with cooler air that

can then be heated. Fans also help to circulate the air within the barn providing a more uniform temperature. Floor heating must take bedding characteristics (material type and depth) into consideration. Bedding acts as an insulator, trapping heat and reducing the passage of that heat to the air (Czarick & Fairchild, 2006). The greater the thickness or density of the bedding, the greater the insulation factor becomes and the less heat is transferred. Due to the above factors, only a small amount of hot dry air is being distributed over the entire barn, and it may not be sufficient in keeping the birds warm enough. Trapping the heat within the bedding also ensures a lower moisture content of the litter but will possibly lead to increased dust and ultimately reduced air quality.

The hot air system works by moving heated air within the barn. Air is forced into the barn through air ducts along the ceiling. These ducts contain holes that allow the heated air to be distributed as equally as possible throughout the entire barn. In some cases, the ducts are shortened and a fan is placed at the open end. This ensures air temperature is uniform within the barn. Additional fans are suspended along the ceiling of the barn to aid in more even temperature distribution.

The air is heated in much the same way water is heated in the hydronic system. A fuel source is burned, releasing heat, which is then transferred to either the water or the air. In an attempt to reduce costs, cheaper fuels such as coal or litter may be used instead of propane (Czarick *et al.*, 2009). A negative aspect associated with the burning of these fuels is uneven heat production. The total amount of heat released from one unit of fuel will not be the same as the next unit. Furthermore, a single unit of fuel will not release a continual flow of heat; rather it will be released in a random manner with varying amounts lost over time. Due to this, more or equal amounts of low quality fuel could be purchased in order to match the heat production of the higher quality fuel. If the cost of the lower quality fuel exceeds the cost of the higher quality fuel per unit of heat produced the purpose of purchasing the lower quality fuel no longer applies and produced net income will be reduced. Regardless of the type of system, electricity is still required to power the pumps and fans necessary for circulating the air or water used throughout the barns.

Electricity is also needed to power the fans used for ventilating barns. Ventilation is used to remove moist, unclean air from the barn and replace it with fresh, outside air. Barn air quality must meet a set standard in order to maintain optimal bird health and productivity. Carbon dioxide levels are required to be below 5,000 ppm, ammonia below 30 ppm and relative humidity (RH) should be no more than 50% (Czarick, 2010). The minimum recommended air flow rate for a poultry barn is 0.84 m^3/min for every m^2 of floor space (Czarick & Fairchild, 2011a). Exhaust fans and air inlets are built into the outer walls of barns and can be found in many different formations. An example of a basic design is to have the fans located on one end of the barn while the inlets are on the opposite end. This design is referred to as tunnel ventilation (Czarick & Fairchild, 2011a) as air is drawn from one end of the barn to the other. The positioning of fans and inlets is important to optimize air quality and uniformity within barns (Czarick & Fairchild, 2012). Inlets spaced farther apart, allow for gradients to form in the air across the barn. Air closer to the inlets may be a different temperature compared to air that is further away. Drafts and stagnant air can be created depending on the position of the fans and air inlets. Both drafts and fan/air inlet placement can have a negative impact on a heating system, as they change the average temperature read by the thermostat (Czarick & Fairchild, 2012). Incorrect readings may result in the heating system running when it is not needed, burning fuel and ultimately reducing producers' net income.

Fan size also plays an important role, with the volume of air moved being proportional to the size on the fan. Larger diameter fans are able to move more air at one time compared to smaller diameters (Czarick & Fairchild, 2011b). This makes them more cost effective to use as the difference in the amount of electricity expended between the two fan sizes is minimal

In the winter, cooler incoming air results in a drop in barn temperature. A loss of heat is also seen as the warm barn air is expelled to the surrounding environment. This situation results in the heating system running more often and for longer periods of time. An increase in the amount of electricity and propane being used then occurs, raising net expenses for producers.

The way in which barn temperatures are regulated is important; however, what are these temperatures based on? Chepete & Xi (2002) collected data on the heat production of chickens and turkeys to produce a heat curve, as a function of body mass at thermal neutral temperatures. Some of the literature used is as early as the 1990s, though most date back to the 1980s and 1970s. These data from older strains of birds are currently being used to determine the energy management practices of today's poultry industry. In addition, during the first 10 days of life, young domestic fowl (chicks and poults specifically) are unable to maintain their body temperatures (Weyjens, 1999). It is important to note that at present both chicken and turkeys grow faster, and have heavier final body weights compared to these older strains when grown under the same management practices, specifically feed composition (Havenstein *et al.,* 2003 and 2007).

Ambient temperatures above 18°C lead to reduced growth in mature turkeys (Hurwitz *et al.*, 1980) due to reduced feed consumption. Turkeys produce body heat through: muscle activity, growth (Buddiger & Wojcinski, 2001) and the digestion of feed (Willmer *et al.*, 2005). Larger birds produce more heat through growth, and when this is combined with feed digestion and ambient temperatures, the removal of this heat becomes very important. Heat is lost though thermoregulation and occurs as heat exchange, primarily through less insulated locations such as the legs and head (Richards, 1970 and 1971; Cangar *et al.* 2008) and, according to Yahav *et al.* (2004), the breast. Heat exchange is determined, in part, by the difference between the surface temperature of the bird and the ambient temperature (Cangar *et al.*, 2008) and the exposure factor of the surface area. Heat moves in the direction of greater temperatures to lower through: conduction, kinetic energy moving between two materials, and radiation, electromagnetic waves within the environment (Tao & Xin, 2003; Willmer *et al.*, 2005). If the surface temperature of a bird is close to that of the ambient temperature, there is little heat exchanged. If there is a larger difference between the two temperatures, more heat is transferred and heat exchange increases. Convection is the movement of heat from a heat source (bird) to a liquid or gas as it passes over the surface of the bird (Tao & Xin, 2003; Willmer *et al.*, 2005). Current poultry production sees this form of heat loss mainly through management practises and not by thermoregulation processes of the birds.

Yahav (2002) found that the surface temperatures of 8-week-old turkeys did not change significantly when the difference between the ambient temperatures was no more than 10°C. A change in ambient temperature more than 10°C resulted in a change in surface temperature. The core temperature of a turkey in a normal barn environment is warmer than the ambient barn temperature, thus creating a temperature gradient between the two. As the surface of the bird is closer spatially to the barn air than the bird's core, it will have a temperature closer to the ambient. However, as the core is warmer, it is constantly radiating heat outwards, providing the surface layer with heat to be lost to the environment. This prevents the surface temperature from ever becoming equal to the ambient temperature.

Raising and lowering the ambient temperature by 10°C from the standard did not cause a change in skin temperature under the wing of 4-week-old turkeys; however, the 10°C decrease in temperature did cause the core temperature to drop (Yahav, 2002). This drop identifies the need for increased internal heat production, resulting in: an increase in feed consumption for heat produced through digestion, an increase in muscle activity known as shivering, changes in bird behaviour or any combination of the three. Reductions in growth may occur in this situation as a portion of the feed being consumed is utilized for the production of heat rather than tissue development.

As previously mentioned, the temperatures being used as a guideline today are from a heat curve that was developed using older, small and slower growing strains of birds (Chepete & Xi, 2002). The larger strains of more recent production birds produce more heat, and negative effects on heat exchange processes have been found to occur when ambient temperature changes by more than 10°C. This affect on heat production may potentially influence the production of current strains of agricultural poultry. Altered feed consumption coupled with a lack of tissue development (feed conversion) and the unnecessary usage of electricity and gas reduces a producer's net income. Due to this, to ensure there are no negative impacts on producers' net income, changes to temperature management practices must take feed consumption as well as electricity and gas usage into consideration.

Basing management practices on the physiological requirements of animals may lead to more efficient animal production (Lacey & Hamrita, 1999). Instead of using thermostats to indicate when a heating system or ventilation system should be turned on or off, it would be more accurate to use the physical temperatures or behavioural responses to ambient temperatures, of the birds themselves. Ultimately, barn temperatures are chosen with bird comfort and productivity in mind. Usage of the heating and ventilation systems when they are not needed will be avoided with a system that measures the bird surface temperatures instead of air temperature. This could improve producer economics by reducing the amount of electricity and heating fuels required.

A system capable of determining if a bird is comfortable will therefore also be able to indicate if birds are not. If a bird's temperature is higher or lower than it should be, the bird may be sick. Knowing a bird's physical state will allow producers to quickly and appropriately deal with the bird in question. Whether it is by removing the bird or medicating the feed/water supply to avoid a large outbreak, the producer will be saving money in the long run.

One potential system capable of sensing bird temperature is the use of an infrared camera to measure surface temperatures of birds. The camera would be able to monitor large portions of the flock to determine their thermal status. This reduces the possibility of using a sick bird as the basis for the rest of the flock in determining the suitability of the current barn temperature. The infrared camera may also be able to indicate whether a bird is sick or not as their temperature may not be within the range of a normal bird.

To have such a system work, it is first imperative to know a normal, healthy bird temperature. Recent work by Cangar *et al.* (2008) looked at the change in surface temperature of broiler chickens raised at industry standards over a 42-day period using an infrared camera. They were able to determine that a change in surface temperature was dependent upon the physical location of the measurement. As ambient temperature decreased, so did the surface temperature of some feathered locations, while featherless and some feathered locations were seen to remain the same. To date, there are no data for turkeys showing how they respond to modern temperature management practices.

CHAPTER 2: Literature Review

2.1. Measuring Body Temperatures

2.1.1. Directly Measuring Temperature

Body temperatures, defined as the internal (core) and surface temperatures of a living organism, can be measured several different ways. Some examples include changes in liquid volume, flow of an electrical current, mechanical deflection (bi-metallic strips) and detection of infrared radiation. The most commonly known temperature-measuring device is the thermometer. There are two different types of thermometers: mechanical and electrical (Cutnell & Johnson, 2004). Mechanical thermometers consist of physical parts that 'move' due to alterations in size. These parts are all metallic and will shrink or expand based upon the temperature to which they are exposed, which results in recorded temperature changes. One example of a mechanical thermometer is the mercury thermometer. The extent of shrinking and expanding exhibited by liquid mercury is directly related to the temperature to which it is exposed (Cutnell & Johnson, 2004). A scale is then used to interpret rise and fall of the mercury within a tube into a comprehensible temperature reading.

Electrical thermometers use the flow of an electrical current to measure temperature (Cutnell & Johnson, 2004). The intensity of vibrations exhibited by metallic atoms increases with an increase in the temperature of the solid metal object of which they are a part (Cutnell & Johnson, 2004). This causes a decrease in the flow of an electrical current through that object. Similarly, cooling a metal will decrease atom vibration, allowing easier passage of electrons and an increase to the flow of an electrical current. Electrical resistance is, therefore, directly related to the thermal state of a metal and can be used to calculate the temperature of the object being measured. This measurement technique is used in clinical thermometers.

Thermocouples use the flow of an electric current through two homogenous and different metals (Pollock, 1971; Kinzie *et al.*, 1975; Cutnell & Johnson, 2004) to determine temperatures. The two wires are set up to create a circuit where one end is connected at the reference junction and the other end is connected and exposed as the

measuring junction (Pollock, 1971; Kinzie *et al.*, 1975; Cutnell & Johnson, 2004). Voltage as a function of the difference between the temperatures of the two junctions is recorded and used to determine the temperature being measured at the measuring junction (Pollock, 1971; Kinzie *et al.*, 1975; Cutnell & Johnson, 2004). The temperature at the reference junction always remains the same (or is measured separately) while the temperature at the measuring junction may change (Pollock, 1971; Kinzie *et al.*, 1975; Cutnell & Johnson, 2004). The resulting voltages are recorded and used with reference tables or standard curves to calculate the temperature being measured at the measuring junction (Pollock, 1971; Kinzie *et al.*, 1975; Cutnell & Johnson, 2004).

Determining temperature by infrared radiation uses electromagnetic radiation waves. These waves occur in two separate parts – an electric wave and a magnetic wave – which are found perpendicular to each other and consist of a series of peaks and valleys (Read, 1980; Mohsenin, 1984; Cutnell & Johnson, 2004). Wavelengths are classified by the length from one peak to the next peak. A short wavelength consists of a small distance between the peaks and long wavelengths have longer distances. Electromagnetic radiation waves range from approximately 10^{-3} to 10^{-6} m between two peaks placing it in the short wavelength category (Read, 1980; Mohsenin, 1984; Cutnell & Johnson, 2004).

Electrons contain energy and create waves through their movement to and from a set point around an atom in an opposite and parallel manner, termed oscillating (Read, 1980; Mohsenin, 1984; Cutnell & Johnson, 2004). The speed at which an atom oscillates is determined by the amount of energy it contains and is a function of temperature (Read, 1980; Mohsenin, 1984; Cutnell & Johnson, 2004). High temperatures are associated with electrons containing high levels of energy which oscillate quickly, producing short wavelengths (Read, 1980; Mohsenin, 1984; Cutnell & Johnson, 2004). Long wavelengths are produced by slower oscillations of electrons containing less energy which are associated with colder temperatures (Read, 1980; Mohsenin, 1984; Cutnell & Johnson, 2004).

To determine the temperature associated with specific infrared radiation, the electromagnetic waves must first interact with a sensor designed to convert the electromagnetic waves into an electrical signal (Cutnell & Johnson, 2004). Such an electrical signal is then converted into a temperature through mathematical equations to provide the thermal state, or temperature of the surface being measured (Cutnell & Johnson, 2004).

2.1.2. Indirectly Measuring Temperature

While not a method of measuring body temperatures directly, heat production can be used to determine thermal responses of poultry. Thermal responses are an indication of how a bird copes with the temperature of its environment and can be linked to changes in body temperature. Feddes & McDermott (1992) studied the pattern of hourly heat production in turkeys at 71 days of age (hens) and 77 days of age (toms); directly, by measuring changes in barn temperature, and indirectly, by measuring oxygen and carbon dioxide concentrations within the air.

A 'whole-house' calorimetric set-up was implemented, in which a production barn was used as a metabolic test chamber. Changes in barn temperature were calculated by measuring heat lost through the ventilation system and building envelope as well as heat gained through the heating system, lighting and bedding material. Although the temperature measurements and techniques were complicated and extensive, temperatures were recorded by digital devices using a computerized system. This limited the errors caused by human interpretation and provided more reliable results.

Over a 12-h period, barn temperatures decreased from 20 to 15°C (16:00 to 4:00) for hens and from 14 to 9°C (20:00 to 8:00) for toms. Heat production of both sexes was found to increase by relatively equal amounts during these times. Hens were found to have their heat production rise from 20 $^{Watts}/_{bird}$ to a maximum of 42 $^{Watts}/_{bird}$, while the toms' heat production rose from 32 $^{Watts}/_{bird}$ to a maximum of 53 $^{Watts}/_{bird}$.

Poultry use evaporative cooling, expressed as a panting behaviour (Yahav *et al.*, 1995; Willmer *et al.*, 2005; Comito *et al.*, 2007), to regulate their body temperature when exposure temperatures exceed their thermal comfort zone (Lacey *et al.*, 2000). This

behaviour releases carbon dioxide, a respiratory waste product, while consuming oxygen, a material utilized in normal respiration, causing a change in the concentrations of each gas within the surrounding environment. An increase in panting would therefore cause an increase in carbon dioxide levels and a decrease in oxygen levels within the surrounding air. Conversely, lower barn temperatures will reduce panting, resulting in higher oxygen and lower carbon dioxide concentrations (MacLeod *et al.*, 1985).

These concentration values are then used as components within an equation to calculate heat production. Returning to the aforementioned study by Feddes & McDermott (1992), air samples were collected from the exhaust fan ducts and external barn environment (outside air) for the determination of changes in oxygen and carbon dioxide concentrations. Using the heat production equation, both hens and toms were found to have increased their heat production during the same 12-h periods mentioned previously. The rise in heat production for hens was seen to be from 30 to 50 $^{Watts}/_{bird}$, with the increase being from 30 to 42 $^{Watts}/_{bird}$ for toms.

Feddes & McDermott (1992) observed a difference in heat production using the two different measurement techniques. Values were higher from the indirect method for hens, while higher values occurred from the direct method for toms. It is unclear why such a difference occurred between the two sexes, however, the difference in heat production values between the two techniques may be due to a behaviour expressed by birds to regulate their body temperature known as gular flutter.

Blood pH increases from approximately 7.5 to 7.9 with a decrease in blood carbon dioxide levels from roughly 30 to 10 mmHg (Weathers & Schoenbaechler, 1976). Change in blood pH can have negative impacts on biological processes (Calder & Schmidt-Nielsen, 1968; Weathers & Schoenbaechler, 1976) and should therefore be avoided. Poultry minimize blood gas and pH shifts by expressing a behaviour known as gular flutter. This behaviour increases heat loss through evaporative cooling, while minimizing gas exchange within the lungs (Calder & Schmidt-Nielsen, 1968). Air is moved across the upper throat, referred to as the gular region, through movement of the hyoid apparatus (refer to Figure 2.1; Calder & Schmidt-Nielsen, 1968). The hyoid

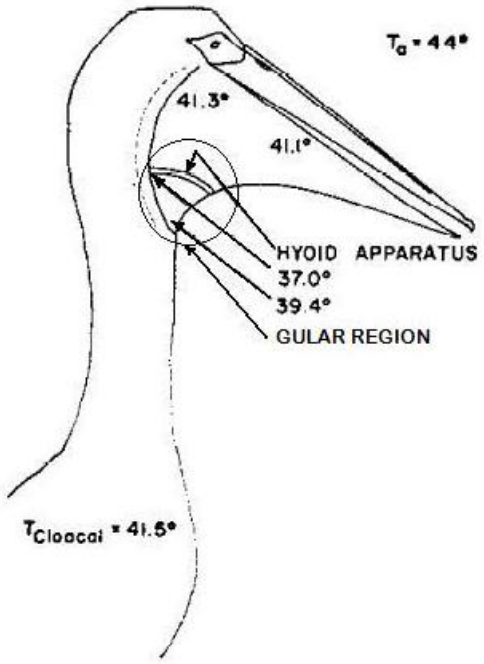

Figure 2.1. Physical locations of the gular region and hyoid apparatus on a white pelican. (Calder & Schmidt-Nielsen, 1968) Temperatures shown are theoretical.

apparatus is a set of bones connected to the tongue and bill, and plays a role in the picking up of feed stuffs and the movement of feed stuffs to the oesophagus (Korzun, 1978).

Switching from panting to gular flutter as the behavioural means to improve heat loss causes a reduction in the release of carbon dioxide into the surrounding air. Consequently, the values calculated from the heat production equation mentioned previously become inaccurate and no longer representative of the total heat produced by the birds. Due to this, the values obtained from the direct method within the study by Feddes & McDermott (1992) are more accurate in providing the pattern of heat production.

From the utilization of infrared measurements, a new technique for measuring core temperature, using surface temperatures, may be possible. Giloh *et al.* (2012) has demonstrated a relationship in broiler chickens between core temperature and the surface temperature of the head. From this correlation, a mathematical equation could be created

and used to determine the core temperature of a bird by measuring the temperature of the head. This technique would allow for easier determination of the internal thermal state of a bird and reduce errors associated with direct measurement of core temperatures, such as an increase in core temperature due to handling (Cabanac & Guillemette, 2001).

2.1.3. Measurement Methods used with Poultry

The documentation of poultry body temperatures is not a new endeavor, as it has been taking place for decades. From the beginning, the methods used in determining these temperatures have progressed. Richards (1970 and 1971) measured core temperature by inserting a thermal resistor, or thermocouple, into the cloacae of mature layer hens using a 6.1-cm probe. Surface temperatures were measured by attaching thermocouples to the comb, toe and back of the hens with squares of surgical tape. Donkoh (1989) measured core temperatures by inserting a medical thermometer into the cloacae of broiler chicks, a method still commonly used today. By the late 1990s, surgical procedures were being implemented. Measurement directly below the skin (Yahav *et al.*, 1995) was used to measure surface temperature, while core temperature was taken within the body cavity (Lacey, 1999). Today small self-contained data loggers (Brown-Brandl *et al.*, 2003; Strawford *et al.*, 2011) can be used for obtaining core temperatures. In these studies, the data loggers were orally ingested by the animal and remain within the digestive system, providing a more consistent measure of core temperature over extended periods of time without the negative effects of surgery. The use of infrared radiation did not become a commonly used tool for measuring surface temperatures until the early 21st century (Tessier *et al.*, 2003; Shinder *et al.*, 2007; Cangar *et al.*, 2008; Nääs, 2010; Giloh *et al*, 2012), though there is documentation of its presence as early as the mid 1990's (Phillips & Sanborn, 1995).

2.2. Thermal Regulation

2.2.1. Regulation of Body Temperature

Thermal regulation is the physiological, morphological and/or behavioural adaptation to environmental temperatures in order to maintain an internal temperature as close to normal as possible and is made up of four different mechanisms: homoeotherm,

poikilotherm, endotherm and ectotherm (Blatteis, 2001; Willmer *et al.*, 2005). Poultry (older than 10 days of age) are classified as endotherms as they are able to regulate their core temperature through physiological means. This is the opposite of ectotherms that must rely on exposure temperatures to regulate their core temperature. Throughout their life span, poultry are classified as both homoeotherms and poikilotherms, though they are generally referred to as homoeotherms. Homoeothermic organisms possess the ability to maintain a constant core temperature through physiological and behavioural adaptation (Blatteis, 2001). Poikilothermic organisms are the opposite of homoeotherms, as they are unable to regulate their core temperature. In the first ten days of life (Yardimci *et al.*, 2006), young chickens and turkeys are unable to maintain their core temperatures (Weytjens, 1999) and can therefore, be classified as poikilotherms. Beyond ten days of age, poultry are homoeotherms, as they are able to produce heat and maximize temperature-regulating behaviours (mainly for losing heat), allowing them to maintain their core temperature. Heat production occurs through metabolism while heat loss occurs through sensible heat loss and respiratory evaporation (Blatteis, 2001; Tao & Xin, 2003; Willmer *et al.*, 2005; Comito *et al.*, 2007).

Metabolism refers to the chemical reactions found within an organism. In animals, the metabolic reactions responsible for nutrient utilization are referred to as catabolism (Bolster, 1997; Willmer *et al.*, 2005). Catabolism is the breakdown of nutrients through a series of chemical reactions to produce usable energy in the form of adenosine triphosphate (Bolster, 1997; Willmer *et al.*, 2005). This process of producing energy is, however, imperfect and some of the potential energy is lost as heat (Willmer *et al.*, 2005). This creation of heat makes catabolism ideal for dealing with low exposure temperatures that have the potential to decrease core temperature. A study by MacLeod *et al.* (1985) was able to demonstrate that the catabolism of ingested nutrients is not the only means for the release of heat. British United Turkeys Big 5, 45 wks-of-age were exposed to 20°C and 70% relative humidity (RH) over a 6 day period. After the first 24 h, metabolic energy (ME) intake was reduced, resulting in a decrease in retained energy (fat stores), while heat production remained relatively constant. These results indicate that in order to maintain their internal temperature, the turkeys' had to utilize a different energy source.

There are four routes by which organisms lose heat to the environment: convection, conduction, evaporation and radiation (Tao & Xin, 2003; Willmer *et al.*, 2005). Convection, conduction and radiation make up the sensible heat loss pathway (Tao & Xin, 2003; Willmer *et al.*, 2005). Sensible heat loss utilizes the temperature gradient created between an organism (example, a bird) and the environment (Tao & Xin, 2003; Willmer *et al.*, 2005). Looking at the individual parts of the sensible heat loss pathway, convection is the movement of heat (kinetic energy) from an animal to another material through a fluid (mainly gas, but also liquid) intermediate (Willmer *et al.*, 2005). Conduction is the direct movement of heat (kinetic energy) from an animal to another solid material (Willmer *et al.*, 2005). Radiation is the loss of heat from an animal in the form of electromagnetic waves, directly into the environment (Willmer *et al.*, 2005).

Evaporation is the movement of heat by water, through a physical change in state from a liquid to a gaseous vapour, into air. This occurs by exploiting the vapour pressure gradient, in which the gaseous pressure of water is greater than atmospheric pressure, allowing water to rise as a gas away from a surface (Tao & Xin, 2003; Willmer *et al.*, 2005), taking heat with it. As poultry do not possess sweat glands (Tao & Xin, 2003; Willmer *et al.*, 2005) they use respiratory evaporation as the main behavioural method for dealing with high exposure temperatures (Yahav *et al.*, 1995; Willmer *et al.*, 2005; Comito *et al.*, 2007). Water within lung and gular tissue is converted to vapor and mixed with the air to be exhaled from the body. This results in heat within the body being lost to the surrounding environment.

Panting and gular flutter are, in combination, the main forms of internal heat loss; however, poultry do have other ways in which they are able to reduce their core temperatures. One such way is the movement of heat to the skin's surface by means of vasodilatation. Vasodilatation is a widening in the diameter of blood vessels (Richards, 1971). Larger diameters allow for more blood to be moved through a blood vessel at a time resulting in more blood being moved from the core of the bird to the skin. When core temperatures are high, the blood becomes heated and moving the heated blood to the surface of the bird allows for the heat to be lost through convection and conduction. For this process to work efficiently convection and conduction cannot be hampered by

insulation and the temperature of the substance receiving the heat must be cooler than the surface temperature for the transfer of heat to occur. A behaviour expressed by poultry to increase heat loss through convection is to spread the wings out, increasing the surface area of skin available for heat transfer (Tao & Xin, 2003). When able, birds will rest in a location where the temperature is lower than the surface temperature of their skin (Sreenivasaiah, 2006; Daghir 2008). The implementation of this behaviour to improve heat loss is hampered in commercial poultry production by the insulation properties of the provided bedding (Sreenivasaiah, 2006; Daghir 2008). Due to this, conduction plays a minor role in heat loss for poultry.

Huddling is a behaviour used to deal with low exposure temperatures by utilizing the sharing of body heat through conduction. It also reduces heat lost through convection (Strawford *et al.*, 2011) as there is less of the bird exposed to the environment. At low exposure temperatures (-5 to -15°C), broiler chickens, aged 32 to 33 days, have been shown to take this huddling behaviour further and burrow under each other to optimize the minimization of their contact with the exposure temperature (Strawford *et al.*, 2011). As radiation is a continual transfer of heat to and from the surrounding environment there are limited behaviours associated with it. In outdoor environments, birds are able to position themselves in shaded locations to reduce radiation given off by the sun. The use of shade isn't always possible in indoor environments, but birds can position themselves different distances from sources and sinks of radiative heat.

Changes in photoperiods are responsible for alterations in behavioural and biological responses that contribute to the development of circadian rhythms in animal temperatures. The term "circadian" means 'about the day' translated from the Latin words, "*circa",* meaning "about" and "*dies",* meaning "day" (Sharma, 2003). Circadian rhythms cycle roughly every 24 h and appear to follow the light-to-dark transitions of a day (Sharma, 2003). The most well known circadian rhythm is coined 'the biological clock', and it determines when natural body events (Sharma, 2003), such as metabolism, occur.

Internal body temperatures have also been found to follow a circadian rhythm. A study by Barrett *et al.* (1993) worked with a human model to illustrate that internal temperatures are lower during the dark hours compared to the light hours. Many factors are believed to be contributors to this affect but the main focus of the Barrett *et al.* (1993) study is sleep. The authors speculate that a lower set point is established for thermal regulation during sleep. A faster decrease in temperature at the onset of sleep was observed compared to the rise in temperature when the subject awoke (Barrett *et al.*, 1993). If the thermal regulation set point was lowered, the body would immediately reduce all heat-producing processes, resulting in a significant decrease in body temperature. Raising the set point again would cause the heat-producing processes to increase, but most likely not beyond their normal state, resulting in a more gradual rise in body temperature.

Similar studies have been conducted on poultry to determine the circadian changes in internal and surface temperatures. Lower skin temperatures in broiler chickens 18 and 35 days-of-age occurred during the dark hours, and high temperatures were measured during the light hours (Tessier *et al.*, 2003). A study by Whittow (1998) showed higher internal temperatures in different avian species during their active phase of the day and lower during the inactive phase. Sleep may have played an indirect role in these studies as it reduces the activity expressed by poultry. Eyes contain two types of photoreceptors: cones, used to help see in light, and rods, used to help see in the dark (Kristensen *et al.*, 2002; Deep, 2010). Poultry eyes contain more cones than rods, making them better able to see in the light than the dark (Deep, 2010). Due to this, agricultural birds would be more active during the light hours than the dark hours. Activities include seeking feed and water as well as exploring their surroundings. Reduction in feed intake will cause reductions in catabolic heat production. Such an effect is illustrated by an increase in heat production during the light hours of the day and a reduction during dark hours (MacLeod *et al.*, 1985). It is important to note that this reduction in heat production is not caused by the change in catabolism alone but the change in physical activity level as well.

2.2.2. Other Factors Affecting Temperature Regulation

It is theorised that hen age at time of lay affects the thermal responses of young poultry, subjected to cold exposure temperatures. Chicks from older hens (60 wks of age) were better able to cope with exposure to 20°C for a 2.5-h period 22 h after hatching compared to chicks from younger hens (25 wks of age; Weytjens, 1999). The chicks from older hens had greater initial body weights upon hatching and had higher core temperatures 24 to 96 h after hatching with the 20°C exposure (Weytjens, 1999). It is possible that this difference in thermal response may be due in part to the lower surface area to body weight ratio occurring in the chicks from older hens. Larger body mass may be providing a greater insulation capacity for older, hen chicks compared to younger, hen chicks, resulting in reduced heat transfer from the surface of the bird.

A second possibility for the difference in thermal response may be found in the chick's transition from poikilotherms to homoeotherms. This transition is speculated to be affected by the lipid composition in the egg yolk (Noble *et al.*, 1986; Weytjens, 1999). Reduced amounts of triglycerides, free cholesterol and phospholipids are found in egg yolk from hens 41 wks of age compared to egg yolk from hens 25 wks of age (Noble *et al.*, 1986). No difference in the total amount of unsaturated fatty acids occurs in egg yolk from different aged hens (Noble *et al.*, 1986), however, a difference is found in the proportion of individual fatty acids (Latour *et al.*, 1998). Lower concentrations of linoleic, arachidonic and oleic acids, are found in yolks of fresh eggs from 36-wk-old hens compared to 51- and 64-wk-old hens (Latour *et al.*, 1998). Latour *et al.* (1998) also described a difference in the absorption rate of yolk lipids by developing embryos from young hens. Higher concentrations of linoleic, arachidonic and oleic acids, are found in yolk sacs of newly hatched chicks from 36-wk-old hens compared to 51- and 64-wk-old hens (Latour *et al.*, 1998). Lipoprotein lipase is speculated to be involved in the utilization of lipids in the developing embryo (Speak *et al.*, 1993). If concentrations of lipoprotein lipase are predetermined by the hen, it may help to explain why chicks from older hens are able to absorb lipid faster compared to chicks from younger hens.

Feathers play an important role in thermal regulation, providing an external layer of insulation for the avian species. Yahav *et al.* (1998) demonstrated the importance of feathers as insulation using a strain of 4-wk-old chickens called naked neck chickens. A difference in the genetics of the naked neck chicken determines the phenotype (extent of feather growth or coverage, from bare to fully covered) on their neck (Patra *et al.*, 2002). The gene responsible for naked neck is dominant, meaning that so long as an individual has one allele there will be reduced feather growth on the neck. A comparison of neck surface temperatures between heterozygous (partially feathered) and homozygous dominant (not feathered) chickens exposed to either 35 or 15°C, showed lower neck temperatures in the homozygous-dominant chickens at the 15°C exposure (Yahav *et al.*, 1998).

It is speculated that poultry are able to change the density of their feathers over extended periods of time – increasing feather density to cope with cold exposure temperatures and decreasing feather density to cope with hot exposure temperatures. A decrease in the density of feather growth has been demonstrated in broiler chickens subjected to an exposure temperature of 32°C from 3 to 9 wks of age (Cooper & Washburn, 1998). A comparison of two strains of similar broiler chickens, one originating from a northern province in China and one from a southern province, showed different amounts of feather follicle densities (Chen *et al.*, 2011). Both strains were subjected to 20°C during 4 to 6 wks of age, resulting in the northern strain having greater feather follicle densities on their backs compared to the southern strain.

The extent of feather cover as a coping mechanism for temperature exposures does not always refer to the insulation effect the feathers provide. As previously mentioned, body heat in poultry is normally lost from the skin through convection. By wetting the skin, the process of heat loss changes from convection to evaporation. Feathers act as a water resistant layer (Xing, 2011); keeping birds dry in wet or humid conditions. Should the feathers become saturated with water, the bird becomes increasingly susceptible to evaporative heat loss in the wet areas. On a side note, soaked feathers provide little insulation due to the loss of trapped and heated air between the feathers and the skin.

At high exposure temperatures this is a positive aspect, providing an alternative pathway for the loss of unwanted body heat. This method is implemented in layer barns, with the hens becoming wet by misting systems installed above the cages (Chepete and Xin, 2000). In situations where the exposure temperature is low or at a standard temperature, the loss of body heat due to evaporation is a negative aspect as poultry have to make up the heat lost by increasing the heat from metabolism. Such a situation can arise due to poor barn maintenance resulting in wet bedding and leaks within the system that provides drinking water for the birds.

High relative humidity also has the ability to reduce respiratory evaporation as the air inhaled or passed over the gular region is already saturated with moisture. The water within the body tissues are therefore, unable to mix with the air and be removed from the body. This restricts the movement of heat from within the bird to the environment, causing the core temperature of the bird to rise (Lacey *et al.*, 2000) and ultimately the bird to become heat stressed.

2.2.3. Thermal Comfort in Poultry

Comfort is defined as a condition in which an animal does not physically or mentally suffer and is considered to be at ease (Collins English Dictionary, 2009). Thermal comfort occurs when the state of an animal meets the aforementioned criteria at an apparent temperature (a specific temperature as affected by RH, wind speed and radiation). A thermal comfort zone is therefore a range of temperatures at which an animal feels comfortable. The difficulty in determining whether an animal is comfortable lies in the ability of being able to evaluate when an animal is not comfortable. By anthropomorphizing, we can speculate that, in regard to exposure temperatures, what causes humans to be uncomfortable also causes animals to be uncomfortable. Exposed to low temperatures, humans feel cold, a state considered being uncomfortable, and measures are often taken to maintain body heat.

Chepete & Xi (2002) developed a total heat production curve for both chickens (broiler and layer) and turkeys as a function of body mass at a set range of exposure temperatures. For broilers, this range was from 19 to 30°C; for layers, it was 21 to 30°C;

and for turkeys, it was 15 to 30°C. The heat production curve for turkeys is not applicable to heavy toms (larger than 12 kg in body weight), as there were insufficient data to make an appropriate comparison. These curves were produced from an analysis of published research reporting heat production in poultry. Analysis parameters included: measurement method of heat production, drinker system and nutrition level provided, lighting conditions, the strain, breed, age, body mass and number of test subjects as well as the duration and value of the exposure temperature and RH. From this study, we have a better understanding of how much heat is normally produced from different sizes of birds within a set range of temperatures. From there, we are able to estimate the exposure temperature required to provide thermal comfort.

It is important to note that not all increases in heat production are due to changes in exposure temperature. An excellent example of this is the increase of core temperatures due to mental stress. This is demonstrated in a study by Cabanac and Guillemette (2001) where core temperatures increased in female common eider ducks, handled every 4 min over a 32-min period. Core temperatures rose significantly during the first 8 min and then slowly began to level off. The rise in core temperature was most likely due to the expression of the fight or flight response. Metabolic processes increase to produce stored energy for either defense or locomotion (Ferreira *et al.*, 2012) causing a rise in internal temperature. A constant temperature was not obtained by the end of the testing period, indicating that the birds never became fully relaxed. Habituation, or the improvement of tolerance to handling, in these birds was presented by a reduction in the rise of core temperatures for the ducks after 10 days of handling for a short period of time each day (long enough to take an internal temperature reading). Core temperatures may, therefore, be used to determine comfort as there should be no change in core temperature if the birds are comfortable (Ferreira *et al.*, 2012).

Measuring core temperature changes in animals is not always feasible, especially within a production setting. For this reason, behaviours are often used as a measure of comfort. As animals express these behaviours to alter their physical state (example, body temperature) they are good indications that an animal is not comfortable; however, it is

important to know that not all behaviours are appropriate indicators of thermal comfort as they can be altered by other factors.

As different behaviours can take place for different reasons, often the agriculture community relies on the productivity of animals to determine if they are comfortable. The perceived notion is that uncomfortable animals will have reduced production characteristics or provide reduced product quality or quantity. A few examples include: reduced growth or reproduction (all agricultural species), reduced muscle quality (meat producing species) and reduced total milk yield (dairy species).

In poultry raised for meat production, the consumption of feed and its conversion to body tissue are vital production characteristics (Ferreira *et al.*, 2012). A reduction in growth or an increase in feed consumption coupled with little to no increase in tissue growth (when fed an appropriate diet), indicates by the above standard that the birds are uncomfortable. Exposure temperature has the potential to affect core temperature, requiring birds to alter their metabolic processes. An increase in feed consumption is observed in cold birds, as they require more energy for thermal regulation (example, shivering or vasodilatation/constriction) and an increase in metabolic heat (Hurwitz *et al.*, 1980). Conversely, if commercial poultry species are too hot, they may consume less feed to reduce heat produced through catabolism (Hurwitz *et al.*, 1980). Feed not being utilized for growth and reduced body weights are a significant concern, as they can have a negative impact on bottom line profits (Hurwitz & Talpaz, 1985). These changes in production, so long as feed quality is not an influencing factor, can therefore be used as a potentially easy way to measure poultry comfort.

It is important to note that no one method for determining comfort in animals is perfect; each has its own restrictions. Using a combination of all the methods in some form is ideal to ensure that the actual state of the bird is not misinterpreted.

2.3. Poultry Responses to Exposure Temperatures

Understanding how birds respond to current production temperatures is vital before adjustments to these temperatures can be made. Changes in thermal responses can only be determined if there is a clear definition of a normal response. A study using

infrared measuring technology by Cangar *et al.* (2008) aimed to develop a 3-dimensional model of surface temperatures in growing broiler chickens. Surface temperatures were obtained from 1 of 3 different images: a side, bottom or top view, with 7 to 11 different body areas being assessed, depending on the view. The chickens were housed at normal standard commercial settings with the exposure temperature starting from 29.5°C at 5 days of age and ending at 21°C by 37 days of age.

Surface temperatures from the cheek (illustrated as the side of the head not including the beak, comb or waddle), measured from the side view, and inner thigh, measured from the bottom view, were the highest in temperature and ranged from 39 to 41°C. The coldest surface temperatures, ranging from 33 to 24°C, were from the neck and wing for the side and top views, as well as the sternum (illustrated as the interpelvic tail/dorsal region), located in the top view. The absolute surface temperature was seen to decrease with the increase in age and speculated to be due to feather growth. The body locations with no feather growth had large differences between their surface temperatures and exposure temperature. Feathered locations were found to have only a small difference between their surface temperatures and exposure temperature.

These differences between surface and exposure temperatures also provide an illustration of the thermal responses for the feathered and featherless body locations over time. A constant difference between the two temperatures indicates that the surface temperature is changing at the same rate and to the same degree as the exposure temperature. An increase in the difference means that the two temperatures are changing at different rates and tendencies (increasing or decreasing). Finally a decrease in the difference indicates that the surface temperature is changing to become more similar to or equal with the exposure temperature or vice versa.

Differences between the exposure temperature and the surface temperatures measured in the side view showed the temperatures of featherless locations remaining constant for the first 21 days of growth. For the remaining 16 days of this study, the surface temperatures became closer in temperature to the exposure temperature, although they never became equal to it (refer to Figure 2.2). The responses of the feathered

locations were more complicated with some locations remaining constant for the first 10 days of age, while others remained constant for the first 21 days. After reaching 10 or 21 days of age, the surface temperatures then decreased in temperature to become closer to the exposure temperature for the remainder of the study period (refer to Figure 2.2).

Surface temperatures of the feathered (top view) and featherless (bottom view) locations stayed constant for the first 10 days, decreased in temperature from day 10 to 15, leveled off to have a constant temperature again from day 15 to 21 and then decreased in temperature from day 21 to 37 (refer to Figure 2.2). The featherless locations (top view) and feathered locations (bottom view), had similar temperature responses as the featherless locations viewed from the side (refer to Figure 2.2). The temperatures remained constant during the first 21 days and then decreased for the remainder of the study.

These data show that the response of chickens to exposure temperatures, assuming that the chickens are in a state of thermal comfort and not requiring alterations to thermal regulation, is variable depending on bird age and the location being measured. It stands to reason then, that changes in exposure temperature will also have varying effects on a bird's thermal response at different stages of growth and different body locations.

2.3.1. Increasing Exposure Temperature

High exposure temperatures have the ability to affect both core and surface temperatures. Changes in body temperature are dependent on the severity of the increase in exposure temperature. Both an instantaneous and gradual increase of exposure temperature from 20 to 40°C caused core temperature to increase by approximately 2°C in mature layer hens (Richards, 1970 and 1971). Raising the exposure temperature by a smaller amount (from 20 to 30°C) resulted in either no change in core temperature

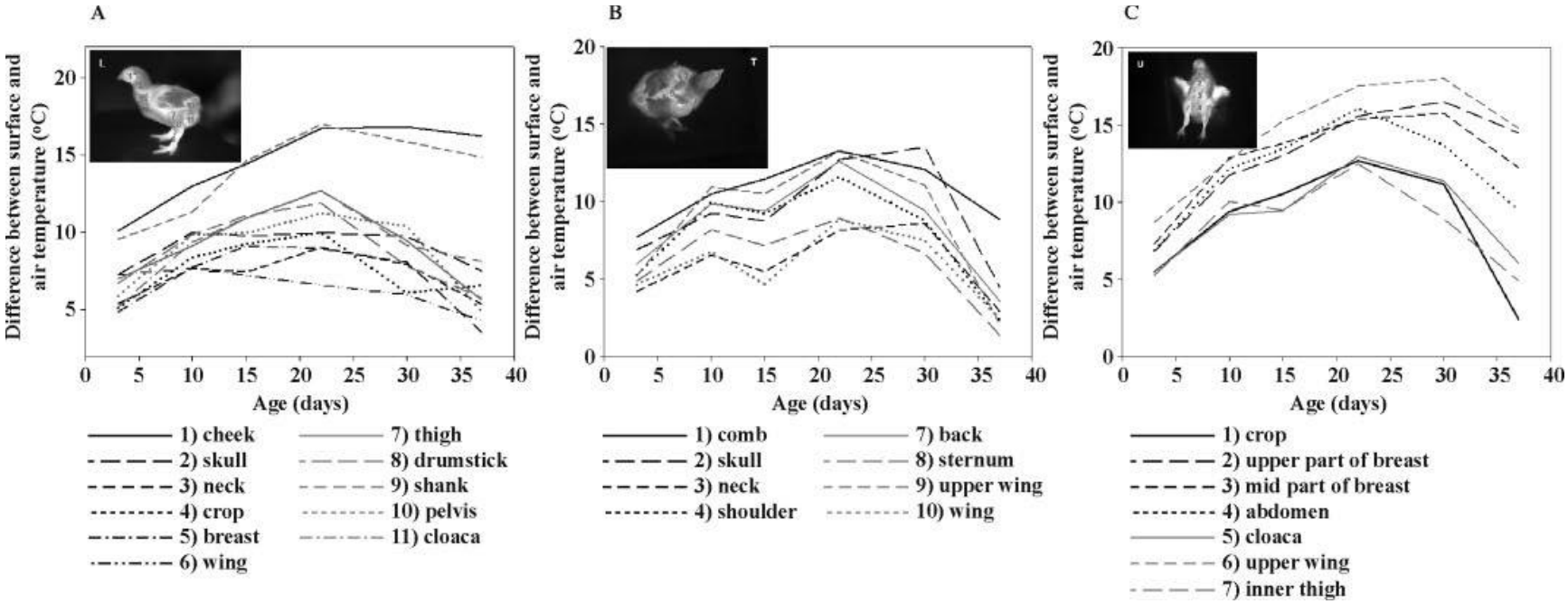

Figure 2.2. Difference between measured body temperatures and exposure temperature of broiler chickens exposed to the standard temperature curve from 0 to 37 days of age, taken from the side (A), back (B) and bottom (C) views. (Cangar *et al.* (2008) n = 5

or an increase in core temperature by 1 (Richards, 1971) to 1.5°C (Cooper & Washburn, 1998). This difference in core temperature response may be due to age and/or strain of the birds, as these both have an effect on heat production.

The effect of exposure temperatures on surface temperatures is more dramatic than it is on core temperature. Surface temperatures are dependent on the extent of feather cover found on the part of the body being measured. Temperatures of body locations covered in feathers remained fairly constant for mature laying hens exposed to a gradual or instantaneous 20°C increase in exposure temperature (Richards, 1970 and 1971). Locations without feather cover increased in temperature from 21-24 to 34-42°C for these same layer hens (Richards, 1970 and 1971). Temperature measured directly below the skin of 8-wk-old turkeys exposed to either 20 or 30°C during a 4-wk growing period, from 4 to 8 wks of age, showed no difference between the two groups (Yahav, 2002). It is arguable whether the temperature below the skin can be classified as a surface measurement or not; however, it still provides important information on the removal of heat from the birds by convection. A minor increase in exposure temperature of approximately 4°C resulted in higher surface temperatures for both feathered and featherless surfaces of broiler chicken at 42 days of age (Nääs *et al.*, 2010). The featherless areas were seen to have a greater rise in temperature than the feathered areas, speculated to be due to the insulation effect of the feathers. During the first 3 wks of growth, natal down produced during embryonic development (Lucas & Stettenheim, 1972) is slowly replaced by feathers. Down offers moderate insulation, and is considered to have an insulation effect between the high insulation of mature feather cover and no insulation provided by bare skin (Lucas & Stettenheim, 1972).

To combat the negative effects caused by high exposure temperatures, the processes of thermal regulation are exploitable at younger ages to improve the birds' responses during later stages of life. Thermal conditioning is the process of subjecting young birds to extreme changes in exposure temperature for short periods of time in order to alter their thermal response levels so they may be better able to cope with similar temperatures later in life. Yahav & Plavnik (1999) completed research designed to obtain the optimal temperature for thermal conditioning chicks. Exposing broiler chickens at 5

days of age to temperatures of 26 or 36°C for 24 h had no effect on the chicks as there was no change in core temperatures between the two groups (Yahav & Plavnik, 1999). At 42 days of age, the chickens were exposed to a temperature of 35°C for 6 h. No difference in core temperature was found between the chickens pre-exposed to 35°C and the chickens that were not. Due to this, Yahav & Plavnik (1999) speculated that 35°C was therefore not an ideal exposure temperature for thermal conditioning.

A later study conducted on broiler chicks tested the optimal age and temperature needed for thermal conditioning (Yahav & McMurtry, 2001). Optimal age of conditioning was determined by exposed chicks to 36°C for a single 24-h period during 1 to 5 days of age (treatment group) and comparing them to chicks that had not be exposed to the change in temperature (control group). The authors concluded that age of exposure is not significant as there was no difference in core temperature between the control and treatment groups when they were subjected to 35°C for 6 h at 42 days of age. The exposure temperature itself was found to have an effect with the smallest rise in core temperature (roughly 3.4°C) occurring at the exposure temperature of 36°C and the highest (roughly 4.5°C) occurring at 40.5°C when chicks were thermal conditioned at 3 days of age. Due to these body temperature responses, it was theorized that the exposure temperature used for thermal conditioning is more important than the age at which thermal conditioning occurs.

A second trial was therefore conducted to determine the optimal temperature at which to thermal condition chicks. As the effect of exposure temperature occurred in the chicks conditioned at 3 days of age in the previous study, this age was selected for further testing. The chicks were thermal conditioned to either: 36, 37.5, 39 or 40.5°C for 24 h (treatment group) and compared to chicks that had not been conditioned (control group) at 42 days of age when both groups were exposed to 35°C (Yahav & McMurtry, 2001). Core temperature was found to be the same between the two treatment groups, regardless of exposure temperature, indicating that the temperature used for thermal condition is not significant.

It should be noted that changes in core temperature by more than a few degrees has negative effects on poultry, potentially resulting in death. The large increases in core temperature within the first trial make the corresponding conclusion questionable. This is further expanded upon in the second trial, when no difference in core temperature occurred due to exposure temperature. Due to this, the results obtained from the second trial are more reliable and the corresponding conclusion more accurate in comparison to the first trial.

Air RH has both negative and positive impacts on the thermal responses of poultry. With an exposure temperature of 35°C, an increase in RH from 35 to 85% was found to reduce core temperature in 1-wk-old broiler chickens from 41.84 to 41.58°C (Lin *et al.*, 2005a) while raising core temperature in 4-wk-old broilers from 42.07 to 42.81°C (Lin *et al.*, 2005b). The entire body surface temperature of 1-wk-old broiler chickens increased from 36.4 to 37.8°C with the increase in RH from 35 to 85%. In comparison, skin temperatures decreased from 39.4 to 38.6°C and feather temperatures decreased from 39.4 to 38.6°C at 4 wks with the increase in RH (Lin *et al.*, 2005a & b). Changing the exposure temperature from the aforementioned 35°C to 30°C with the same levels of RH showed a different thermal response in the surface locations of the 4-wk-old chickens. Skin temperatures increased from 35.0 to 37.1°C and feather temperatures increased from 33.9 to 35.2 °C when the humidity levels were increased. Core temperature remained relatively the same between the different RH exposure groups at 30°C. Levels of humidity in the air, as discussed in previous sections, are important when determining the thermal responses of poultry.

A relatively small increase, compared to the previous examples, in RH from 50 to 80% showed an increase (on average, of 0.8°C) in core body temperature for broiler chicken at 6 wks of age (Lacey *et al.*, 2000). A comparison of core temperatures between chickens exposed to 50 and 80% RH showed a continual and parallel rise in temperature between the exposure temperatures of 31°C and 34°C. Conditions at 80% RH resulted in higher core temperatures compared to 50% RH.

While high RH at high exposure temperatures produces negative effects, being physically wet may not provide the same negative impact. Chepete & Xin (2000) tested the effect of sprinkling water onto the head, head appendages (example, comb and waddle) and neck of layer hens exposed to a temperature of approximately 40°C at 20, 38 or 56 wks of age. Hens of all 3 ages not sprinkled with water upon the onset of panting had a mortality rate of 100%, with an average survival length of approximately 2.3 h. The core temperature of these hens was seen to rise by roughly 2.9°C. Hens that did receive sprinkling had a mortality rate around 40%, and core temperature of the surviving birds rose by approximately 1.8°C. The core temperature of the birds that died in the sprinkled group rose by approximately 2.8°C and the survival length was roughly 3.5 h. The age at which the chickens were tested affected the rise in core temperatures with smaller increases associated with older birds. This reduction in core temperature response occurred in both hens sprinkled and not sprinkled with water.

Strain and age have been shown to dictate the effectiveness of reducing heat stress by sprinkling water on the surface of layer chickens. Groups of ATABEY (White) and ATAK (Brown) chickens were subjected to exposure temperatures of 30.2 or 40.2°C with RH ranging from 16 to 65% during wks 20 or 62 of age (Mutaf *et al.*, 2009). The hens were divided into two treatment groups: sprinkled with water or not sprinkled with water (Mutaf *et al.*, 2009). Core temperatures were higher in chickens not sprinkled with water, for both strains at 20 and 62 wks of age, by roughly 0.27°C. The head, defined as the location behind the comb, temperature of the 62-wks-old chickens was roughly 0.65°C higher than the 20-wks-old chickens when both age groups were not sprinkled with water. In the sprinkled group, chickens at 62 wks of age had lower head temperatures by roughly 1.3°C compared to the head temperatures of chickens at 20 wks of age. The brown strain of chickens had a higher head temperature at 62 wks of age compared to the white strain of chickens when both strains were sprinkled with water. Similar to the core temperatures, the dorsal (back between the wings) surface temperatures were the same between strains and age when the chickens were not sprinkled with water. Dorsal temperatures between the white and brown chickens sprinkled with water also showed no difference at 20 wks of age. Brown chickens 62 wks old had higher dorsal surface temperatures compared to white chickens when both strains were sprinkled. White and

brown chickens, 62-wks-old and sprinkled with water, had higher dorsal temperatures than white and brown chickens that were 20-wks-old and sprinkled with water. These results show that older birds are affected to a greater degree when wet compared to younger birds, and ATAK chickens were less affected by wetting than ATABEY.

Ventilation also has a key role in helping birds reduce their body temperatures during periods of high exposure temperature. The speed of air moving through a barn determines the extent of heat loss by convection. Entire body surface temperatures of 4-wk-old broiler chickens exposed to 35°C decreased with an increase in air speed from 0.8 $^{m}/_{s}$ to 1.5, 2.0 and 3.0 $^{m}/_{s}$ (Yahav *et al.*, 2004). A more detailed study by Yahav *et al.*, (2008) measured body (colon), head and leg temperatures of 3-wk-old turkeys exposed to either 25, 30 or 35°C in combination with an air speed of either 0.8, 1.5, 2.0 or 2.5 $^{m}/_{s}$.

Thermal responses of turkeys were seen to be dependent on exposure temperature as well as air speed (refer to Figure 2.3). Body temperature remained relatively constant at each air speed when exposed to 25°C. An increase in exposure temperature to 30°C resulted in an increase in body temperature when air speed was increased from 0.8 to 2.0 $^{m}/_{s}$. No change in temperature occurred when air speed was raised from 2.0 to 2.5 $^{m}/_{s}$. Finally an exposure temperature of 35°C caused body temperature to decrease when air speed increased from 0.8 to 2.0 $^{m}/_{s}$. Raising the air speed from 2.0 to 2.5 $^{m}/_{s}$ resulted in an increase in body temperature. While body temperature remained constant at 25°C, head and leg temperatures decreased when air speed increased from 0.8 to 2.0 $^{m}/_{s}$. When air speed was increased from 2.0 to 2.5 $^{m}/_{s}$ these body temperatures were seen to increase. Exposure to 30°C caused an increase in head and leg temperatures from 0.8 to 1.5 $^{m}/_{s}$, a decrease from 1.5 to 2.0 $^{m}/_{s}$ and finally an increase again from 2.0 to 2.5 $^{m}/_{s}$. Head and leg temperature responses were found to be different with the exposure temperature of 35°C. An increase in head temperature occurred when air speed increased from 0.8 to 2.0 $^{m}/_{s,}$ followed by a decrease from 2.0 to 2.5 $^{m}/_{s}$. In comparison leg temperatures remained relatively constant at all air speeds.

Changes in temperature response occurred mainly when the air speed was set to 2.0 $^{m}/_{s}$. It is unclear why this would have happened, as increasing air speed should have improved heat loss through convection. Head and leg temperatures should therefore, have continually decreased as air speed increased. In comparison, so long as the birds were not heat stressed, body temperature should have remained constant. Loss of heat from the surface would be balancing out heat production within the birds. At high exposure temperatures birds attempt to reduce heat production and increase heat loss through thermal regulating locations. This should result in higher surface and body temperatures, which was found within the aforementioned study.

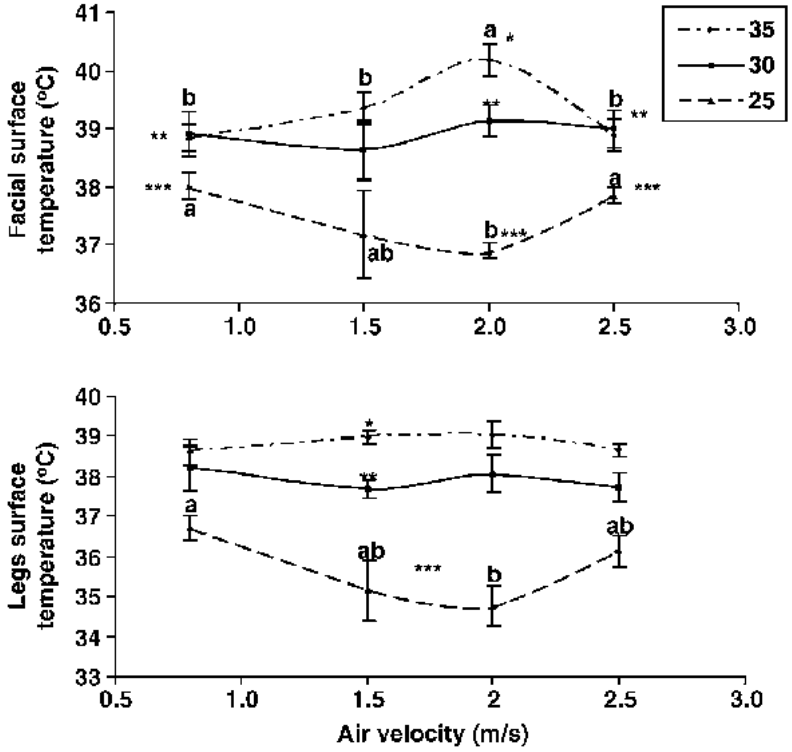

Figure 2.3. Measured facial and leg temperatures of 3-wk-old turkeys exposed to either 25, 30 or 35°C in combination with an air speed of either 0.8, 1.5, 2.0 or 2.5 $^{m}/_{s}$. (Yahav *et al.*, 2008) Different letters indicate differences between air speeds exposed to the same temperature and * indicate differences between temperatures exposed to the same air speed ($P<0.05$). n = 8

2.3.2. Decreasing Exposure Temperature

In some climates, exposure to especially low temperatures is a greater concern than exposure to very high temperatures. Lower core temperatures were found in turkeys reared from 4 to 8 wks of age at an exposure temperature of 10°C compared to turkeys at 20°C (Yahav, 2002). The temperature measured directly below the skin of these same turkeys was found to be the same between the turkeys exposed to 10°C and the turkeys exposed to 20°C. Thermal responses of naked neck and normal feathered broilers at a similar age (4-wk-old) exposed to either 25°C or 15°C showed no change in core temperature and an approximate 1°C drop in the temperature directly below the skin from the 25°C to the 15°C group (Yahav *et al.*, 1998). The exposure of skin along the neck of naked neck chickens did not show any difference in temperature when compared to the normal feathered birds exposed to the same temperature. Lowering exposure temperature has varying effects on core and surface temperatures, making the likelihood of predicting a single general normal thermal response unlikely.

The majority of studies testing low exposure temperatures focus on poultry at young ages as they are poikilotherms. One example of this is a study by Shinder *et al.* (2007), which exposed chicks at 3 and/or 4 days of age to extreme reductions in exposure temperature. Exposure durations were 3 h at 33 (standard), 15 and 10°C and 1.5 h for 5°C. Length of exposure and the specific temperature were found to be important as core temperature decreased (1 to 12°C) with lower temperatures and longer exposure periods. Surface temperatures dropped by a greater extent and were not affected by age of exposure. Surface temperatures of chicks exposed to 15°C dropped by approximately 12°C compared to surface temperatures of chicks exposed to 33°C. The 10°C exposure resulted in a drop in surface temperature from 14 to 18°C and the 5°C exposure resulted in a drop in surface temperature from 19 to 23°C. When the exposure temperature was increased to 33°C the core and surface temperatures were observed to increase and match the core and surface temperatures of the chicks continually subjected to 33°C. A less severe drop in core temperature, only 2°C, occurred in male layer chick ages 1 or 4 days, exposed for 3 h to 12°C compared to chicks exposed to 30°C (Mujahid & Furuse, 2010). A change in exposure temperature from 30 to 20°C resulted in a decrease in core temperature of roughly 0.5°C in chicks of the same age (Mujahid & Furuse, 2010). These

studies indicate that the greater the drop in exposure temperature, the greater the effect there is on chick body temperatures.

Exposing young birds to severe drops in temperature not only provides information on how these birds respond, but it also improves their thermal tolerances to low exposure temperatures at older ages. One example of thermal conditioning poultry to low exposure temperatures is in broiler chicks exposed for 3 h to 15°C at 3 and 4 days of age (Shinder *et al.*, 2002). At 21 days of age, a smaller decrease in core temperature was observed in conditioned chickens compared to non-conditioned when they were all exposed to 15°C (Shinder *et al.*, 2002). An exposure temperature of 22°C, believed to be an acceptable exposure temperature for 21-day-old broiler chickens, showed core temperatures of conditioned and non-conditioned chicks to be relatively the same (Shinder *et al.*, 2002), indicating that thermal conditioning did not alter normal thermal responses.

2.3.3. Changes in Production with Changes in Exposure Temperature

A producer's income is based, in part, on the quality and quantity of the final product they send to market. Changes to production management practices must therefore, be made with caution to ensure there are no negative repercussions on the products. When considering changes to rearing temperatures, it is important to look at the effects these changes may have on growth and feed efficiency, which affect the financial return from the final marketable product.

In 1980, Hurtwitz *et al.* studied the feed energy requirements and growth of chickens and turkeys at different exposure temperatures from 4.5 to 8.5 wks of age. The chickens were tested at one of four exposure temperatures: 12, 19 (standard), 28 or 32°C. As exposure temperature increased, weight gain in the chickens decreased. The temperature that resulted in the greatest weight gain was 12°C and the second best temperature was 19°C. Feed efficiency ($^{feed}/_{gain}$) decreased with the increase in exposure temperature from 12 to 28°C and then increased again at 32°C. The best feed efficiency ($^{feed}/_{gain}$) was coupled with the exposure temperature of 28°C, followed by 19, 32 and

finally 12°C. Energy maintenance requirement as a function of exposure temperature saw the lowest feed energy requirements associated with 28°C and the highest with 12°C.

In a similar study, turkeys were tested at one of five exposure temperatures: 12, 18, 24 (standard), 28 or 32°C. Weight gain improved with the increase in exposure temperature from 12 to 18°C, followed by a decline with the increase in exposure temperature from 18 to 32°C. Feed efficiency ($^{feed}/_{gain}$), as a function of exposure temperature, also followed this increasing to decreasing curved pattern, with the turkeys exposed to 24°C having the best feed efficiency ($^{feed}/_{gain}$). Feed energy requirement as a function of exposure temperature was dependent on gender, with females having their lowest requirements at 28°C and males having their lowest at 24°C. The highest feed energy requirements for both genders were associated with the 12°C exposure temperature.

Assessing the effects of increasing exposure temperatures, turkeys exposed to either 15 (standard) or 30°C at 20 wks of age showed reduced cold carcass yields (final market product) in the 30°C group (Veldkamp *et al.*, 2000). A positive aspect observed with increasing the exposure temperature in this study was an enhancement in feed efficiency. The turkeys exposed to 30°C gained more body weight for the amount of feed they consumed. The optimal temperature to raise turkeys between 4.5- to 8.5-wks-old was found to be the standard exposure temperature of 24°C.

A similar response was seen in 21- to 42-day-old broilers, with lower body weight gains occurring in birds exposed to 35°C compared to 20°C (Donkoh, 1989). Opposite of the turkey experiment, an increase of 15°C in exposure temperature from 20 to 35°C resulted in a reduction in feed efficiency. Increasing the exposure temperature by approximately 10°C (from 21 to 32°C; Cooper & Washburn, 1998), had the same effect as increasing the temperature by 15°C. Weight gain was seen to be reduced, while feed conversion ratios ($^{feed}/_{gain}$) were seen to be higher in broiler chickens age 28 to 49 days (Cooper & Washburn, 1998). A smaller increase in exposure temperature from 20 to 25°C showed no change in body weight gain for 21- to 42-day-old broiler chicken (Donkoh, 1989) and no difference was seen in the feed efficiency ($^{feed}/_{gain}$) between these

two groups. This study indicates that during the ages of 21 to 42 days, chickens become heavier and generate more body tissue per feed consumed at temperatures lower than the standard.

In an attempt to reduce the decrease in body weight gain that occurs at high exposure temperatures, as demonstrated by the above experiments, young birds may be thermal conditioned to high exposure temperatures. A study by Yahav & Plavnik (1999) illustrated greater body weights over a 1 to 6 wk growth period, in broiler chicken exposed to temperatures of 36°C for 24 h at 5 days of age, compared to chickens that were not exposed. Feed efficiency ($^{feed}/_{gain}$) was not seen to be different between these two groups, having an average ratio of 1.69. Thermal conditioning to high exposure temperatures therefore, improves weight gain but results in the birds consuming more feed to be able to deposit the extra tissue as they maintain the same feed efficiency as the birds not conditioned.

Increases in RH starting from 40-45% and rising to 60-65% has also been shown to increase feed intake and final body weight of both male and female broiler chickens, exposed to 35°C during 4 to 8 wks of age (Yahav *et al.*, 1995). Increasing the RH beyond 65% caused a reduction in feed intake and final body weight. Feed intake and final body weight decreased in turkeys, aged 4 to 8 wks, exposed to 35°C, when RH was increased from 40-45% to 50-55%. A rise in RH from 50-55% to 70-75% resulted in relatively constant feed intakes and final body weight. The responses reported by Yahav *et al.* (1995) for chickens are the opposite of what is expected. Increases in RH are accepted to cause reductions in heat loss through respirator evaporation. As a result body temperature would rise and feed consumption would decrease. Lower feed intake over an extended period of time will lead to lower final body weight; so long as the birds are not provided time to make up for this loss.

The difference seen between chickens and turkeys may be due to the chickens developing hyperthermia (defined by high cloacal temperatures) when RH was above or below 60-65%, for all 4 wks of study. It is possible that these high cloacae temperatures were influenced by other factors such as illness to stress. Data obtained from birds in

such a situation would result in inaccurate conclusions, making the responses seen in the turkeys more reliable.

Exposing turkeys from 4 to 8 wks of age to 10°C resulted in lower final body weights compared to an exposure of 20°C (standard) (Yahav, 2002). The feed efficiency ($^{feed}/_{gain}$), was also found to be higher in the turkeys exposed to 10°C compared to the group exposed to 20°C. A decrease in body weight has also been found between broiler chickens exposed to 20°C compared to 10 and 15°C (Chen *et al.*, 2011). Unfortunately feed intake was not measured within this study, making a comparison of feed efficiency between the two studies impossible. In comparison, male broiler breeder chicks exposed to lower exposure temperatures over the first 3 wks of growth showed lower body weights compared to chicks exposed to the standard temperature (Ipek & Sahan, 2006). The control (standard temperature) chicks were subjected to a starting temperature of 33.3°C which decreased by roughly 2.8°C each wk, while the cold exposure chicks were subjected to a starting temperature of 29.0°C which decreased by 3°C per wk. When both groups of birds were subjected to a standard exposure temperature of 21°C at 6 wks-of-age, the body weights of both groups became similar. From these three studies it can be determined that reducing exposure temperature lowers the rate of body weight gain and increase the feed required to gain 1 g of tissue.

This negative effect on weight gain due to low exposure temperature is not always observed. A study by Mujahid & Furuse (2009) was conducted with two groups of 2-day-old broiler chicks exposed to either the standard recommended exposure temperature of 30°C or 10°C below the standard for a 12-h period. It was determined that upon conclusion of the 12 h, there was no difference in body weights of the groups. As well, feed consumption during the 12 h was no different between the two groups. As this study only lasted a short time and used young birds, it is difficult to extrapolate if this effect will be observed over longer periods or in older birds. A difference in exposure temperature from approximately 25°C to an average of 10°C (temperatures dependent on environmental conditions) during 21 to 42 days of age in male and female broiler chickens was seen to have no effect on total body weight (Blahová *et al.*, 2007), illustrating that it may be possible to generalize the effects observed in young birds and

that the effects due to low exposure temperatures are not always negative. A negative aspect, however, was seen with low temperature exposures within this study. Feed efficiency ($^{feed}/_{gain}$) was higher in chickens exposed to low temperatures compared to chickens exposed to higher temperatures (ranging from 25 to 22°C).

Breed of chicken has been document to be connected to changes in body weight due to low exposure temperatures. Huainan broiler chickens from a northern province in China had lower body weight gains at 15 and 10°C compared to Wenchang broiler chickens from a southern province (Chen *et al.*, 2011). The geographical origin of these birds may have been the reason for this difference in body weight if the Wenchang were from the north and the Huainan were from the south. The Wenchang chickens would have most likely adapted over generations to lower temperatures being from a colder climate compared to the Huainan chickens having come from a warmer climate. The adaptation, thus would have allowed the Wenchang chickens to more easily and efficiently cope with decreases in exposure temperature, as illustrated by the improved weight gain. As this is not the case, a different adaptation due to the difference in genetics between the 2 strains may be occurring.

Unlike thermal conditioning to high exposure temperatures, no improvement was observed with thermal conditioning to low exposure temperatures in a study by Yardimci *et al.* (2006). A group of 5-day-old broiler chicks was exposed to 15°C for 3 h while a second group was not conditioned. Measuring wkly body weights and feed efficiency during 1 to 6 wks of age revealed no difference between the two groups (Yardimci *et al.*, 2006). Broiler breeders exposed to a cold temperature curve (wk 1: 29°C, wk 2: 26.4°C and wk 3: 23.1°C) during the first 3 wks of age were observed to have a higher weight gain at 5 and 6 wks of age compared to birds that were exposed to the standard temperature (Ipek & Sahan, 2006). Given the differences in weight gain, both groups of chickens had the same total weight at 6 wks of age. An improvement in energy intake and energy retention, though not significant, was found in broiler chickens at 35 days of age exposed to 28°C at 5 days of age, compared to broiler chickens of the same age exposed to 34°C (Baarendse *et al.*, 2006).

Objectives

Poultry barns are created to optimize bird health as well as productivity and minimize expenses. Efforts have been made to maintain uniform air quality, relative humidity (RH) and a predetermined ambient temperature. The problem with these improvements, however, is that they are not necessarily being developed with the current production bird's physiology in mind. As previously discussed, poultry today have changed significantly from what they were even as early as a decade ago. Due to this, the temperatures being utilized in poultry barns may no longer be optimizing bird health and productivity, while minimizing production expenses.

Before making any changes, it is therefore, important to re-evaluate poultry production temperature management practices and how appropriate they are for the current genetic potential. Within the literature, temperature studies have been conducted to determine the thermal responses of heat or cold stressed poultry. To date, few studies have examined the thermal responses of current production birds to present thermal management practices. Of these studies, no work has been conducted on turkeys. Objectives for this project were therefore selected to answer some basic but important questions. These objectives were to:

1. Determine the thermal (surface temperature) response of turkeys to ambient temperature;

2. Determine the thermal (surface temperature) response of turkeys weekly over the first 12 weeks of production, and

3. Compare the change in thermal (surface temperature) response of turkeys at two different ambient temperature regimes over the first 12 weeks of production.

CHAPTER 3: Materials and Methods

3.1. Birds and Housing

Twelve tom Hybrid Converter turkeys, obtained from Lilydale Hatchery (Edmonton, AB), were randomly assigned to one of two treatment groups (n=6). Turkeys remained within the same group for the entire 12 wks of study and were identified using wing bands and one of six colours on either the head (carunculate skin) or the back (interscapular region or post-dorsal region), using animal markers. All birds were housed in a single square shaped home pen (floor space was roughly 3m by 3m, with a height of roughly 2m) within the turkey barn at the University of Saskatchewan Poultry Centre. From day 0-9, turkeys were housed in a brooder ring within the home pen. During the 12 wks of testing, turkeys were moved to a separate trapezoid shaped holding pen (floor space was roughly 3m by 1m long and 2m wide, with a height of roughly 2.5m) near the testing chamber, where they were housed for 24 hours (h) each wk starting at 7±1 days. Bedding of the home pen consisted of a base layer of shavings, and straw was placed as needed on top from day 9 to the end of the study. The holding pen contained only shavings as bedding for the entire study period and fresh shavings were added as needed.

Feed and water were provided *ad libitum* over the entire duration of the study in both the home and holding pens. The feeding program provided in the home pen was a commercial feeding program, consisting of 5 different diets (2 starter, 2 grower and 1 finisher). A detailed breakdown of each diet can be found within the appendices (refer to Appendix A to C). Within the holding pen, turkeys were provided starter diet #1 from wk 1-3, starter diet #2 from wk 4-10 and grower diet #2 from wk 11-12. More starter diet #2 was supplied to the holding pen then necessary and the amount of time the birds were on this feed was therefore extended causing the feeding program to progress directly to grower diet #2 and not reach finisher diet #1. Water was supplied by bell drinkers in both the home and holding pens.

Lighting for both pens consisted of two cycles: 23 h of light with 1 h of darkness for the first 9 days, and then 18 h of light and 6 h of darkness for the rest of the study. Artificial dusk and dawn were provided by slowly decreasing the light intensity 15

minutes (min) prior to being fully off at 5:00 (0-9 days of age) or 0:00 (10-84 days of age), and slowly increasing the light intensity 15 min prior to being fully on at 6:00 (0-84 days of age). Incandescent bulbs provided illumination at the intensity of 20 lux during the first 9 days with the addition of supplemental energy provided by an infrared heat lamp. Illumination intensity was reduced to 10 lux from day 10-35 and then again at day 36 to 2 lux for the remainder of the study in order to prevent aggression among the birds.

Barn (home and holding pen locations) temperatures were set using the standard temperature curve provided by Hybrid Turkey for the Hybrid Converter strain (Table 3.1). Ventilation was set to a minimum ventilation curve at which the efficiency of the fans did not go below a set level. The barn fans' ability to maintain proper air quality, with minimal dust, carbon dioxide, ammonia and relative humidity is determined by the movement of air through the fan and was adjusted based on bird weight.

Table 3.1. Duration of rearing temperature within the home barn

Age (days, d)	Temperature (°C)
0-9	30 + heat lamp
10-35	Decreased on average 0.32 °C/day from 30 °C (10 d) to 22 °C (35 d)
36-42	21
43-49	19
50-84	18

Trials were performed using a temperature-regulating chamber (floor space was roughly 0.8m by 1.2m, with a height of roughly 0.6m). The chamber had two mesh barriers, which made up two opposite walls of a six-sided box. One mesh barrier covered the air inlet pipe and one covered the air outlet pipe. Three solid insulated walls (floor, roof and one side wall) and one removable insulated wall used as a door (located on the side of the chamber) made up the other four walls (Figure 3.1). An infrared camera (FLIR model S60 with an accuracy of 2°C, FLIR Systems Inc. Burlington ON) used to measure surface temperatures (refer to Section 3.2.) was mounted on a tripod outside of the chamber with the lens set within a hole in the middle of the back chamber wall. Located directly beside and in line with the infrared camera was a web camera (Logitech model C905, Logitech, Fremont CA) used to take visual images. Two arm holes were placed within the removable wall to allow the handler access to the turkeys.

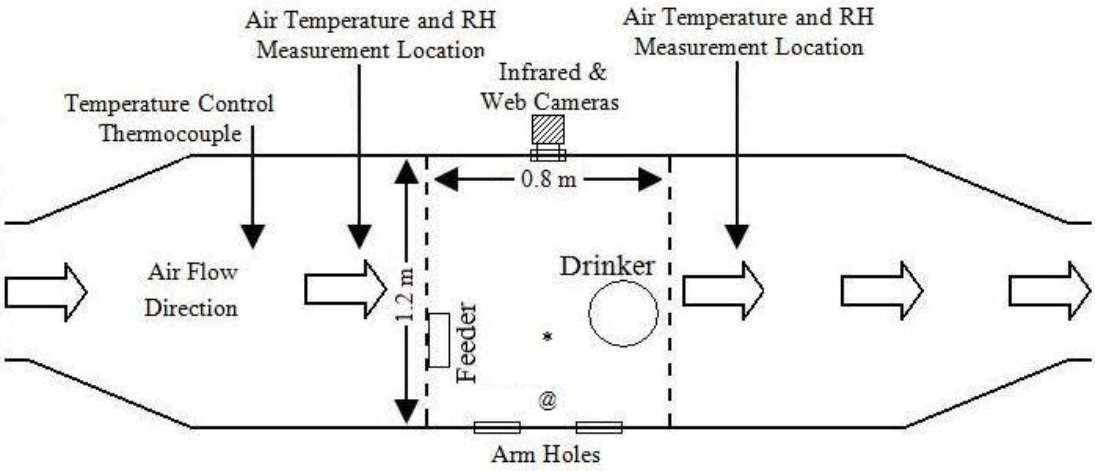

Figure 3.1. Internal, overhead diagram of the environmental test chamber. White arrows indicate the directional flow of air. * illustrates where the turkeys were placed for image collection during the first 4 wks. @ illustrates where the turkeys were placed for image collection during wks 5-12. Object sizes and placements within the diagram are not to scale.

The turkeys were acclimated to the chamber from day 2-4 for 2-h periods each day. During the trials, turkeys were housed individually within the chamber for 2 h. They were given 30 min to acclimate to the temperature inside the chamber, followed by 90 min of exposure to the same temperature for data collection. Experimental temperatures (Table 3.2) consisted of the control (T^{con}), defined as the Hybrid recommended rearing temperature curve, and the treatment (T^{trt}), 4°C below the control temperatures. Both feed and water were provided *ad libitum* within the chamber and the feeding program followed that of the holding pen. Continual light was provided within the chamber by six small lights set within the insulation of the roof. No attempt was made to control the relative humidity, however measurements every 60 seconds (s) by three relative humidity sensors located upstream of the chamber (refer to Figures 3.1 and 3.2) showed relative humidity to vary between approximately 18% and complete saturation. The large range in RH may have been caused by the cooling of air required for some trials. Warm air has a higher capacity to hold water vapor compared to colder air. As the warm air was cooled the percentage of water vapor held compared to the total amount that could be held decreased, thus resulting in a high measured RH. It is also possible that additional

Table 3.2. Experimental chamber exposure temperatures for the two treatment groups over the 12 wks of study

Age (days)	Control (°C)	Treatment (°C)
7	29	25
14	28	24
21	27	23
28	26	22
35	23	19
42	21	17
49	19	15
56	18	14
63	18	14
70	18	14
77	18	14
84	18	14

moisture was provided by way of the cooling system releasing moisture to the air which was then released into the testing room and ultimately re-circulated back into the chamber.

Thermocouples (Type-T, OMEGA Engineering, INC., Stamford, Connecticut) used to measure the exposure temperature during trials were positioned upstream and downstream from the chamber and connected to a CR1000 data logger (refer to Figure 3.1; Campbell Scientific, Edmonton AB). Measurements were taken every 30 s using Loggernet program version 3 (Campbell Scientific, Edmonton AB). Air was drawn into the chamber (0.25 m^3/s) from the external barn environment (outside air) and from within the testing room (refer to Figure 3.2) by a single fan (0-84 days of age). Thermocouples located upstream of the chamber were used to determine if the air temperature entering the chamber was at the required exposure temperature (refer to Figure 3.1), as required for age and treatment group. A heater located within the air inlet duct preceding the thermocouples (refer to Figure 3.2), increased the incoming air temperature when the temperature fell below the pre-set limit. A cooling system was also attached to the air inlet duct located between the external air inlet duct and the heater (refer to Figure 3.2). The cooling system consisted of cold water being pumped (Monarch ½ Effluent Pump,

Franklin Electric Co, Bluffton IN) through a radiator from a cooler (100L). The warmed water was returned to the cooler from the radiator where it was cooled again using crushed ice. The water temperature within the cooler was monitored using a thermocouple and crushed ice was added in varying amounts (approximately 4 litres) when the temperature increased to approximately 4°C below the target exposure temperature. The cooling system was operated when the external air temperature outside the barn was warmer than the experimental test temperature. This resulted in the cooling system mainly running during wk 6-12 for the treatment group, though it was used in some instances for the control birds and several times throughout the 5th wk.

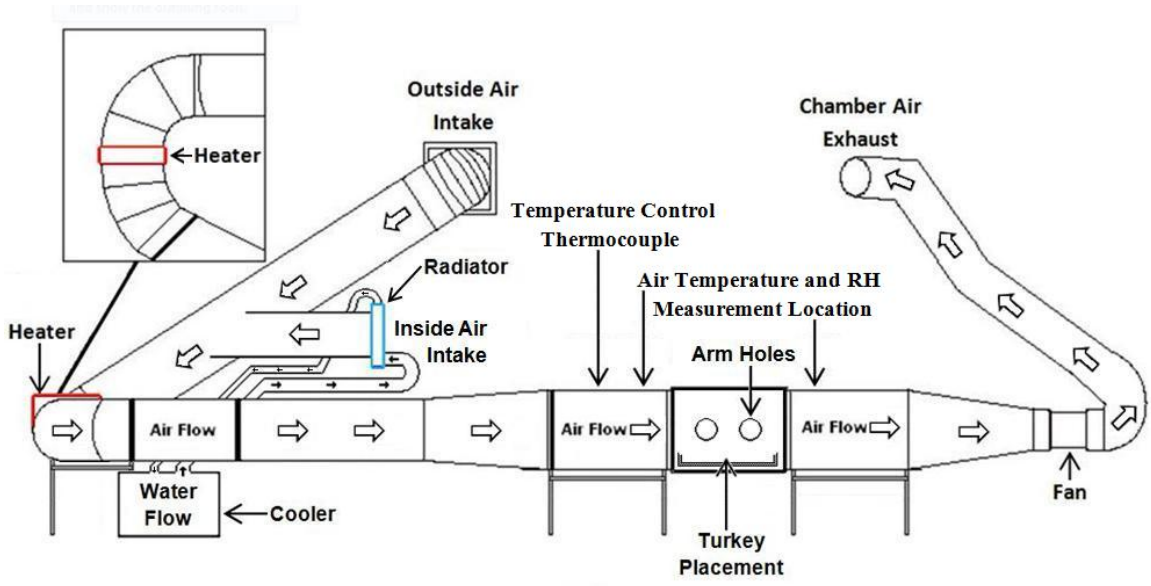

Figure 3.2. External, side diagram of the environmental test chamber. Directional movement of air, white arrows, and water, black arrows.

A modified wagon (floor space was roughly 0.5m by 1m, with a height of roughly 1m) was used to transport the turkeys from the home pen to the holding pen. Turkeys were acclimated to the wagon from day 2-4, in which all 12 birds were moved to the testing room at one time. During the study period, birds were moved 4 at a time (wk 1-7) and 2 at a time (wk 8-12), 13 h prior to the start of each day's trials. Trials were run 4 times each day for 3 consecutive days per wk [age = (wk*7) ± 1 day] at 6:00, 8:30, 11:00 and 13:30 from wk 1-5, and 1:00, 3:30, 6:00 and 8:30 from wk 6-12. The switch from beginning the trials in the daylight hours to beginning in the dark hours was an attempt to take advantage of the lower environmental temperatures at this time and to reduce the

strain placed upon the cooling system. Two turkeys from each treatment group were randomly selected for day of the wk and time of day. All 12 wks were randomized at the beginning of the study to minimize the occurrence of a turkey being involved in tests on the same day or time from one wk to the next. During the first 5 wks, the 4 turkeys on trial were randomly assigned a time out of the 4 possible options for that day. For the remaining 8 wks, each day was divided into 2 sections; night (1:00 & 3:30) and morning (6:00 & 8:30), where 1 of the 2 birds from a treatment group was assigned to a section. The order in which the treatments were run within a section was randomized.

3.2. Measurements

Feed and water consumption within the chamber were measured after each trial. Consumption was calculated as the initial weight of the container plus the feed or water, minus the final weight of the container plus the feed or water. Feed was provided within a small rectangular metal dish suspended from the wire mesh barrier positioned over the opening of the air inlet pipe (refer to Figure 3.1). A small drinker, similar to a bell drinker with an enclosed water supply, was provided for the turkeys within the chamber (refer to Figure 3.1). As the turkeys grew, both containers were raised to minimize wastage.

Cloacal temperatures (T_{core}) were measured using a digital medical thermometer (Vicks comfort flex, V966F-CAN, with an accuracy of 0.2°C, KAZ Inc., Hudson, NY) inserted 0.5-2 cm, dependent on bird size, into the cloaca of the turkeys. A handler supported the turkey on his/her lap, breast down, while restraining the bird by wrapping his/her arm around the turkey's back. This position also ensured the wings were restrained and provided freedom of the handler’s second hand to hold the legs for the same reason. T_{core} was recorded immediately upon handling the bird to reduce errors caused by bird stress. This resulted in temperatures being measured approximately 20 min before the turkey was placed within the chamber (due to requirement of other data measurements) and immediately upon the bird's removal.

Turkey body weight was measured wkly, after T_{core} measurement and prior to the turkey placement within the chamber. Young turkeys, age 1-3 wks, were suspended from a hanging scale (Electro Samson with accuracy of 0.01kg, Salter Brecknell, Cleveland

OH) within a bucket as they were not physically developed enough to be hung inverted by their legs. During wk 4-6, body weight was measured by suspending the birds inverted by their legs from the hanging scale. A floor scale (RW 1000 with accuracy 0.2kg, Cardinal Detecto, WEBR MO) was used to measure weights from wk 7-12 as the birds were too large to hang from the scale. The turkeys were held for these measurements (to reduce injuries to the bird and handler) and the weight of the handler was then subtracted from the combined weight to obtain the turkey's weight.

A miniature data logger (iButton, model DS1922L with accuracy 0.5°C, Maxim Integrated Products, Sunnyvale, CA) was attached to the skin on the underside of the wing along the boundary between the shoulder region and the wing (Lucas & Stettenheim, 1972). Each turkey was issued a specific logger throughout the 12 wks, ensured through bird and logger identifications. The loggers were programmed to record temperature measurements every 30 s, starting 30 min before the trial began. These measurements consisted of room temperatures and the temperature of the skin at the juncture between the wing and the shoulder region on the underside of the wing (T_{logger}). A strip of self-adhesive bandaging tape (3M Vetwrap; Digi-Key Co., Thief River Falls MN) measured and cut to snugly fit around the base of the wing without impeding circulation was used to secure the logger in place approximately 20 min prior to the start of the trial. This early placement allowed for the turkeys to become accustomed to the bandage while providing a time where the data logger and bandage could be easily fixed by the tester if necessary. The data collection period was broken down into four 30-min periods and data recorded during the last 10 min of each period were archived for later analysis. During the first two wks of testing, the data loggers fell off the turkeys during the 2-h exposure period. When this occurred, T_{logger} was no longer measuring the skin temperature under the wing but the chamber exposure temperature. These temperatures were removed from the data using a visual assignment, by plotting T_{logger} for the entire 2-h period, combined with the times recorded when the data loggers were no longer on the turkeys. A calibration analysis was run on the loggers after the trials were concluded to determine the accuracy of each logger and correct the recorded temperatures for any bias in the sensor.

While the turkeys were in the chamber, images of each bird were acquired every 30 min using an infrared camera (FLIR model S60 with an accuracy of 2°C, FLIR Systems Inc. Burlington ON) and a portable web camera (Logitech model C905, Logitech, Fremont CA). Images were taken every 30 min starting at the beginning of the acclimation period and ended at the conclusion of the data collection period. Turkeys were positioned on a platform 30.48 cm above the chamber floor during the first 3 wks to ensure quality images. For the first 4 wks, the turkeys were placed 0.91 m away from the camera's lens and then held 1.22 m from the camera's lens for the remainder of the study (refer to Figure 3.1). Two poses were recorded – a side and a front view – to provide an unobstructed view of the body locations to be measured. These locations included the external ear opening (head), the skin covering the lateral region of the tarsometatarsus bone, commonly known as the shank (shank), the distal lateral region of the tibiotarsal bone, commonly known as the drumstick (drum) and the anterior lateral region of the wing (Lucas & Stettenheim, 1972) from the side view and the breast (the boundary between the neck and the trunk below the thoracic inlet [Lucas & Stettenheim, 1972]) from the front view (refer to Figure 3.3). Gentle manipulation of the turkeys by hand was required to obtain the correct physical orientation needed for each pose. The frontal pose was obtained prior to the side pose, resulting in the turkey's ending orientated to face the inflowing air. Two images per pose were acquired using software developed in-house and written in Labview (National Instruments, Austin TX). Images were stored on a computer until they were analyzed using the software program ENVI (Excelis Visual Information Solutions Inc., Boulder CO).

The method used to obtain the temperature measurements in ENVI from each surface location remained constant over the 12 wks. The geometric dimensions remained the same with the shapes and their total pixel counts as follows: breast, oval of 324 pixels; drum, circle of 32 pixels; head, circle of 116 pixels; shank, circle of 52 pixels and wing, oval of 272 pixels. The physical dimensions of the measurement locations were affected by their distance from the camera lens and the bird's orientation and therefore varied from one wk to the next and even within each trial period. Taking this into consideration, the average physical dimensions of the measured locations from wks 1-3

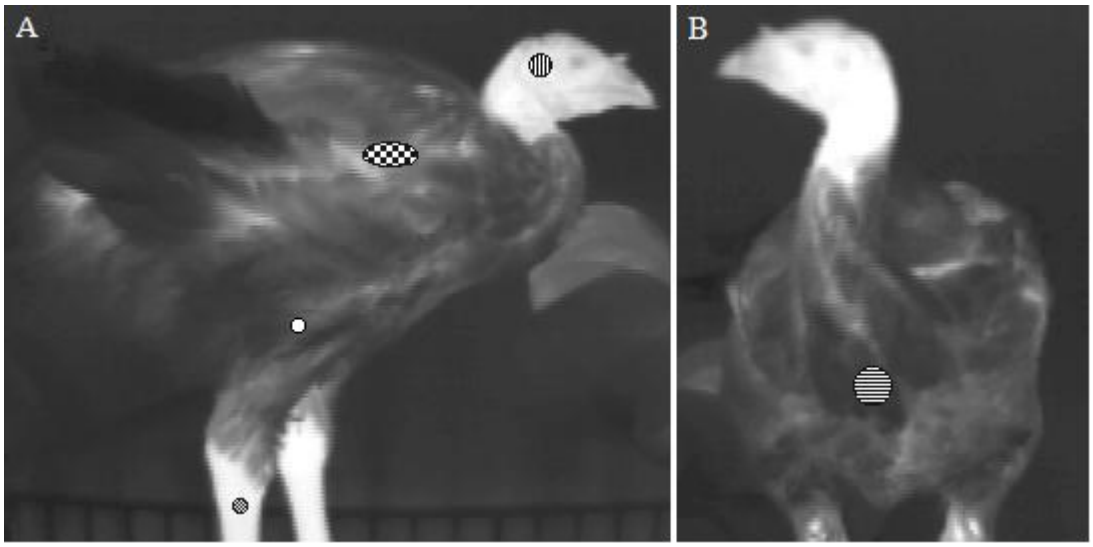

Figure 3.3. Examples of an infrared side (A) and front (B) pose. ▤ illustrates the size, shape and placement of the measured breast location, ▥ illustrates the size, shape and placement of measured head location, ▭ illustrates the size, shape and placement of the measured drum location, ▩ illustrates the size, shape and placement of the measured shank location and ▦ illustrates the size, shape and placement of the measured wing location

were: breast 9.6 cm^2, drum 0.9 cm^2, head 3.4 cm^2, shank 1.5 cm^2 and wing 8.0 cm^2. During wks 4-12 the average physical dimension for the measured locations were: breast 11.3 cm^2, drum 1.1 cm^2, head 4.0 cm^2, shank 1.8 cm^2 and wing 9.5 cm^2. An average temperature was calculated for each location per week; breast (T_{breast}), head (T_{head}), shank (T_{shank}), drum (T_{drum}) and wing (T_{wing}), and stored for later statistical analysis. The change in surface area as the turkeys grew was not accounted for in the statistical analysis.

3.3. Data Analysis

Statistical analysis was completed using SAS 9.2 English (SAS Institute Inc., Cary, NC). All data sets required transformations to provide normal distributions for accurate statistical analysis. The type of transformation required was determined by the largest Shapiro-Wilk value calculated using the normality analysis in SAS. Log transformations were used for T_{breast}, T_{drum} and T_{wing} data sets and the T_{core}, T_{head}, T_{logger}, T_{shank}, body weight and feed/water consumption data sets were square transformed. The difference between body temperatures and exposure temperature (calculated differences) data sets were square transformed, for all measurement locations. The variation between calculated differences were analysed to remove any possible effect caused by the

decrease in exposure temperature with age. Temperatures recorded during the acclimation period for all locations were not included within any statistical analysis. In addition, T_{logger} has missing data for wks 5 and 7.

A procedural mixed model analysis was used to determine the changes in the recorded body temperatures, calculated difference temperatures and feed/water consumption during the 2-h trial period, as well as body weight, over the 12 wks of study. A correlation analysis was used to determine the relationship between the exposure temperature and the recorded temperatures from T_{breast}, T_{core}, T_{drum}, T_{head}, T_{logger}, T_{shank} and T_{wing} for both the control and treatment groups. A regression analysis was used to determine the relationship between the exposure temperature and T_{breast}, T_{drum} and T_{wing} for both the control and treatment groups. A regression analysis between exposure temperature and, T_{core}, T_{head}, T_{logger} and T_{shank} revealed no relationship and was therefore removed from the analysis. Results from all analyses are considered to be significant if calculated P values are less than or equal to 0.05.

Body weight as well as feed and water consumption measurements were taken as a means to assess bird growth performance and behaviour. Due to no deviation being measured away from the standard expected values the data for these measurements are not discussed further within this paper. For supplementary information please consult the appendix section (Appendix L to O).

CHAPTER 4: Results

4.1. Changes in Body Temperature

4.1.1. Surface Temperatures at Specific Exposure Temperatures

Figures 4.1 to 4.7 show the temperatures measured at seven different body locations each wk from 1-12 wks of age when exposed to either T^{con} or T^{trt}. Temperatures of the feathered locations are seen to reflect the change in exposure temperature over the 12 wks of growth (Figure 4.1-4.3). Warmer temperatures, for these feathered locations, are seen in the group of turkeys subjected to T^{con} compared to the group of turkeys subjected to T^{trt} (Figure 4.1 – 4.3). Temperatures of featherless locations remained relatively constant compared to the change in exposure temperature (Figure 4.4 – 4.7). T_{core} from both treatment groups overlap each other indicating the different exposure temperature had little effect on the measured temperature (Figure 4.4), while T_{head}, T_{logger} and T_{shank} showed temperatures from the control group being greater than temperatures of the treatment group (Figure 4.5 – 4.7).

4.1.2. Comparison of Weekly Body Temperatures at Specific Exposure Temperatures

A comparison of body temperatures wkly within the two treatment groups showed two distinct patterns between the feathered and featherless body locations. Square brackets surrounding a set of wks indicate these wks to not be significantly different in temperature. Wks not located within a set of square brackets are found to be significantly different in temperature from those within the brackets. For the feathered locations, T^{con}_{breast} (temperature of the breast when exposed to the standard temperature curve) and T^{trt}_{breast} (temperature of the breast when exposed to 4°C below the standard curve) were shown to have similar temperatures during wks [1-3], [8-12] and [7 & 12] ($P<0.01$; Figure 4.8). T^{con}_{drum} had similar temperatures during the wks [1 & 2], [3 & 4], [6 & 7] and [7-12], while T^{trt}_{drum} had similar temperatures during wks [1 & 2], [7, 9 & 12] and [8-12] ($P<0.01$; Figure 4.9). Temperatures were similar during wks [1 & 2], [7 & 10-12] and [8-12] for T^{con}_{wing}, and T^{trt}_{wing} had similar temperatures during wks [1 & 2], [1 & 3],

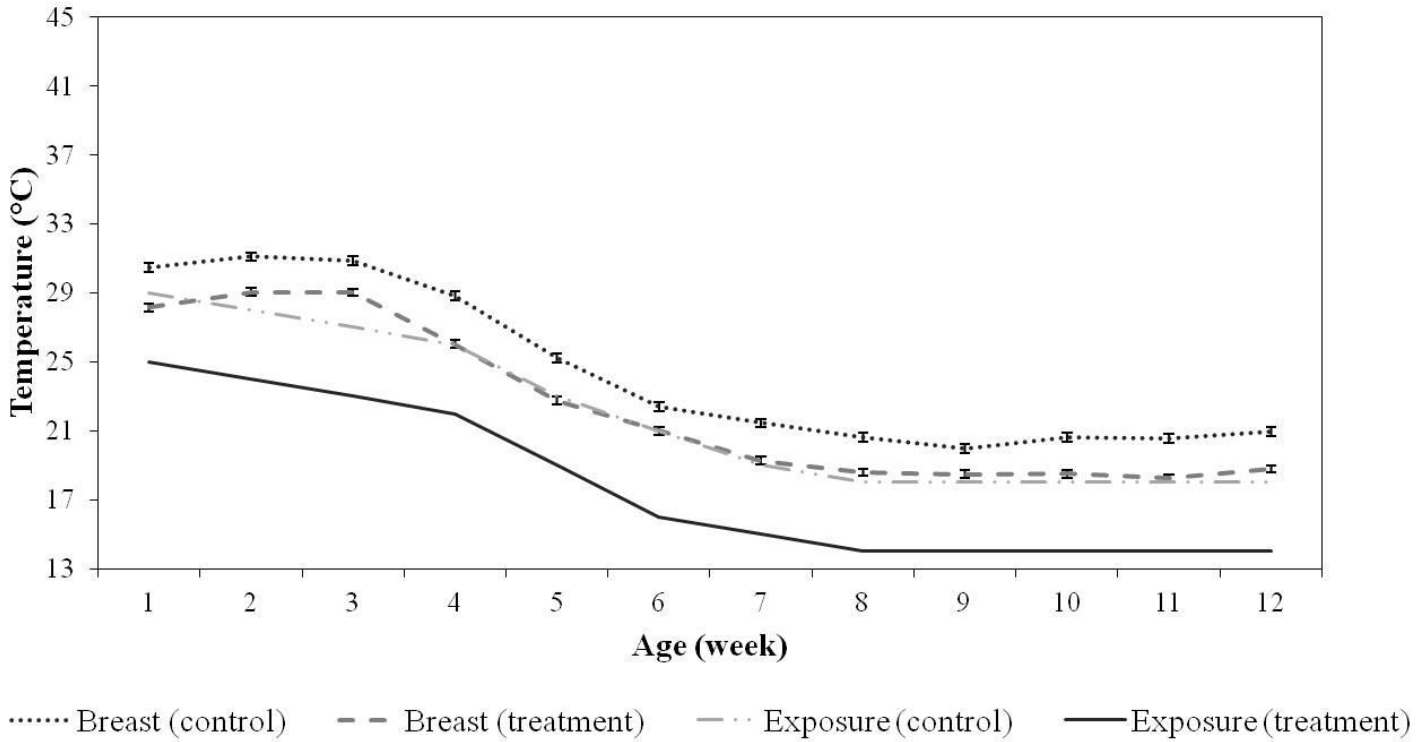

Figure 4.1. Breast temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). SEM(control) = 0.26,SEM(treatment) = 0.22; n=48 ($2\ ^{images}/_{collection\ time}$ by $4\ ^{collection\ time}/_{data\ collection\ period}$ by $6\ ^{birds}/_{treatment}$)

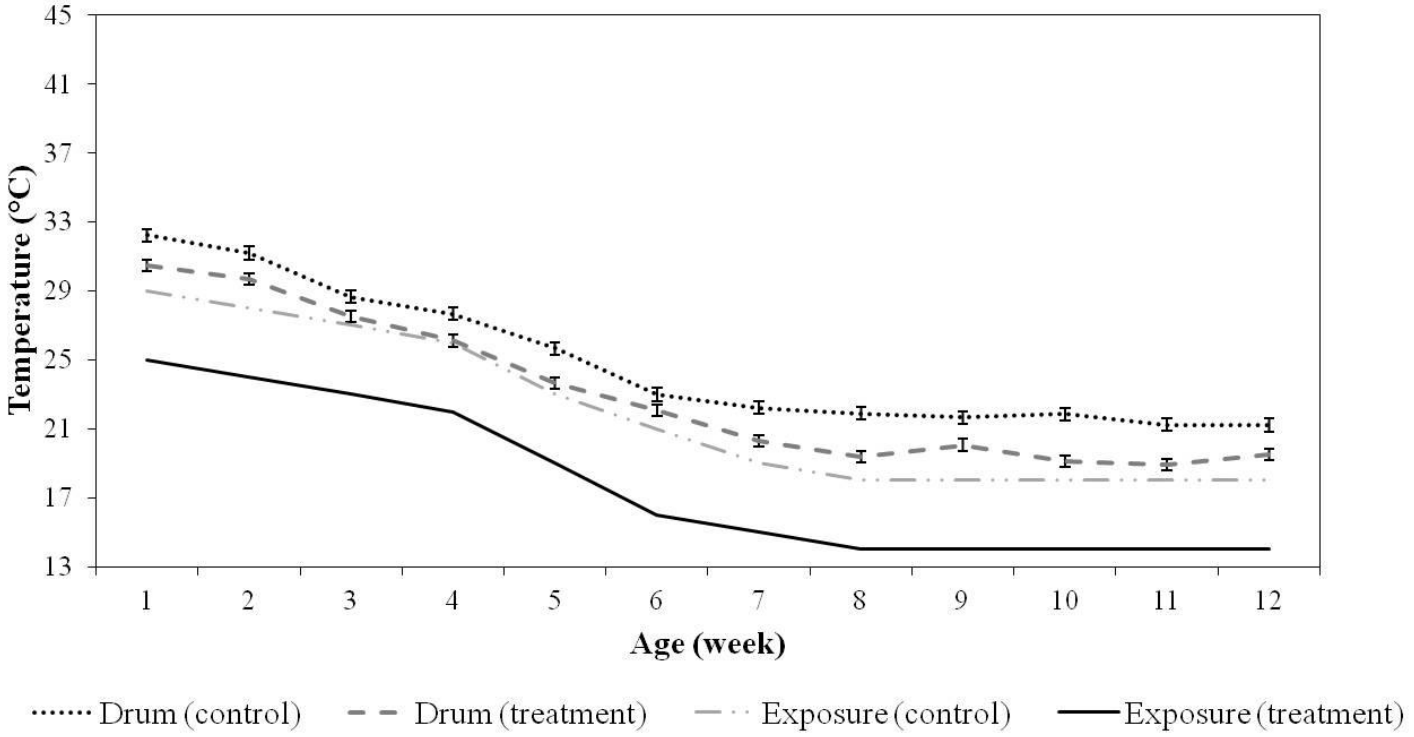

Figure 4.2. Distal lateral region of the tibiotarsal bone (drum) temperatures of Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). SEM(control) = 0.37, SEM(treatment) = 0.34; n=48 (2 $^{\text{images}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

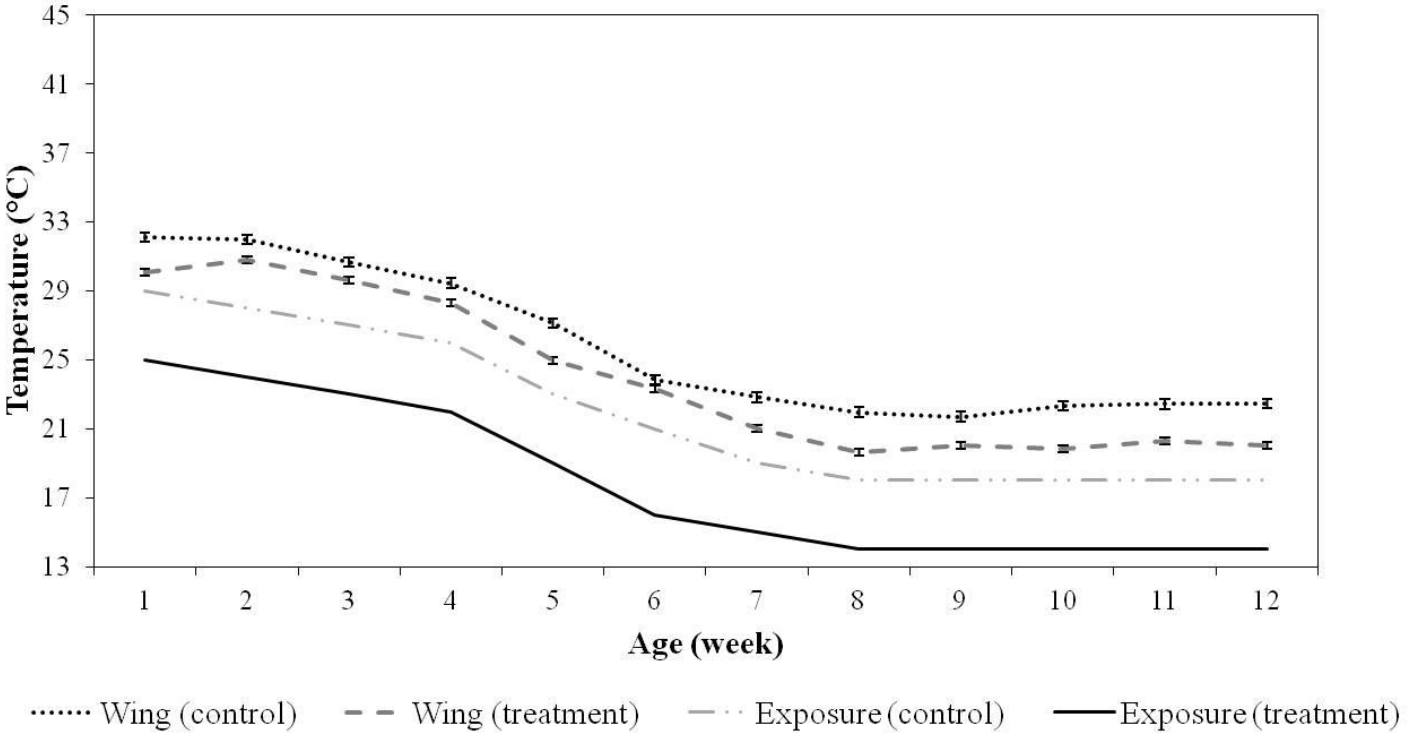

Figure 4.3. Wing temperatures of Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). SEM(control) = 0.27, SEM(treatment) = 0.20; n=48 ($2^{images}/_{collection\ time}$ by $4^{collection\ time}/_{data\ collection\ period}$ by $6^{birds}/_{treatment}$)

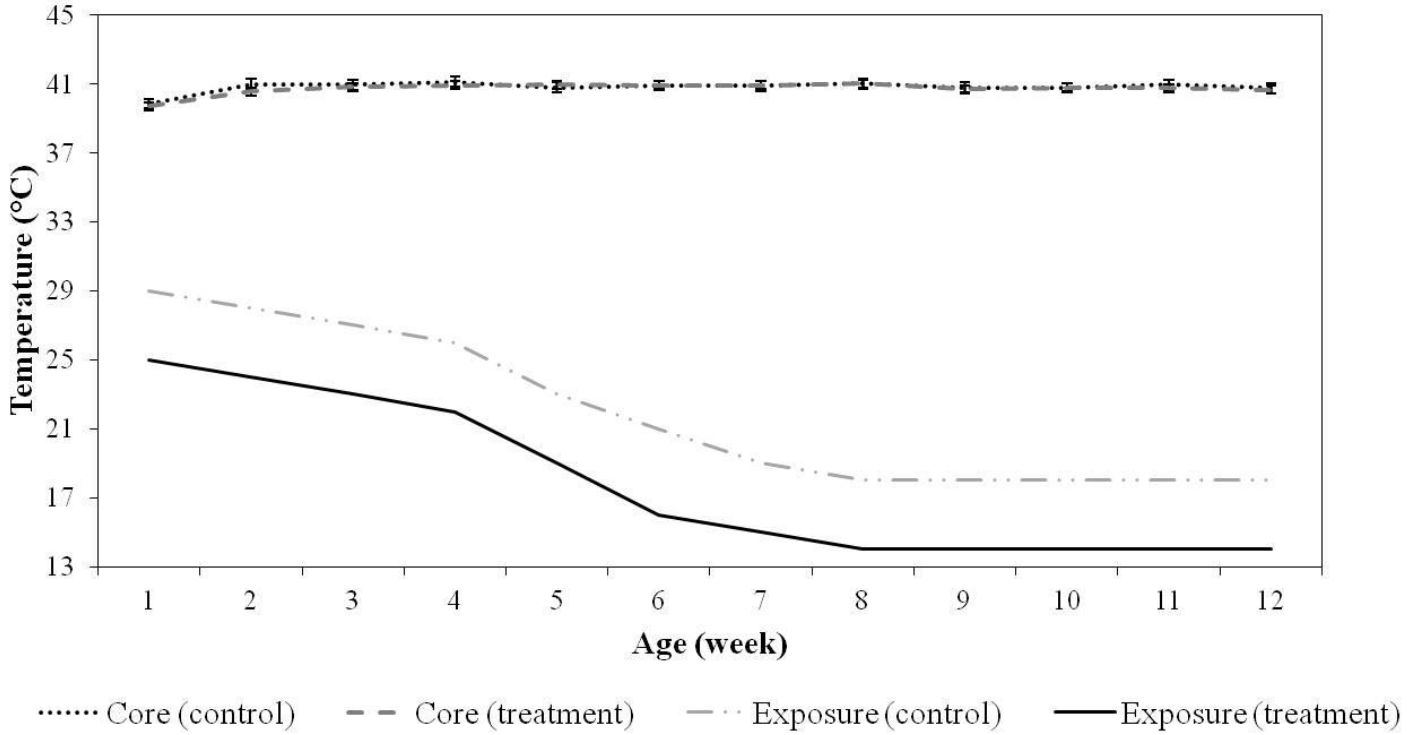

Figure 4.4. Cloaca (core) temperatures of Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). SEM(control) = 0.28, SEM(treatment) = 0.23; n=6 ($1^{\text{measurement}}/_{\text{data collection period}}$ by $6^{\text{birds}}/_{\text{treatment}}$)

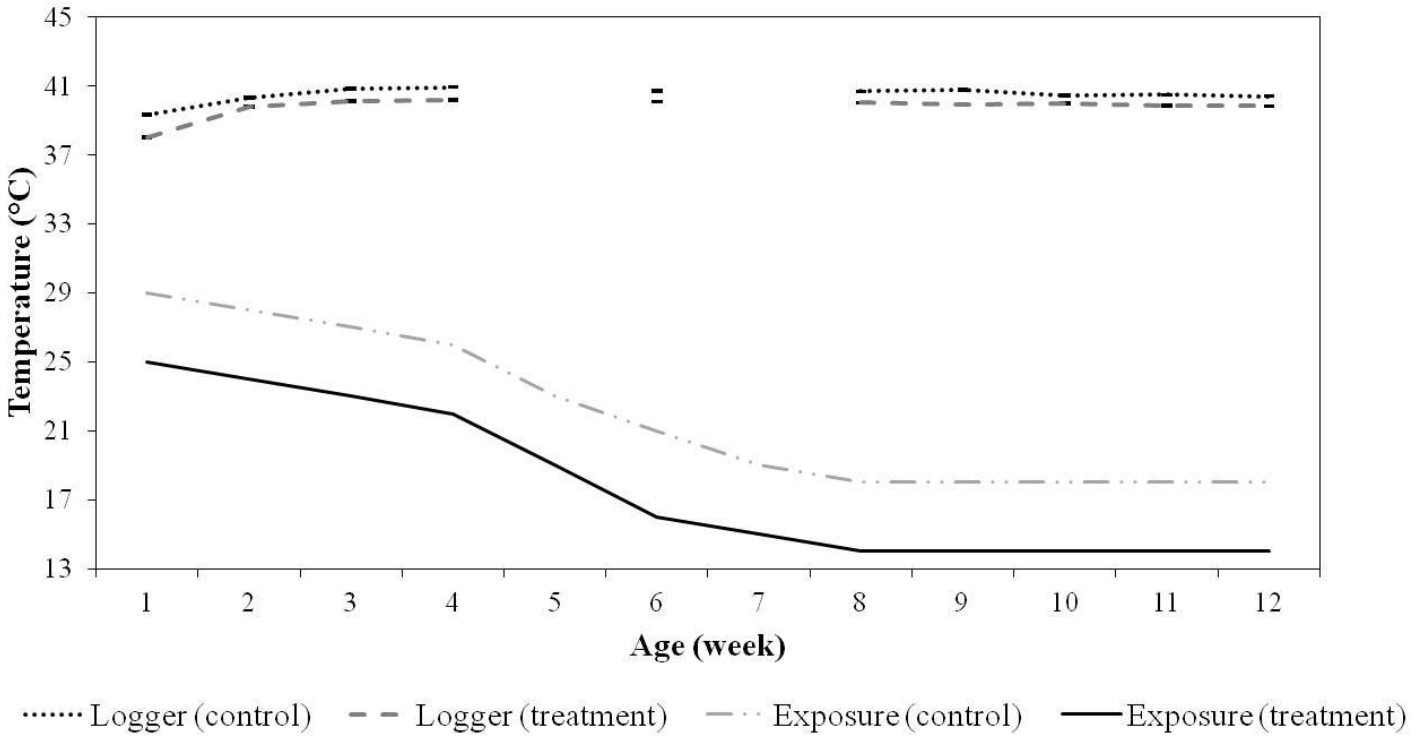

Figure 4.5. Skin under the wing (data logger) temperatures of Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4 °C below the standard (treatment). SEM(control) = 0.05, SEM(treatment) = 0.05; n=480 (10 $^{\text{measurements}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$), missing data for weeks 5 and 7 not included

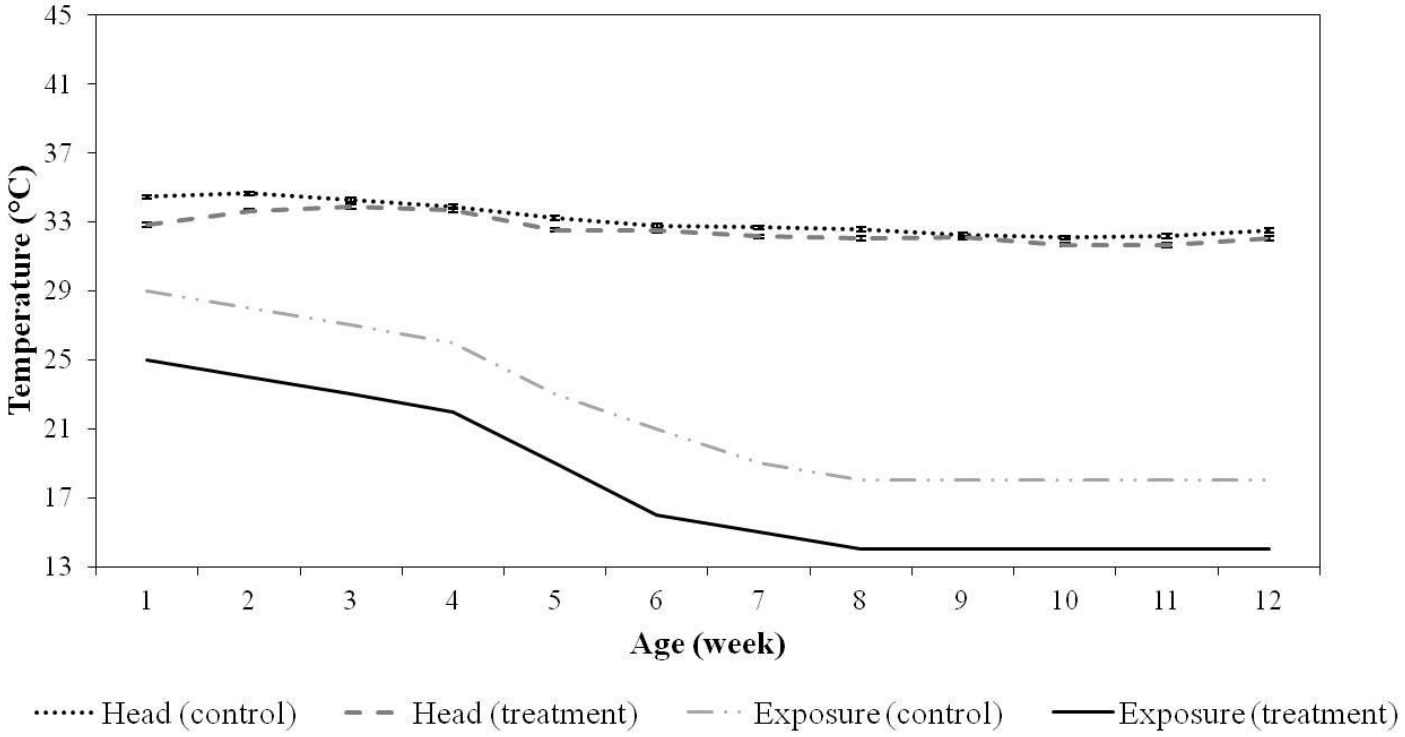

Figure 4.6. External ear opening (head) temperatures of Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). SEM(control) = 0.12, SEM(treatment) = 0.11; n=48 ($2^{images}/_{collection\ time}$ by $4^{collection\ time}/_{data\ collection\ period}$ by $6^{birds}/_{treatment}$)

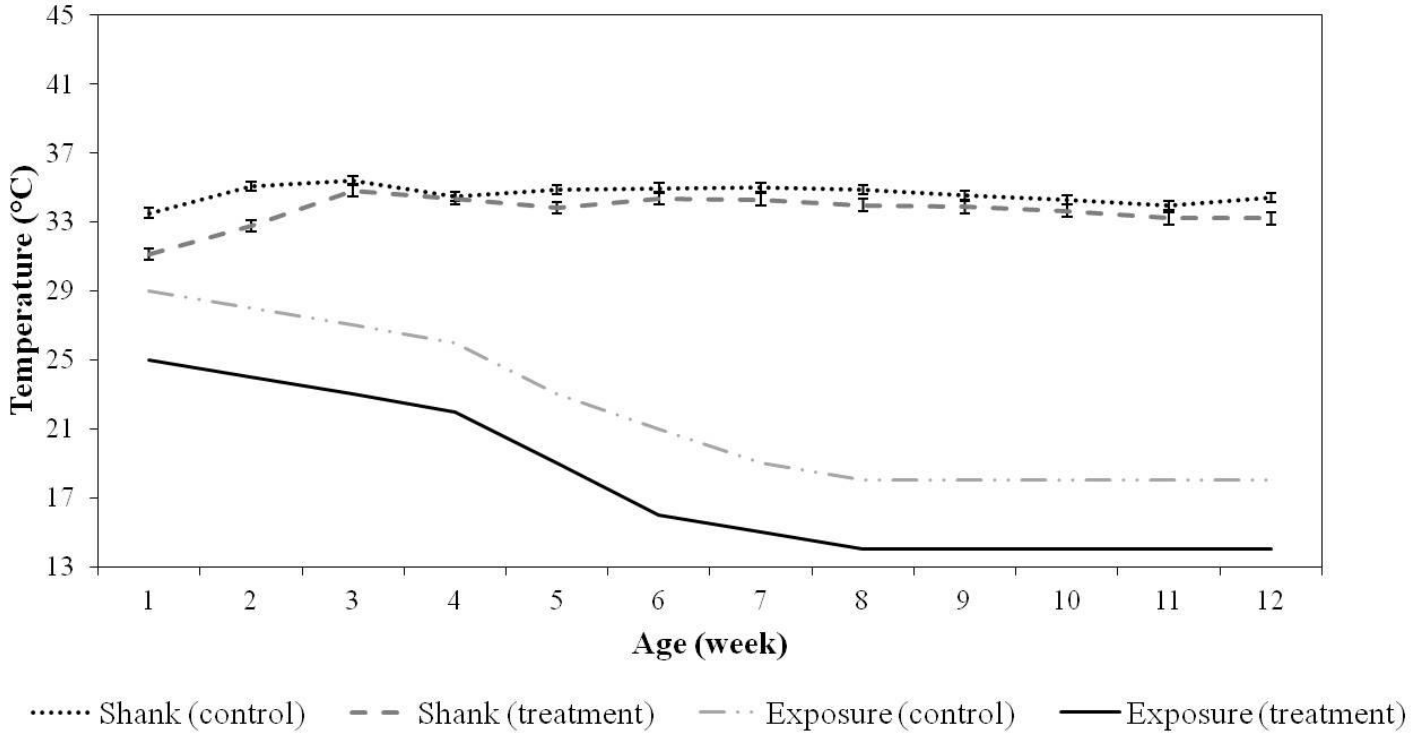

Figure 4.7. Skin over the tarsometatarsus bone (shank) temperatures of Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). SEM(control) = 0.27, SEM(treatment) = 0.35; n=48 (2 $^{images}/_{collection\ time}$ by 4 $^{collection\ time}/_{data\ collection\ period}$ by 6 $^{birds}/_{treatment}$)

[8-10 & 12] and [9-12] (P<0.01; Figure 4.10). For the featherless locations, T_{core}^{con} and T_{core}^{trt} were shown to have similar temperatures during wks [2-12] with the first wk being different (P<0.01; Figure 4.11). T_{logger}^{con} had similar temperatures during wks [6 & 8-9], [10 & 11] and [10 & 12], while T_{logger}^{trt} had similar temperatures during wks [3 & 4], [3 & 6], [8 & 10], [9 & 10] and [11 & 12] (P<0.01; Figure 4.12). Temperatures were similar during wks [1-3], [3 & 4], [6-8 & 12] and [8-12] for T_{head}^{con} and during wks [1, 5 & 6], [2-4], [5-9 & 12] and [8-12] for T_{head}^{trt} (P<0.01; Figure 4.13). T_{shank}^{con} was similar during wks [1 & 11], [2, 3 & 5-8], and [2 & 4-12] and T_{shank}^{trt} was similar during wks [2, 11 & 12], [3, 4, 6 & 7] and [4-12] (P<0.01; Figure 4.14). The feathered locations showed similar temperatures from one wk to the next when the exposure temperature either, remained constant (wks 8-12) or had a difference of only 1°C (wks 1-4) from one wk to the next. Temperatures for the featherless locations remained relatively constant during the 12 wks of study for T_{core} and T_{shank} locations. T_{head} had relatively constant temperatures during the first half of the study and then the second half of the study, with the changes in temperature occurring at wk 4 and 6 for the control group and wk 6 for the treatment group. Temperatures for T_{logger} were relatively constant during the second half of the study, starting at 6 wks-of-age and changing temperature at wk 9 for the control group. The treatment group was more consistent over the 12 wks of study with temperatures remaining relatively constant starting at wk 3 and changing temperature at wk 6.

A wkly comparison of the calculated difference between the body location temperatures and their corresponding exposure temperature within the two treatment groups showed opposite patterns to the measured temperatures of the body locations discussed above. Square brackets surrounding a set of wks indicate these wks to not be significantly diverse in calculated differences. Wks not located within a set of square brackets are found to be significantly diverse in calculated differences from those within the brackets. Measured temperature location labels (example, T_{breast}^{con}) followed by the word 'difference' within a set of circular brackets indicates that the data being discussed are the calculated difference between the measured body location temperatures and the corresponding exposure temperatures. Within the feathered locations group,

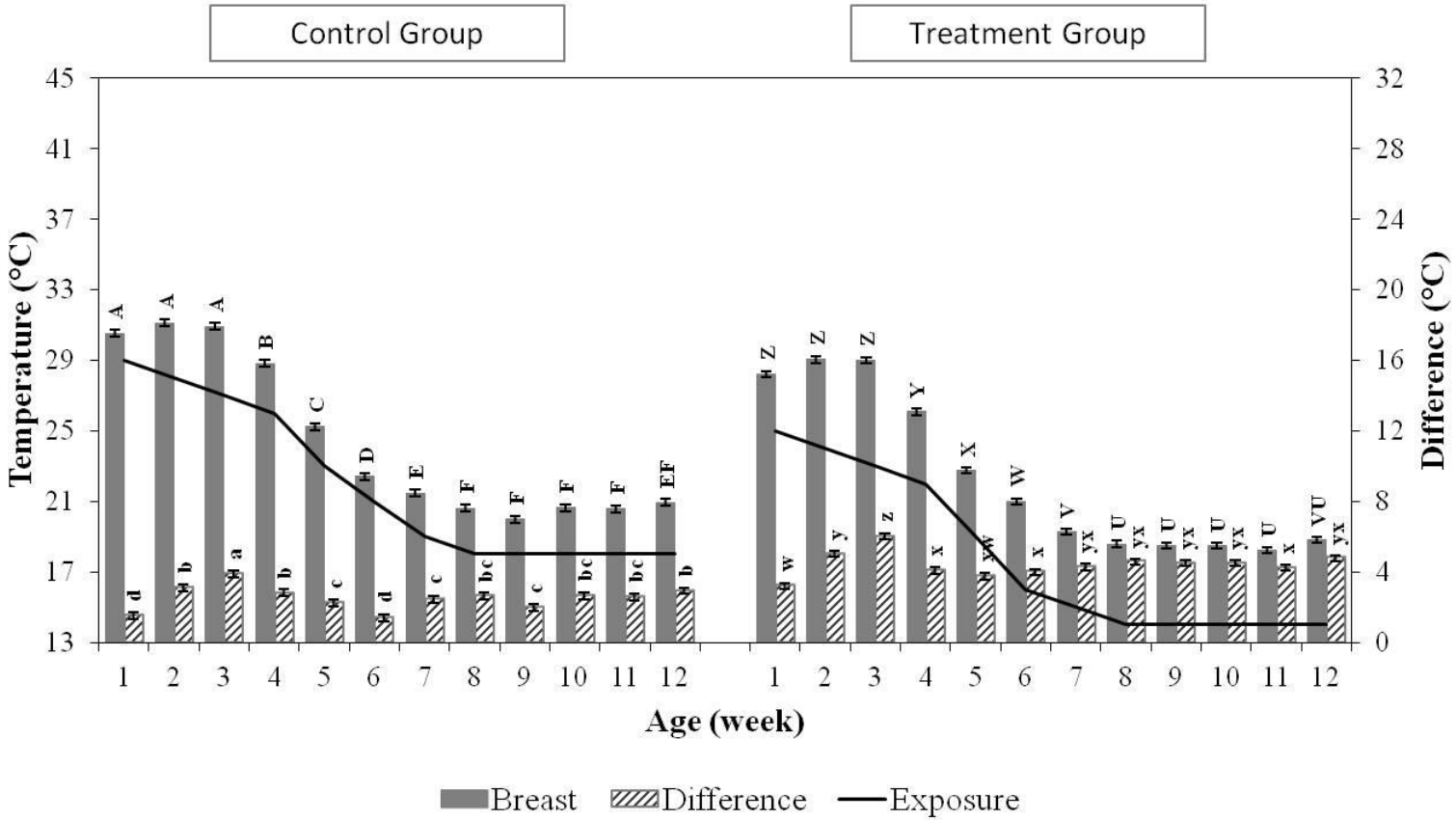

Figure 4.8. Weekly temperatures of the breast and differences between the breast and corresponding exposure temperature for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). Common letters indicate no significant difference between weeks, with upper case letters representing body temperatures and lower case letters representing the difference between exposure temperature and body temperature. SEM(breast- control) = 0.20, SEM(breast- treatment) = 0.19, SEM(difference- control) = 0.20, SEM(difference- treatment) = 0.19; n=48 (2 $^{\text{images}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

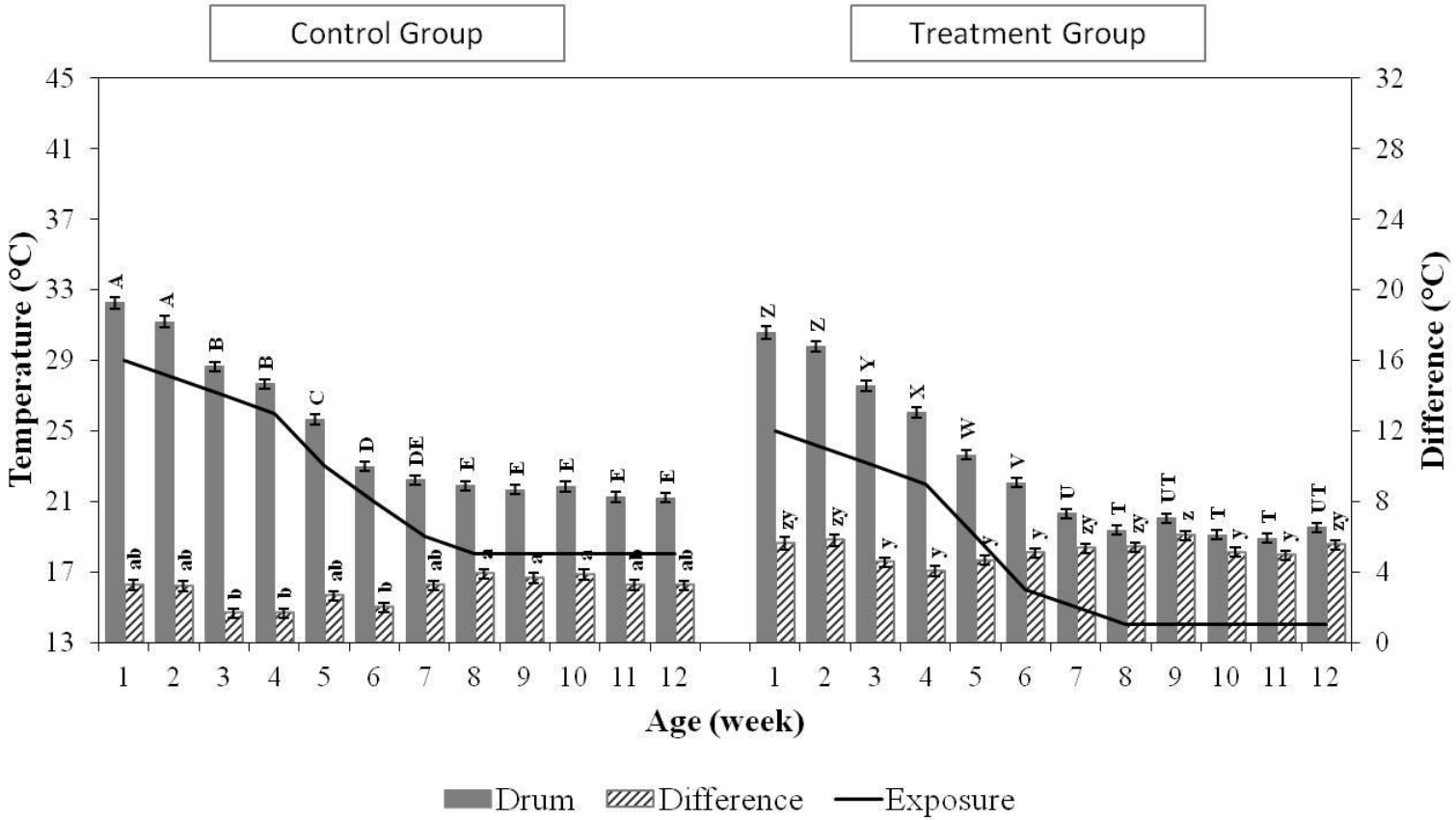

Figure 4.9. Weekly temperatures of the distal lateral region of the tibiotarsal bone (drum) and differences between the drum and corresponding exposure temperature for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). Common letters indicate no significant difference between weeks, with upper case letters representing body temperatures and lower case letters representing the difference between exposure temperature and body temperature. SEM(drum- control) = 0.31, SEM(drum-treatment) = 0.37, SEM(difference - control) = 0.31, SEM(difference - treatment) = 0.37; n=48 (2 $^{\text{images}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

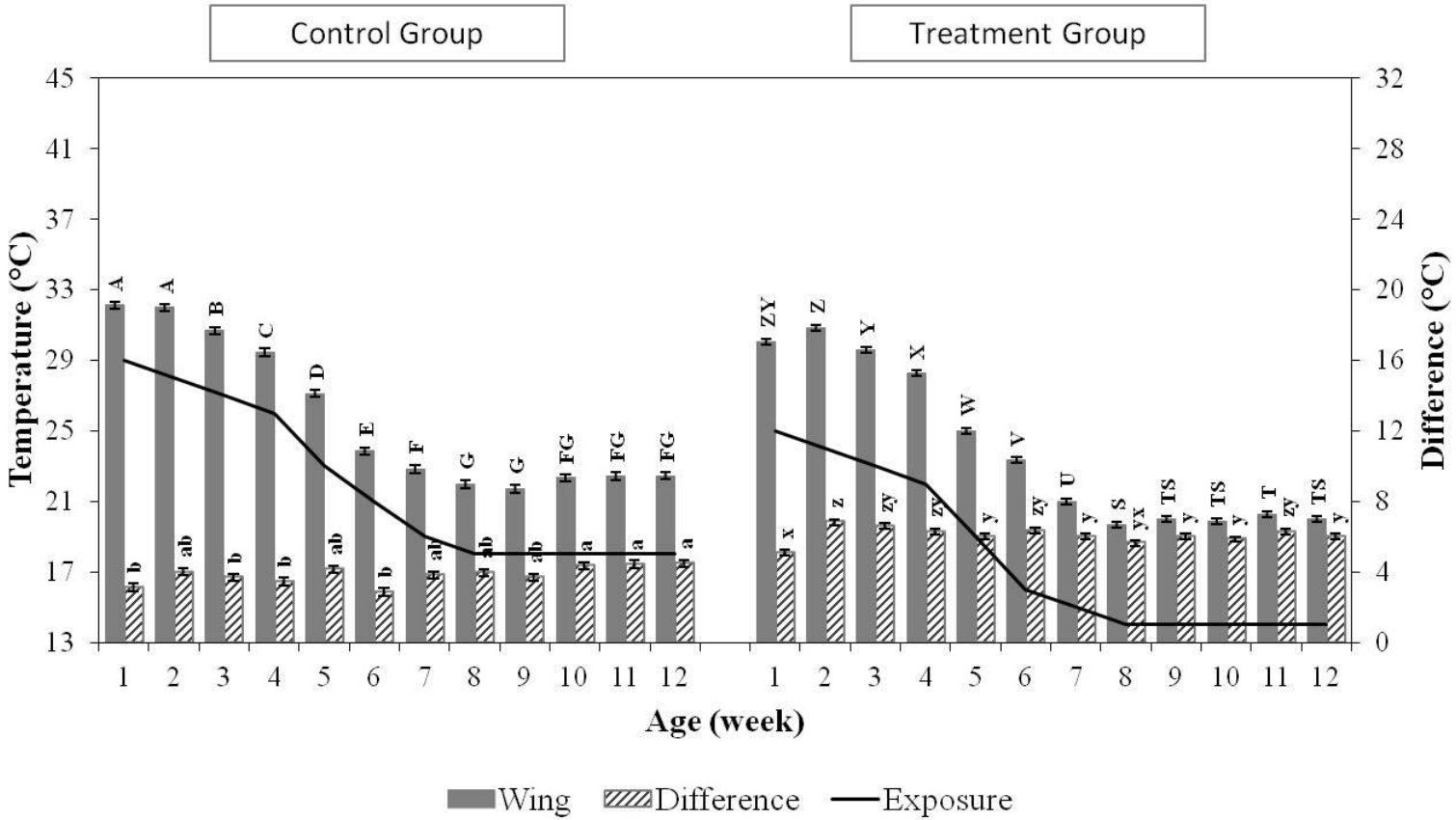

Figure 4.10. Weekly temperatures of the wing and differences between the wing and corresponding exposure temperature for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). Common letters indicate no significant difference between weeks, with upper case letters representing body temperatures and lower case letters representing the difference between exposure temperature and body temperature. SEM(wing - control) = 0.21, SEM(wing - treatment) = 0.18, SEM(difference - control) = 0.21, SEM(difference - treatment = 0.18; n=48 (2 $^{\text{images}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

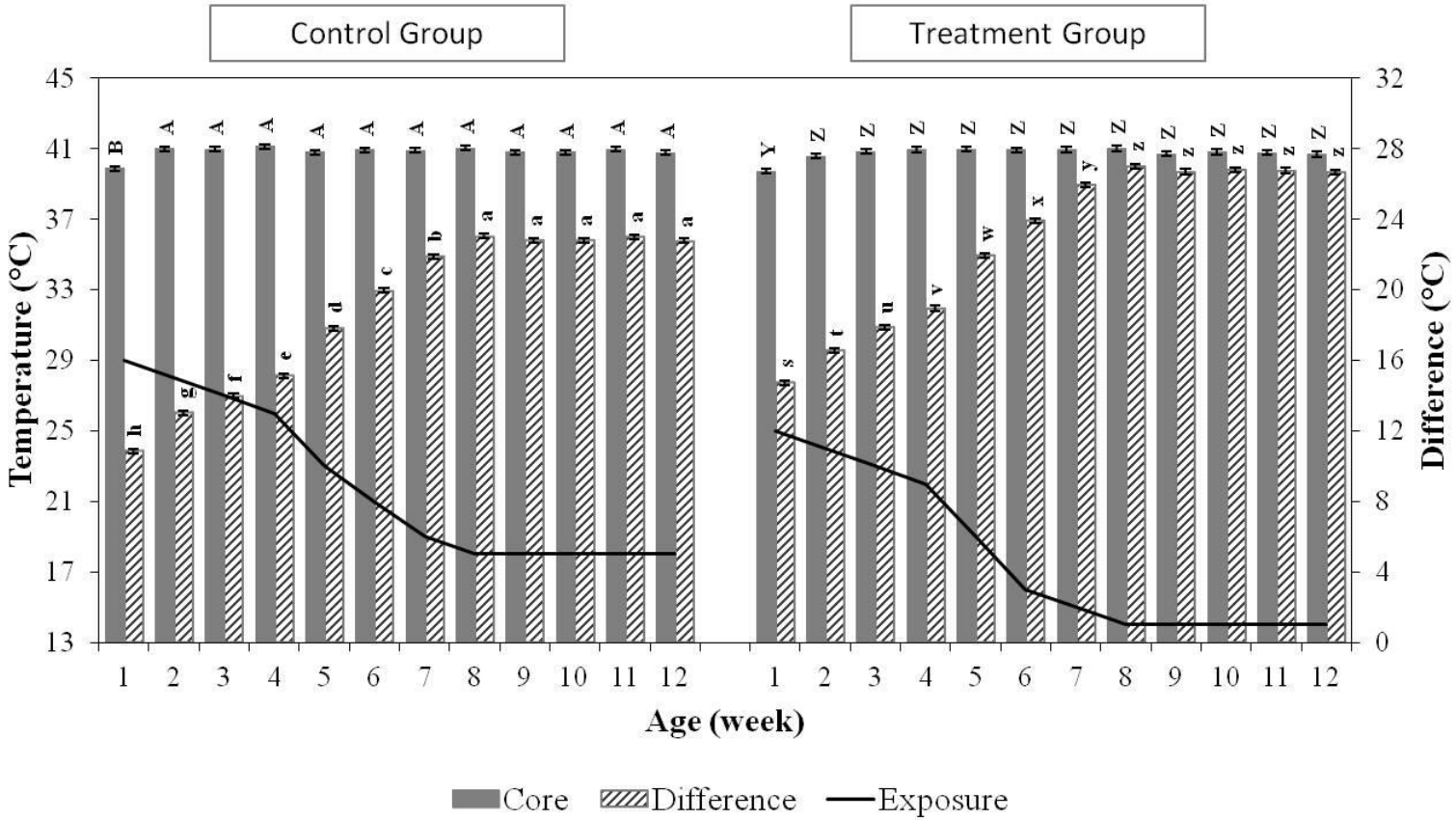

Figure 4.11. Weekly temperatures of the cloaca (core) and differences between the core and corresponding exposure temperature for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). Common letters indicate no significant difference between weeks, with upper case letters representing body temperatures and lower case letters representing the difference between exposure temperature and body temperature. SEM(core - control) = 0.14, SEM(core - treatment) = 0.15, SEM(difference - control) = 0.14, SEM(difference - treatment) = 0.15; n=6 (1 $^{measurement}/_{data\ collection\ period}$ by 6 $^{birds}/_{treatment}$)

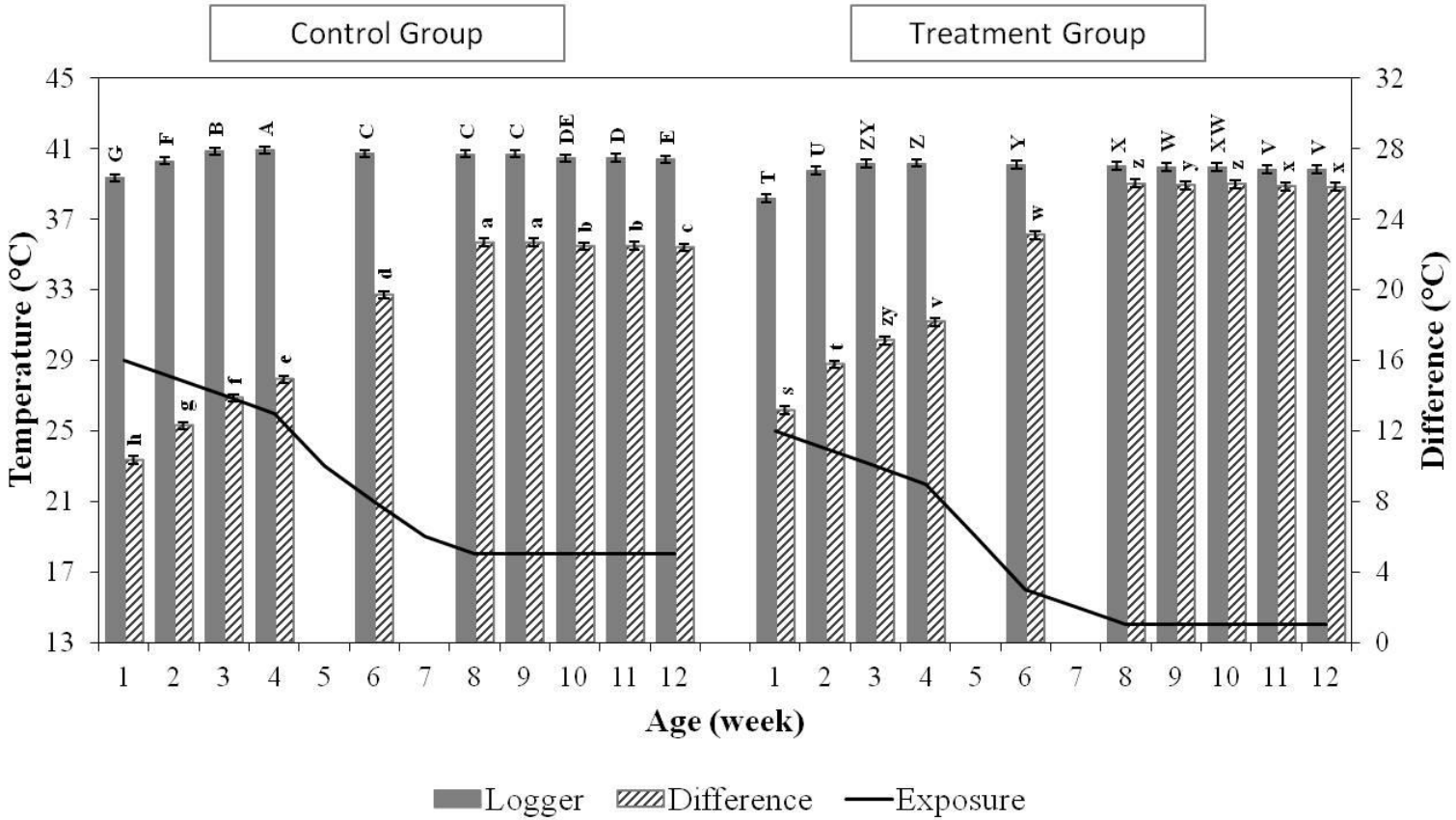

Figure 4.12. Weekly temperatures of under the wing (data logger) and differences between the data logger and corresponding exposure temperature for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). Common letters indicate no significant difference between weeks, with upper case letters representing body temperatures and lower case letters representing the difference between exposure temperature and body temperature. SEM(logger - control) = 0.20, SEM(logger - treatment) = 0.23, SEM(difference - control) = 0.20, SEM(difference - treatment) = 0.23; n=480 (10 $^{\text{measurements}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$), missing data for weeks 5 and 7 not included

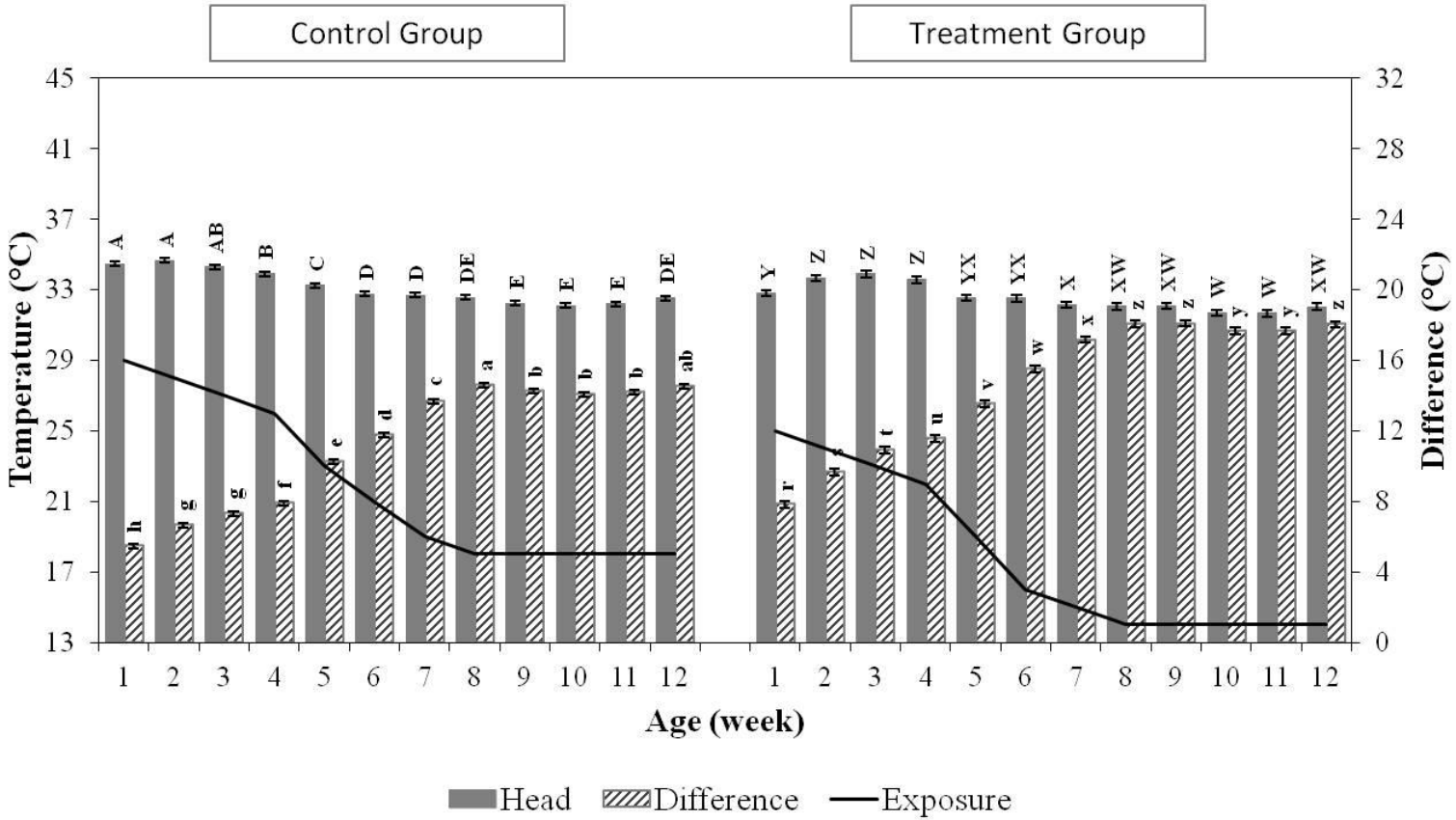

Figure 4.13. Weekly temperatures of the external ear opening (head) and differences between the head and corresponding exposure temperature for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). Common letters indicate no significant difference between weeks, with upper case letters representing body temperatures and lower case letters representing the difference between exposure temperature and body temperature. SEM(head - control) = 0.13, SEM(head - treatment) = 0.18, SEM(difference - control) = 0.13, SEM(difference - treatment) = 0.18; n=48 (2 $^{\text{images}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

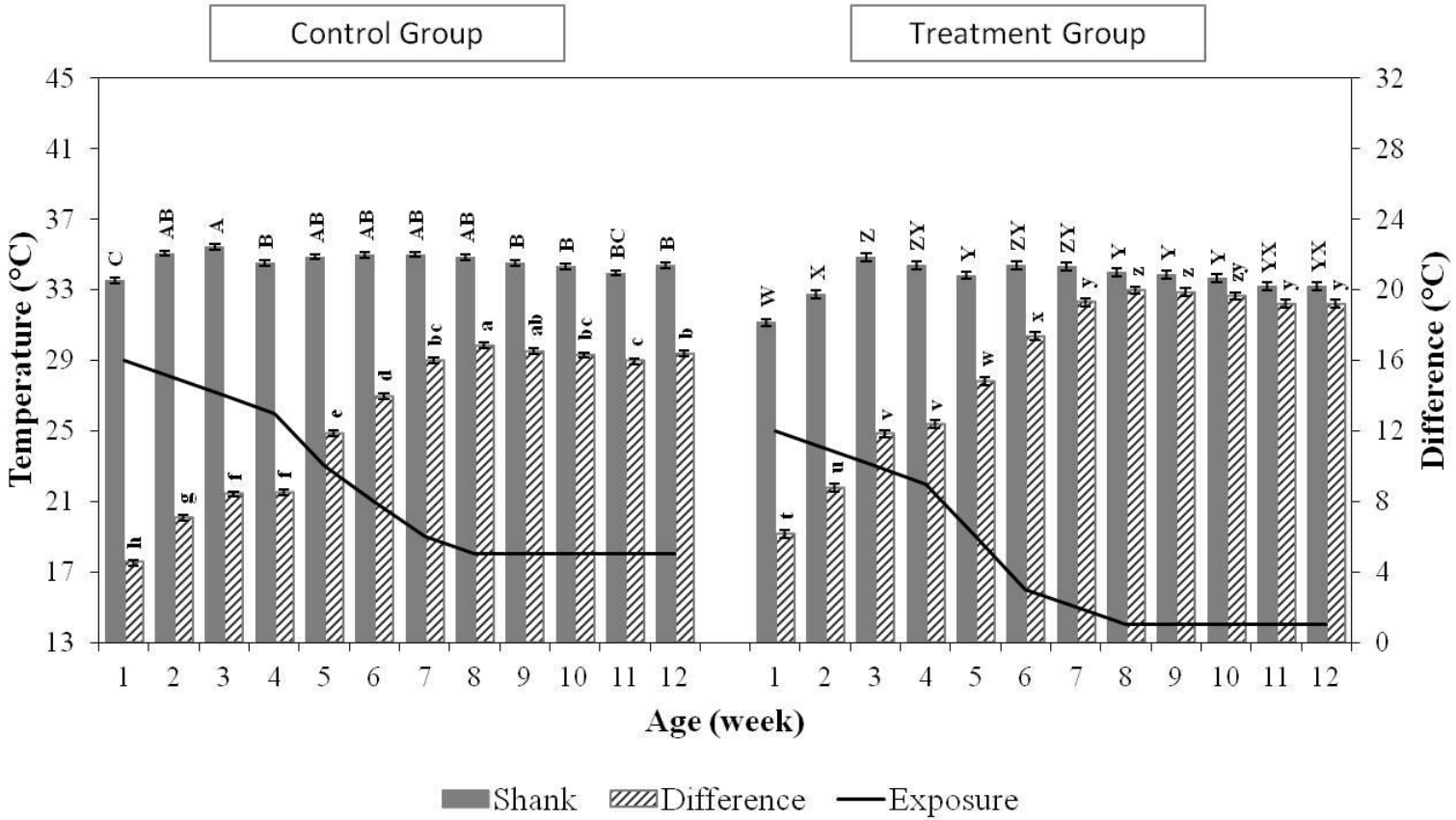

Figure 4.14. Weekly temperatures of the skin over the tarsometatarsus bone (shank) and differences between the shank and corresponding exposure temperature for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment). Common letters indicate no significant difference between weeks, with upper case letters representing body temperatures and lower case letters representing the difference between exposure temperature and body temperature. SEM(shank - control) = 0.16, SEM(shank - treatment) = 0.23, SEM(difference - control) = 0.16, SEM(difference - treatment) = 0.23; n=48 ($2^{\text{images}}/_{\text{collection time}}$ by $4^{\text{collection time}}/_{\text{data collection period}}$ by $6^{\text{birds}}/_{\text{treatment}}$)

T_{breast}^{con}(difference) had similar calculated differences during wks [1 & 6], [2, 4, 8 & 10-12] and [5 & 7-11] and T_{breast}^{trt}(difference) had similar calculated differences during wks [1 & 5], [2, 7-10 & 12] and [4-12] (P<0.01; Figure 4.8). T_{drum}^{con}(difference) had similar calculated differences during wks [1, 2, 5 & 7-12] and [1-7, 11 & 12] while T_{drum}^{trt}(difference) was similar during wks [1, 2, 7-9 & 12] and [1-8 & 10-12] (P<0.01; Figure 4.9). Similar calculated differences were seen during wks [2, 5 & 7-12] and [1-9] for T_{wing}^{con} (difference) and wks [1 & 8], [2-4, 6 & 11] and [3-12] for T_{wing}^{trt}(difference) (P<0.01; Figure 4.10). T_{core}^{con}(difference) and T_{core}^{trt}(difference), had similar calculated differences during wks [8-12] (P<0.01; Figure 4.11). For T_{logger}^{con}(difference) similar calculated differences were seen during wks [8 & 9] and [10 & 11], while T_{logger}^{trt}(difference) was similar during wks [8 & 10] and [11 & 12] (P<0.01; Figure 4.12). T_{head}^{con}(difference) showed similar calculated differences during wks [2 & 3], [8 & 12] and [9-12], and T_{head}^{trt}(difference) was similar during wks [8, 9 & 12] and [10 & 11] (P<0.01; Figure 4.13). T_{shank}^{con}(difference) was seen to have similar calculated differences during wks [3 & 4], [8 & 9], [7, 10 & 11] and [7, 9, 10 & 12] and T_{shank}^{trt}(difference) was seen to have similar differences during wks [7 & 10-12] and [8-10] (P<0.01; Figure 4.14).The calculated difference between the temperatures of feathered body locations and the exposure temperature, therefore, varied little over the 12 wks of study, while the featherless body locations had generally consistent calculated differences when the exposure temperature remained constant between wk 8-12. From wk 1-7 the calculated difference between the exposure temperature and the temperatures of the featherless body locations tended to increase as the exposure temperature decreased.

4.1.3. Comparison of Body Temperatures at Different Exposure Temperatures

Measured temperature location labels (example, T_{breast}^{con}) followed by the word 'week' within a set of circular brackets indicates that the data being discussed are a comparison of measured body location temperatures between the control and treatment groups during each wk of study. Measured temperature location labels followed by the words 'week-difference' within a set of circular brackets indicates that the data being discussed are a comparison of the calculated difference between the measured body location temperatures and the corresponding exposure temperatures between the control

and treatment groups during each wk of study. Comparing the temperature of the different body locations between the control and treatment group for each wk of study showed that the featherless locations had similar temperatures, while the feathered locations were, in comparison, different. The feathered locations had similar temperatures between the control and treatment groups at wks 6 and 9 for T_{breast}(week) and T_{wing}(week), and wks 2, 6 and 9 for T_{drum}(week) ($P<0.05$; Figure 4.15-4.17). The average difference in temperature between the control and treatment groups (average measured body temperature of the control group over 12 wks minus the average measured body temperature of the treatment group over the same 12 wks) was 2.12°C for T_{breast}(week) and 1.75°C for T_{drum}(week) and T_{wing}(week) with the control group having the warmer temperatures. T_{core}(week) was found to never have different temperatures between the control and treatment groups during each wk of study over the 12 wks ($P>0.05$; Figure 4.18). For the rest of the featherless locations, there were differences between the control and treatment groups at wks 3, 4 and 9 for T_{logger}(week) ($P<0.05$; Figure 4.19), wks 1, 2 and 5 for T_{head}(week) ($P<0.05$; Figure 4.20) and wks 1, 2, 5, 8 and 11 for T_{shank}(week) ($P<0.05$; Figure 4.21). The average difference between the control and treatment group was 0.71°C for T_{logger}(week), 0.56°C for T_{head}(week) and 0.99°C for T_{shank}(week), with the control group having the warmer temperatures.

A comparison of the calculated difference (body location temperature minus exposure temperatures) each wk between the control and treatment groups showed changes between the differences. The feathered locations were found not to have similar calculated differences between the control and treatment groups during wks 1-3, 5-8 and 10-12 for T_{breast}(week-difference) ($P<0.05$; Figure 4.15), wks 1-9 and 12 for T_{drum}(week-difference) ($P<0.05$; Figure4.16) and was never seen to be similar during the 12 wks for T_{wing}(week-difference) ($P<0.05$; Figure4.17). An average calculated difference between control and treatment group was 1.88°C for T_{breast}(week-difference) compared to 2.25°C for T_{drum}(week-difference) and T_{wing}(week-difference). The control and treatment groups had an average calculated difference of 3.74°C for T_{core}(week-difference), 3.29°C for T_{logger}(week-difference), 3.44°C for T_{head}(week-difference) and 3.01°C for T_{shank}(week-difference). In all cases the calculated differences of the treatment group were higher than the control group. The control and treatment group showed significant calculated

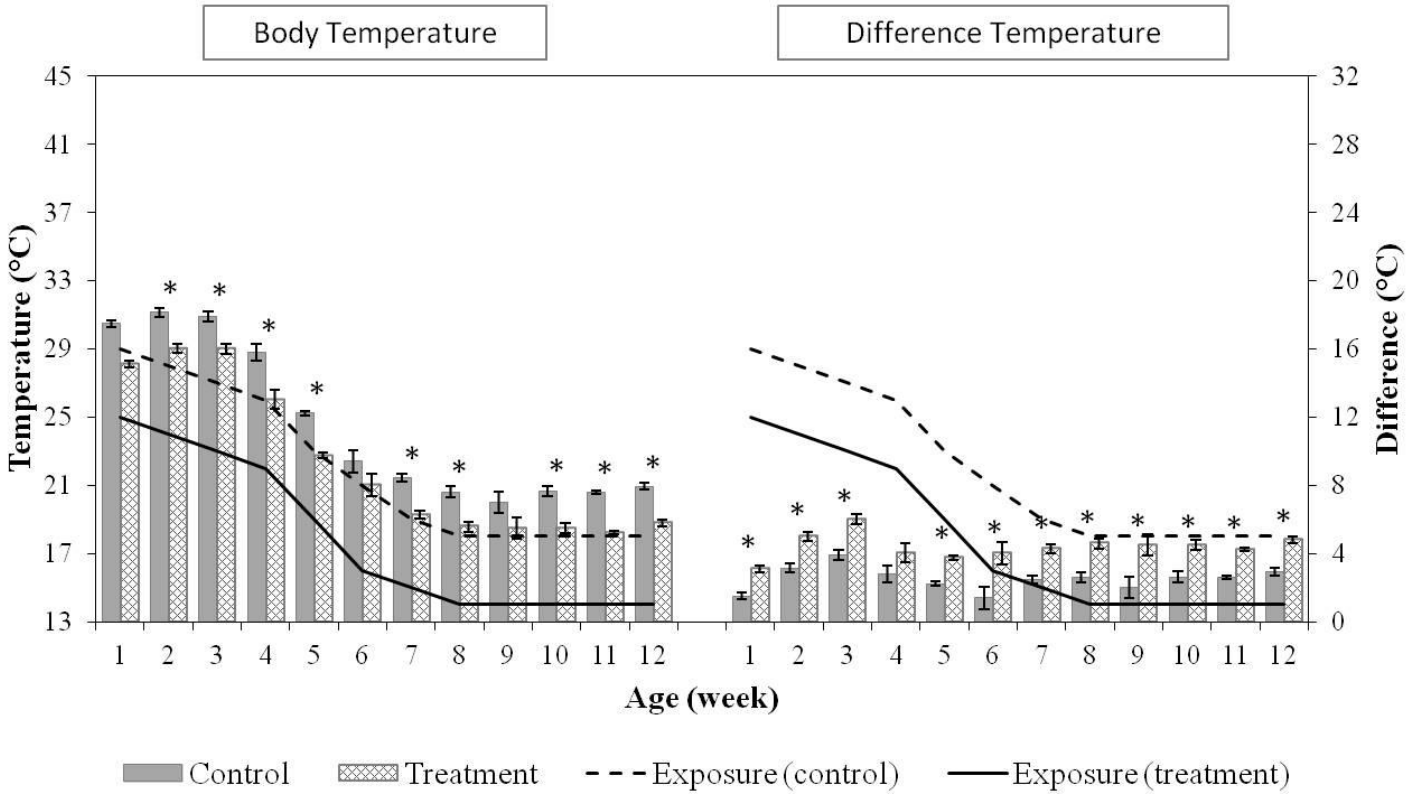

Figure 4.15. Comparison of breast temperatures and differences between the breast temperatures and corresponding exposure temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment) during each week of study. A significant difference between control and treatment is indicated by an '*'. SEM(both control and treatment) = 0.65; n=48 (2 $^{\text{images}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

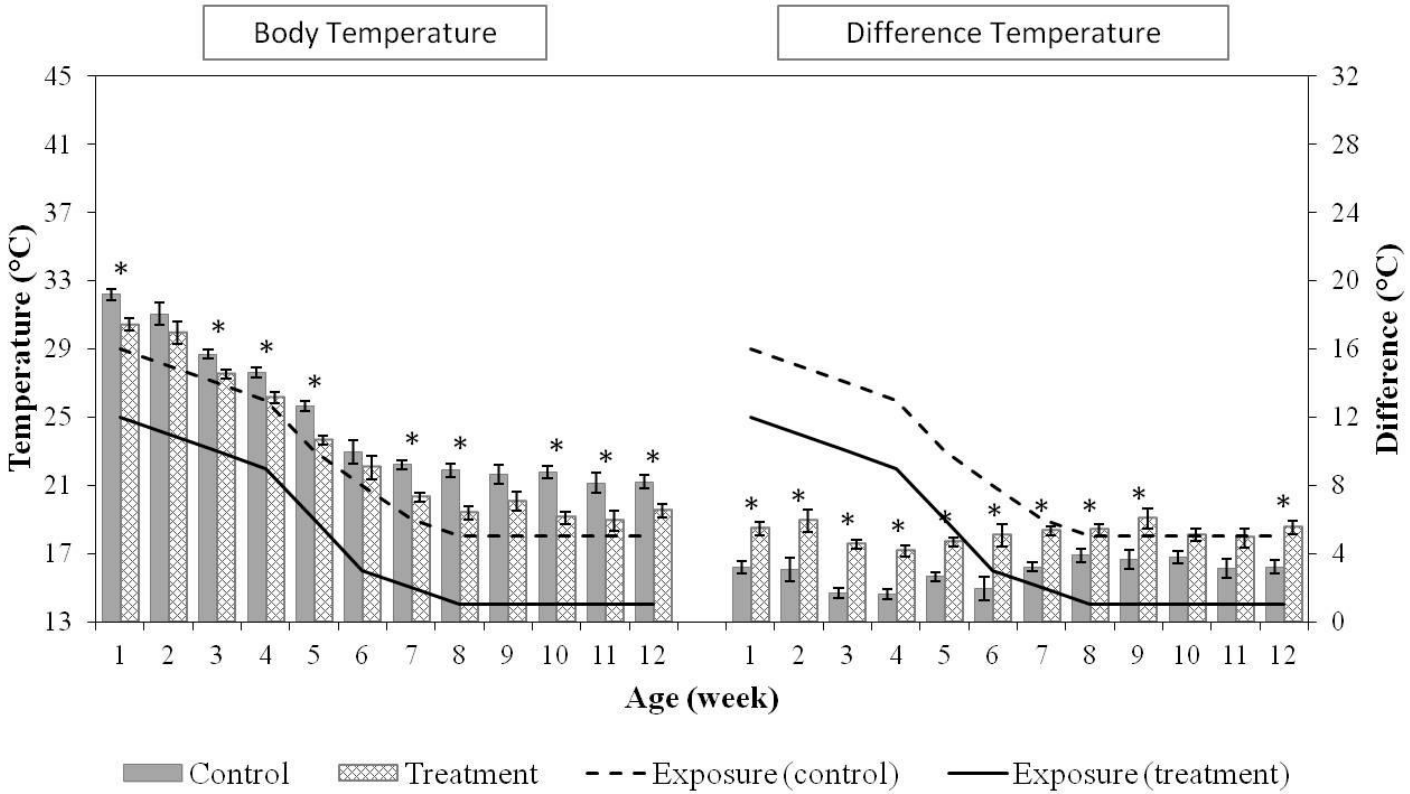

Figure 4.16. Comparison of distal lateral region of the tibiotarsal bone (drum) temperatures and differences between the drum temperatures and corresponding exposure temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment) during each week of study. A significant difference between control and treatment is indicated by an '*'. SEM(control) = 0.68, SEM(treatment) = 0.67; n=48 (2 $^{images}/_{collection\ time}$ by 4 $^{collection\ time}/_{data\ collection\ period}$ by 6 $^{birds}/_{treatment}$)

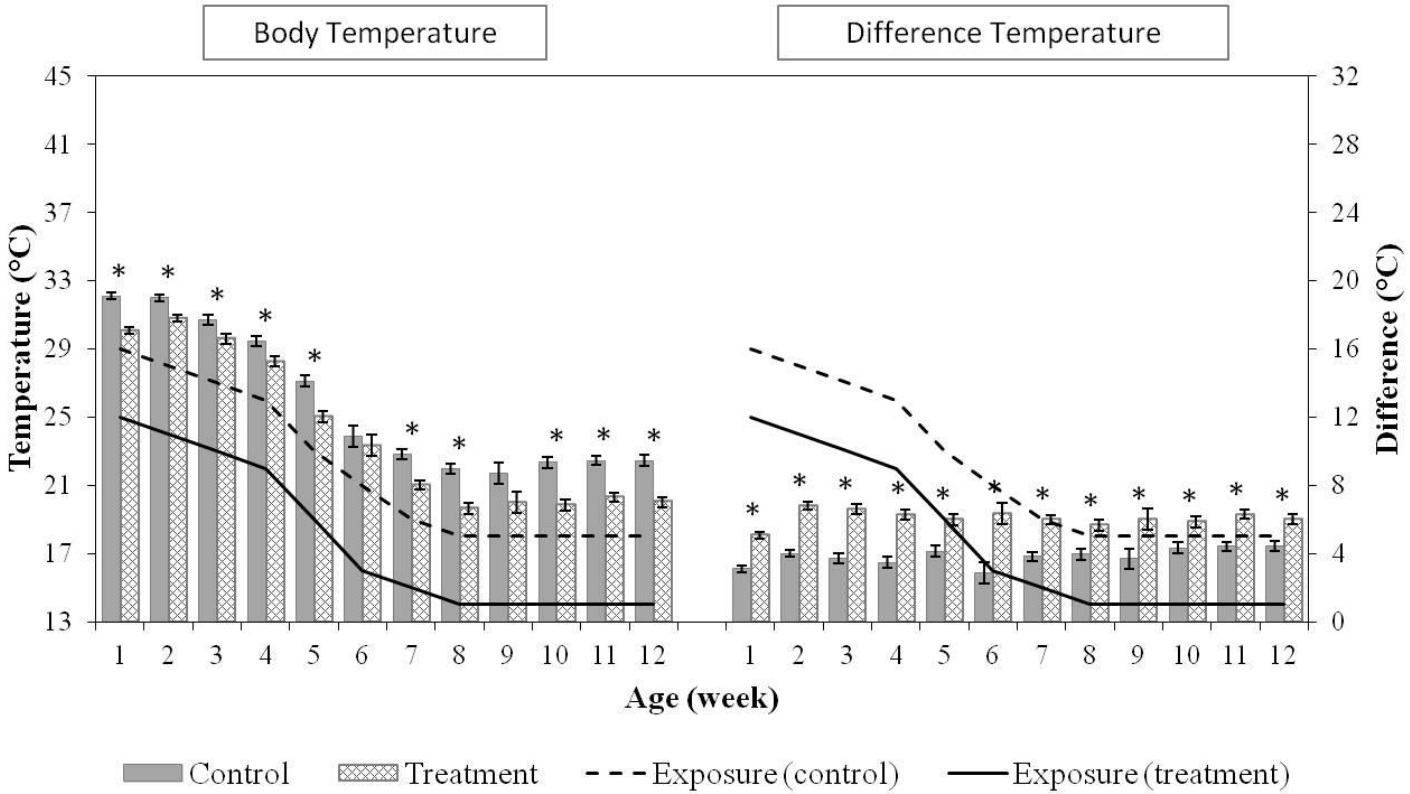

Figure 4.17. Comparison of wing temperatures and differences between the wing temperatures and corresponding exposure temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment) during each week of study. A significant difference between control and treatment is indicated by an '*'. SEM(both control and treatment) = 0.63; n=48 (2 $^{\text{images}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

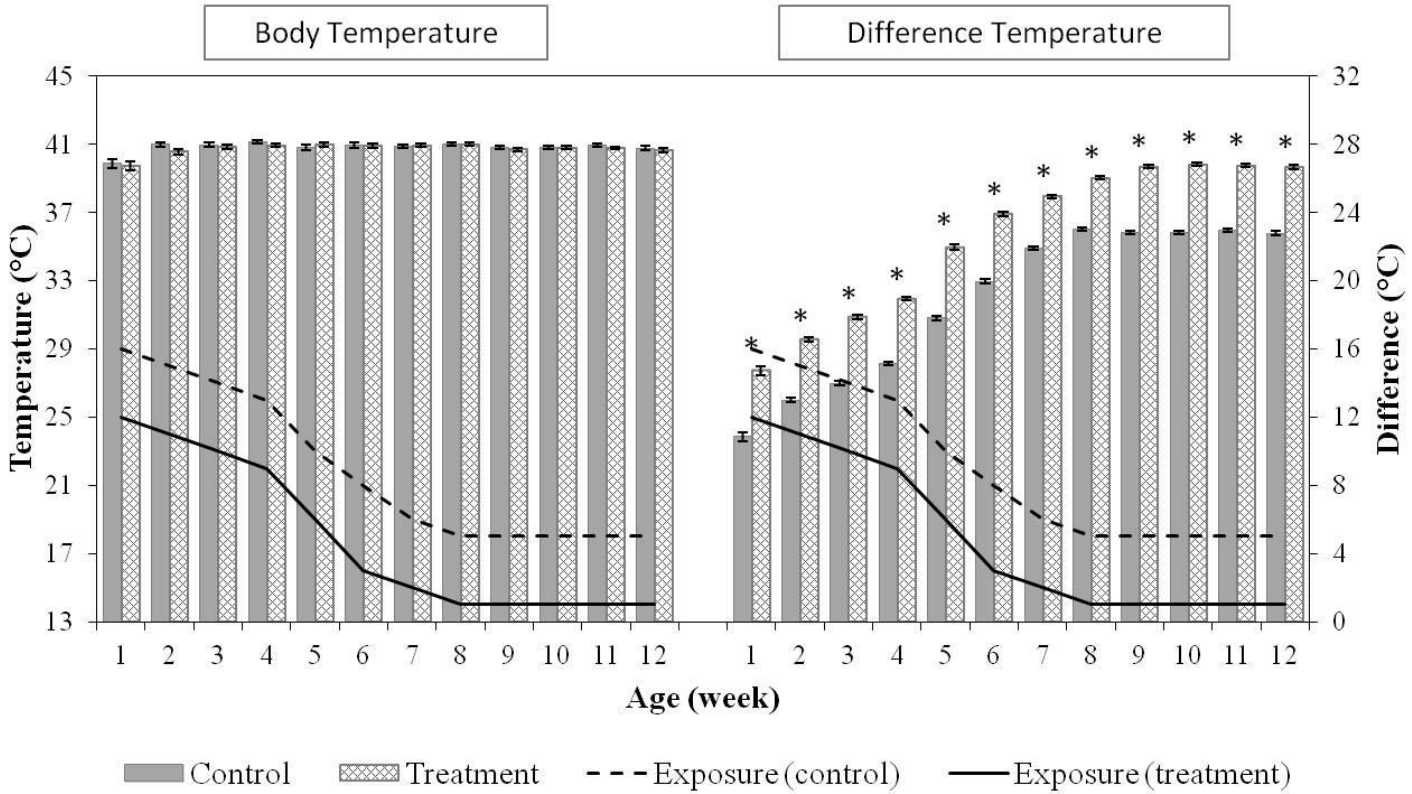

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Figure 4.18. Comparison of cloacae (core) temperatures and differences between the core temperatures and corresponding exposure temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment) during each week of study. A significant difference between control and treatment is indicated by an '*'. SEM(both control and treatment) = 0.26; n=6 (1 $^{\text{measurement}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

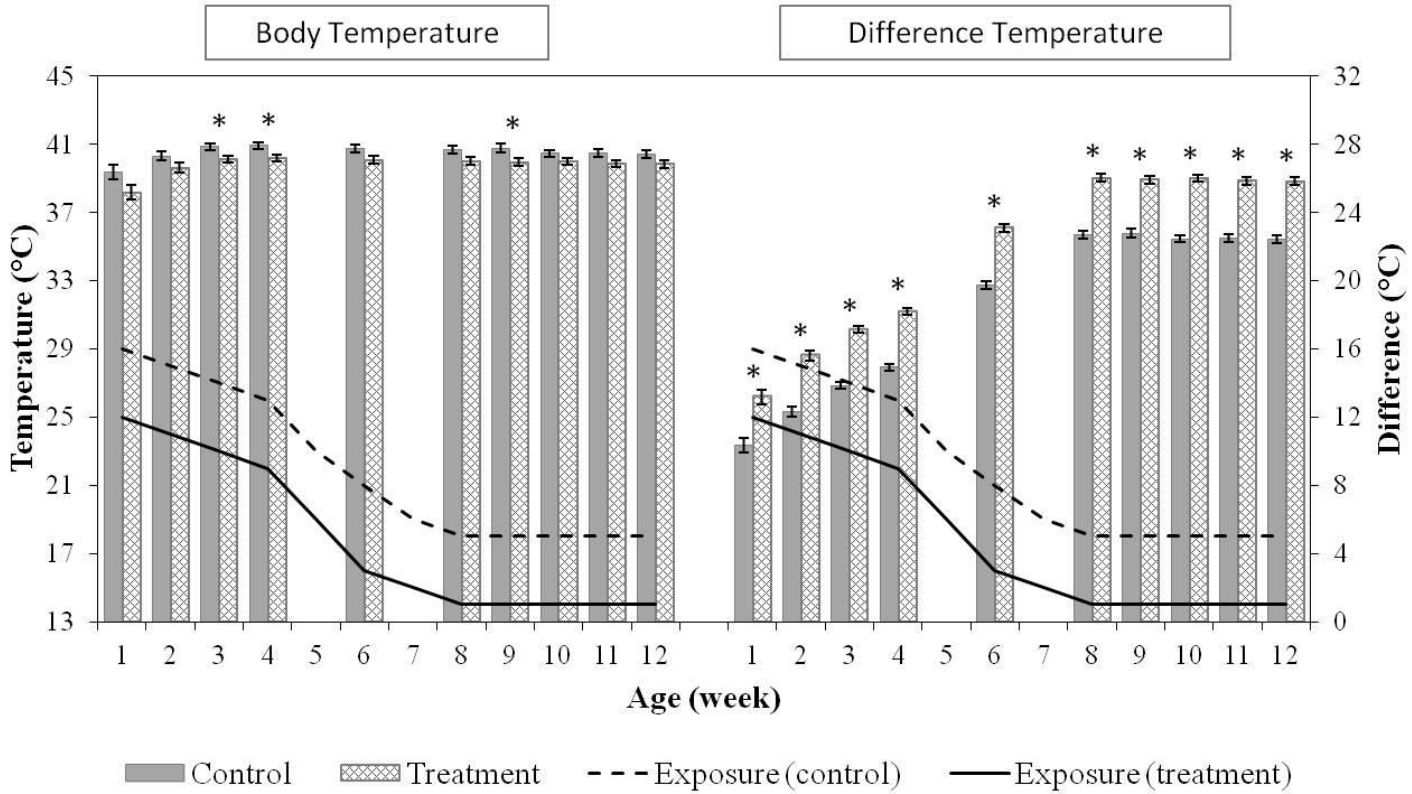

Figure 4.19. Comparison of under the wing (data logger) temperatures and differences between the data logger temperatures and corresponding exposure temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment) during each week of study. A significant difference between control and treatment is indicated by an '*'. SEM(both control and treatment) = 0.43; n=480 (10 $^{\text{measurements}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$), missing data for weeks 5 and 7 not included

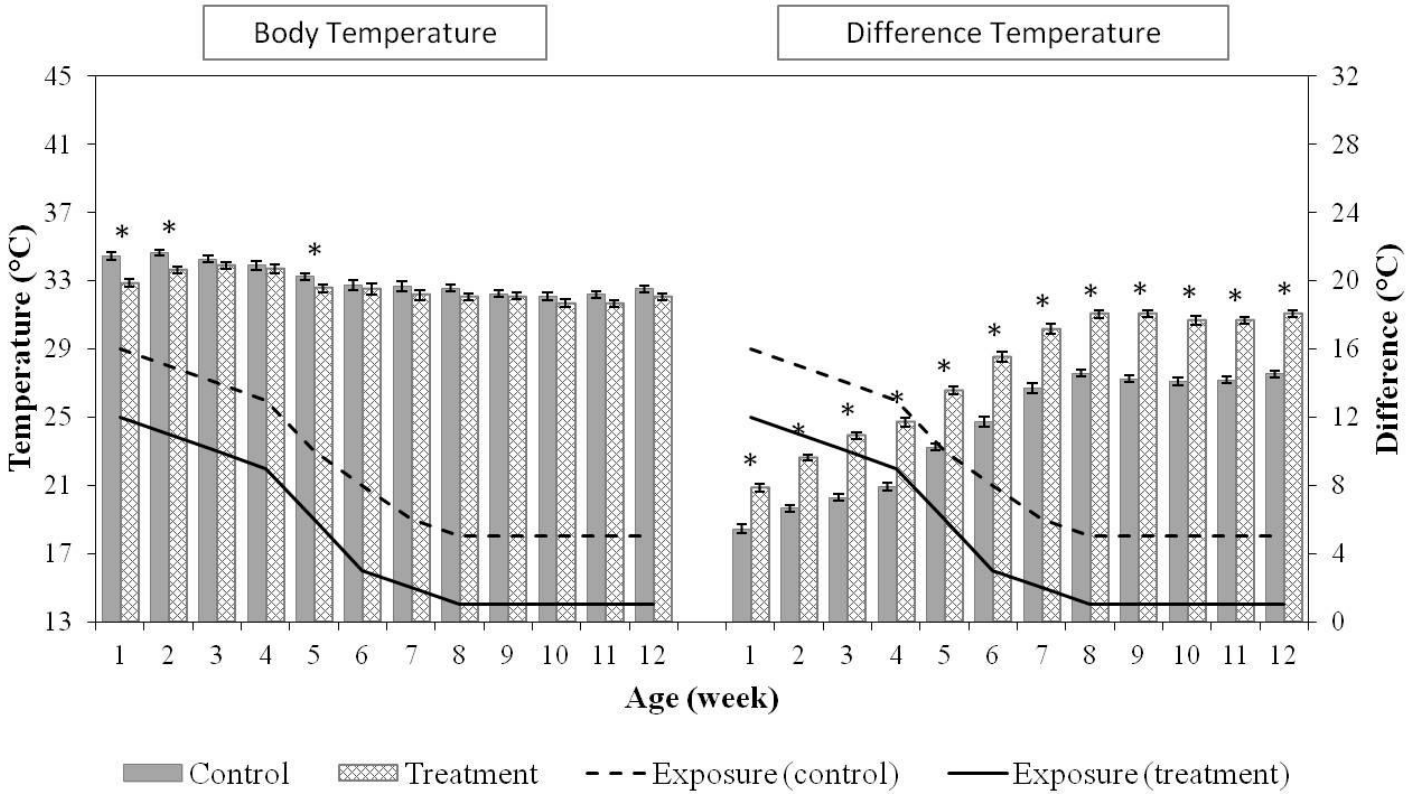

Figure 4.20. Comparison of external ear opening (head) temperatures and differences between the head temperatures and corresponding exposure temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment) during each week of study. A significant difference between control and treatment is indicated by an '*'. SEM(both control and treatment) = 0.30; n=48 (2 $^{\text{images}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

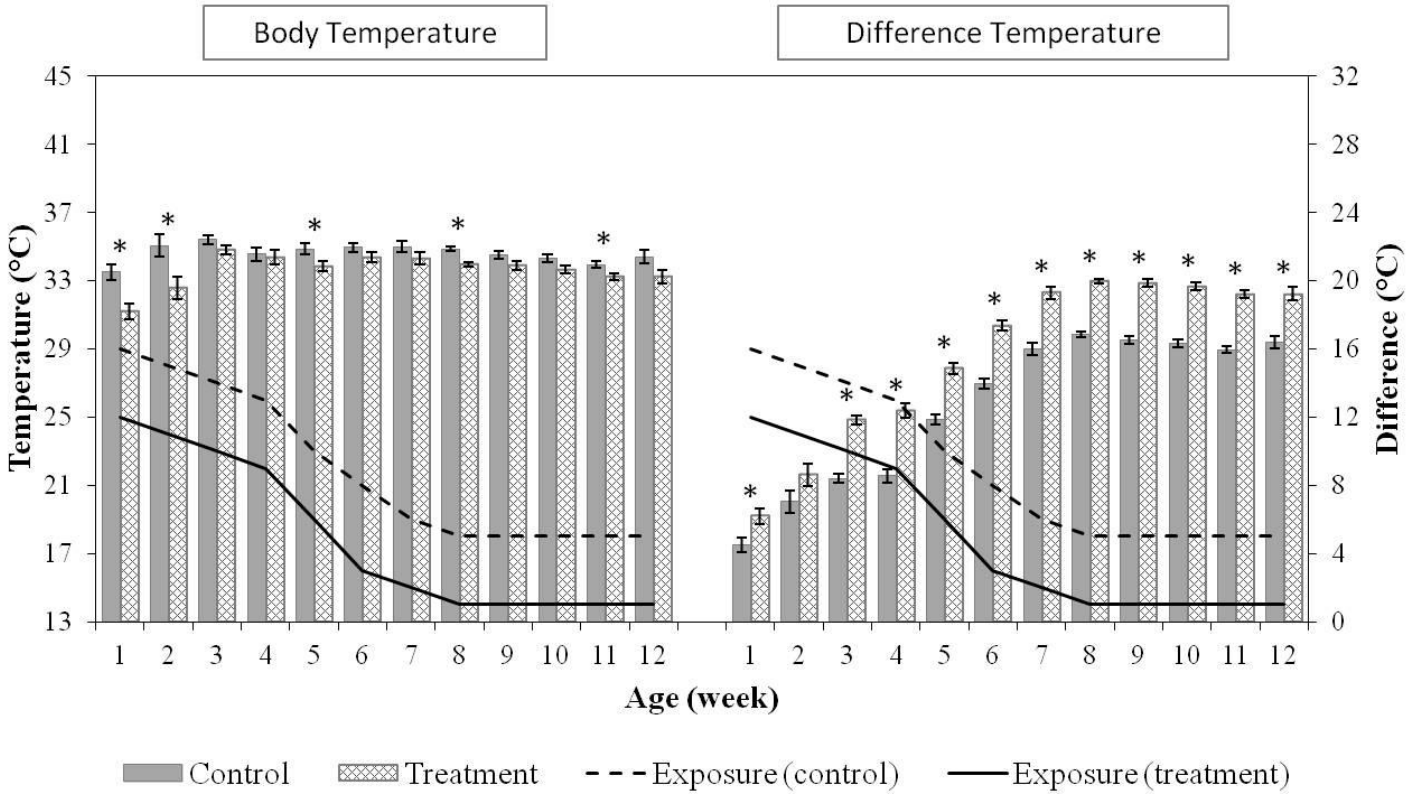

Figure 4.21. Comparison of skin over the tarsometatarsus bone (shank) temperatures and differences between the shank temperatures and corresponding exposure temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to one of two different temperature curves: the standard temperature curve (control) or 4°C below the standard (treatment) during each week of study. A significant difference between control and treatment is indicated by an '*'. SEM(both control and treatment) = 0.65; n=48 (2 $^{\text{images}}/_{\text{collection time}}$ by 4 $^{\text{collection time}}/_{\text{data collection period}}$ by 6 $^{\text{birds}}/_{\text{treatment}}$)

differences (P<0.05; Figure4.18-4.20) for T_{core}(week-difference), T_{logger}(week-difference) and T_{head}(week-difference) at all 12weeks of study. A similar calculated difference was observed for T_{shank}(week-difference) during week 2 (P<0.05; Figure4.21) between the control and treatment groups.

4.2. Correlations

Analysis of the featherless locations (Table 4.1), showed T_{head}^{con} to have a strong positive relationship with exposure temperature and T_{head}^{trt} to have a positive intermediate relationship (P<0.0001 for both treatment groups). Both T_{logger}^{con} and T_{logger}^{trt} had weak negative relationships with exposure temperature (P<0.01). There was no relationship observed between exposure temperature and T_{shank}^{con} (P=0.30) or between exposure temperature and T_{core}^{con} (P>0.05). For T_{core}^{trt} (P=0.01) a negative intermediate relationship was observed with exposure temperature, while a negative weak relationship was observed between exposure temperature and T_{shank}^{trt} (<0.01). A strong positive relationship was observed between exposure temperature and T_{breast}, T_{drum} and T_{wing} (P<0.01, respectively), for both treatment groups (Table 4.2).

Table 4.1. Correlation between featherless (core, head, shank and data logger) locations and exposure temperature for the entire 12 weeks of study

Group	Core		Head		Shank		Data Logger	
	r	P-value	r	P-value	r	P-value	r	P-value
Control	-0.230	0.0535	0.811	<0.0001	0.044	0.3	-0.208	<0.0001
Treatment	-0.369	0.0016	0.433	<0.0001	-0.195	<.0001	-0.284	<0.0001

n=576 (2 $^{images}/_{time}$ by 4 $^{image\ collection\ times}/_{data\ collection\ period}$ by 6 $^{birds}/_{treatment}$ by 12 $^{week}/_{study\ period}$) for core, head and shank locations, n=1440 (10 $^{measurements}/_{time}$ by 4 $^{collection\ time}/_{data\ collection\ period}$ by 6 $^{birds}/_{treatment}$ by 12 $^{week}/_{study\ period}$) for logger location

Table 4.2. Correlation between feathered (breast, drumstick and wing) locations and exposure temperature for the entire 12 weeks of study

Group	Breast		Drum		Wing	
	r	P-value	r	P-value	r	P-value
Control	0.962	<0.0001	0.905	<0.0001	0.957	<0.0001
Treatment	0.958	<0.0001	0.920	<0.0001	0.968	<0.0001

n=576 (2 $^{images}/_{time}$ by 4 $^{image\ collection\ times}/_{data\ collection\ period}$ by 6 $^{birds}/_{treatment}$ by 12 $^{week}/_{study\ period}$)

4.3. Regression

A regression analysis was used to determine the relationship between the temperatures of the feathered locations (T_{breast}, T_{drum} and T_{wing}) for both the control and treatment groups and the corresponding T^{con} and T^{trt}, over the entire 12 wks. R^2 values provided by the regression analysis are the proportion of variance within data that can be explained by a regression equation. Larger R^2 values indicate that more of the variance found within the data can be explained by the regression equation created and the equation is sufficient in explaining the relationship between the two tested variables. In this analysis, the variables are T^{con} and one of either T^{con}_{breast}, T^{con}_{drum} or T^{con}_{wing} as well as T^{trt} and one of T^{trt}_{breast}, T^{trt}_{drum} or T^{trt}_{wing}. From highest to lowest, the R^2 values were as follows: 0.97 for T^{trt}_{wing}, 0.94 for T^{con}_{breast}, T^{trt}_{breast}, T^{trt}_{drum} as well as T^{con}_{wing} and 0.90 for T^{con}_{drum}. Testing this analysis on the featherless locations (T_{core}, T_{head}, T_{shank} and T_{logger}) provided small R^2 values that indicate the regression equations created were insufficient in explaining the relationship between the measured temperatures at these locations and their corresponding exposure temperature.

The slopes contained in the regression equations created for the feathered locations compared to the exposure temperatures of the control and treatment groups are close to 1 (Figure 4.22-4.28). This indicates that a change in T^{con} or T^{trt} will result in a similar change to the temperatures of the feathered locations. Indirectly, the equations also provide the numerical difference between T^{con} or T^{trt} and T_{breast}, T_{drum} and T_{wing} when the exposure temperature is set to 0. T^{con}_{breast} is 1.99 units higher, T^{con}_{drum} is 5.02 units higher and T^{con}_{wing} is 5.04 units higher than T^{con}. T^{trt} is found to be 4.47 units, 5.68 units and 5.82 units lower than T^{trt}_{breast}, T^{trt}_{drum} and T^{trt}_{wing} , respectively.

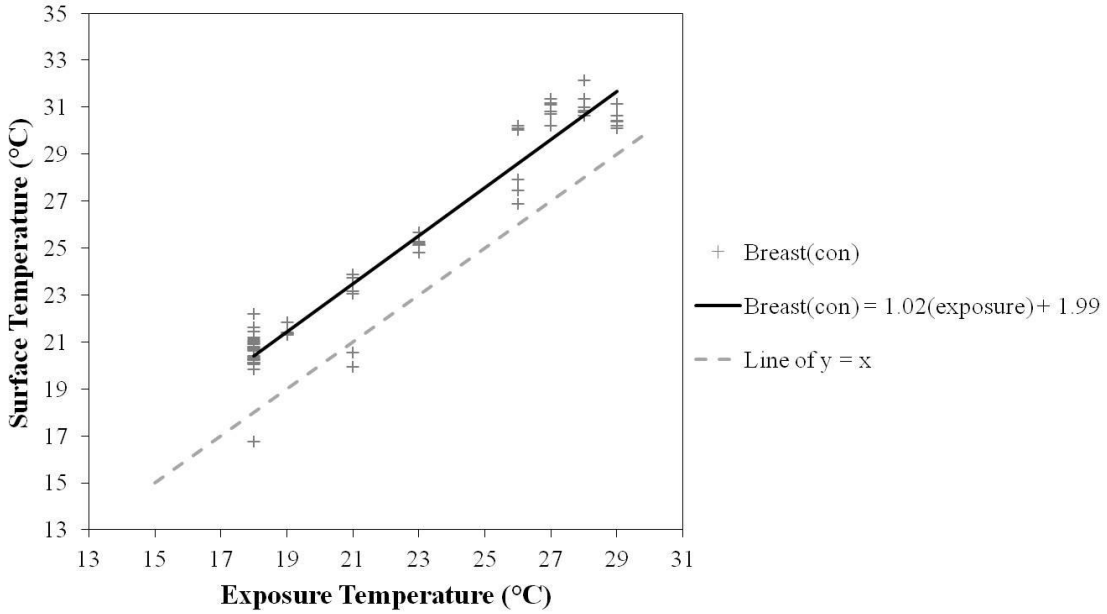

Figure 4.22. Regression analysis of the breast temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to the standard temperature curve. The solid line represents the regression equation for the control breast data [$\mathbf{T_{breast}^{con}}$ = 1.02(exposure temperature) + 1.99]. The dotted line represents a regression equation where the slope is 1 and the y-intercept is 0.

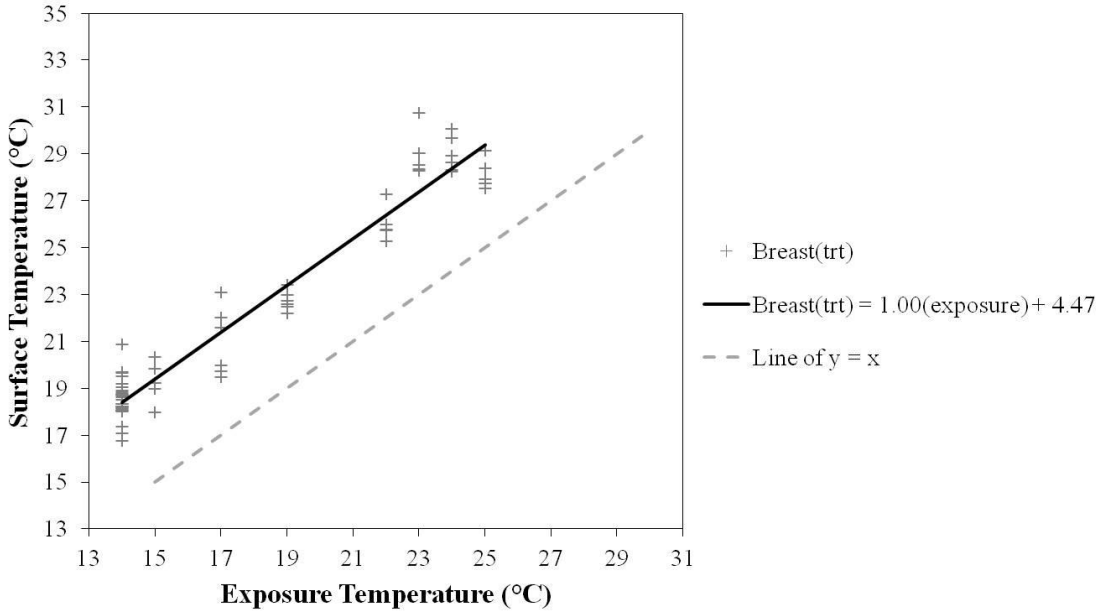

Figure 4.23. Regression analysis of the breast temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to 4°C below the standard temperature curve. The solid line represents the regression equation for the treatment breast data [$\mathbf{T_{breast}^{trt}}$ = 1.00(exposure temperature) + 4.47]. The dotted line represents a regression equation where the slope is 1 and the y-intercept is 0.

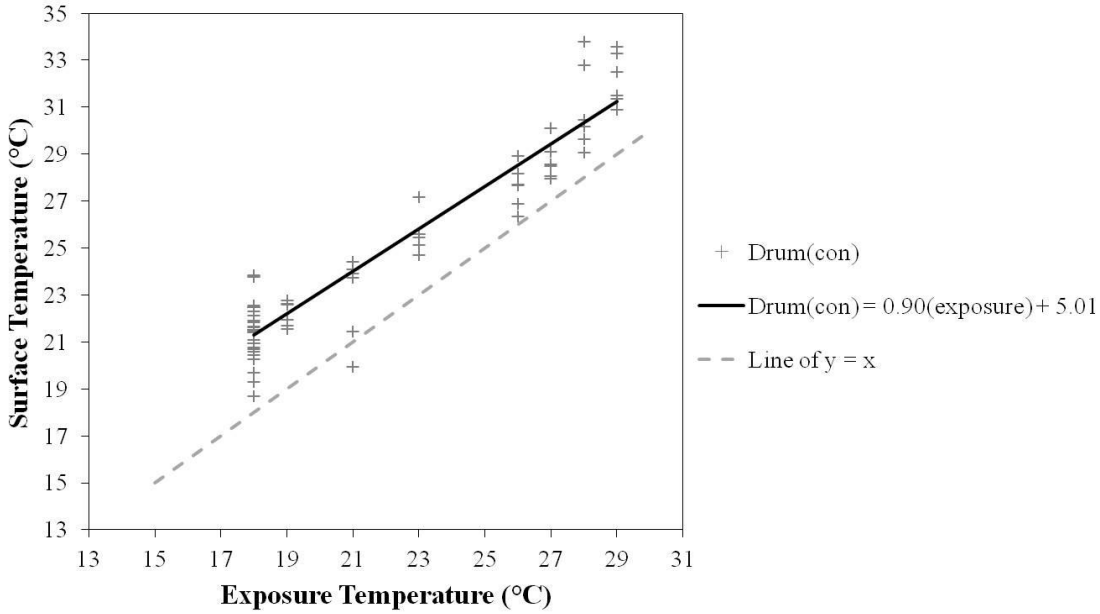

Figure 4.24. Regression analysis of the drum temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to the standard temperature curve. The solid line represents the regression equation for the control drum data [$\mathbf{T_{drum}^{con}}$= 0.90(exposure temperature) + 5.01]. The dotted line represents a regression equation where the slope is 1 and the y-intercept is 0.

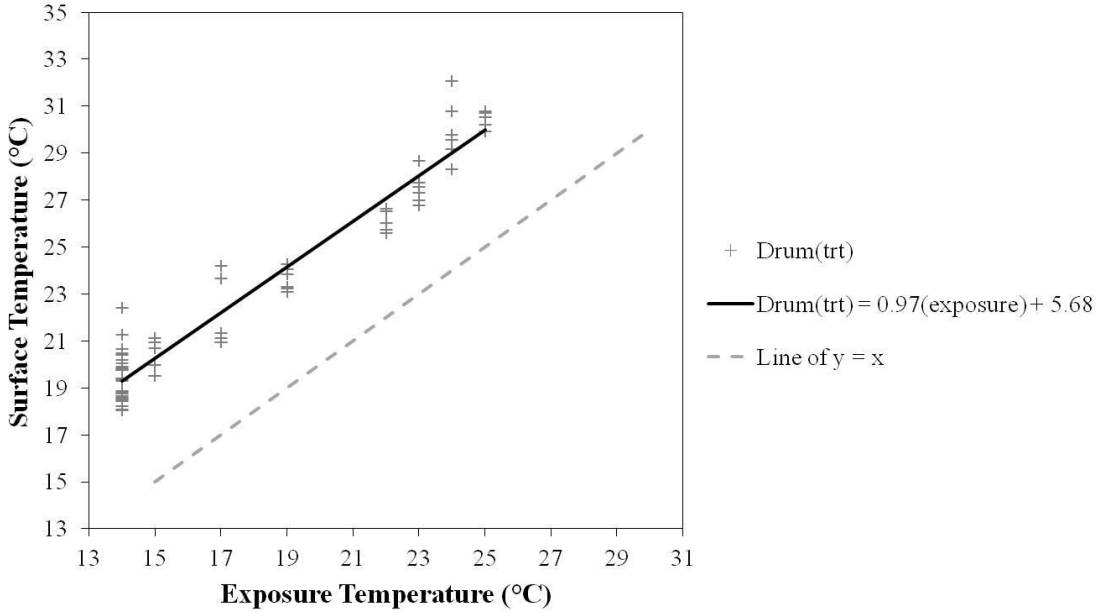

Figure 4.25. Regression analysis of the drum temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to 4°C below the standard temperature curve. The solid line represents the regression equation for the treatment drum data [$\mathbf{T_{drum}^{trt}}$= 0.97(exposure temperature) + 5.68]. The dotted line represents a regression equation where the slope is 1 and the y-intercept is 0.

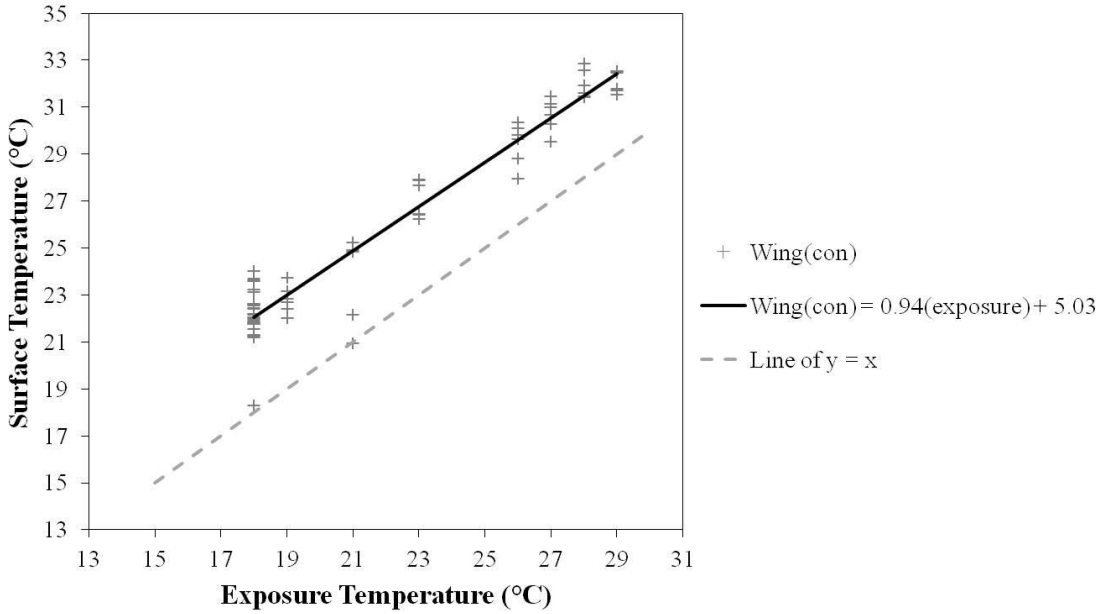

Figure 4.26. Regression analysis of the wing temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to the standard temperature curve. The solid line represents the regression equation for the control wing data [$\mathbf{T_{wing}^{con}}$ = 0.94(exposure temperature) + 5.03]. The dotted line represents a regression equation where the slope is 1 and the y-intercept is 0.

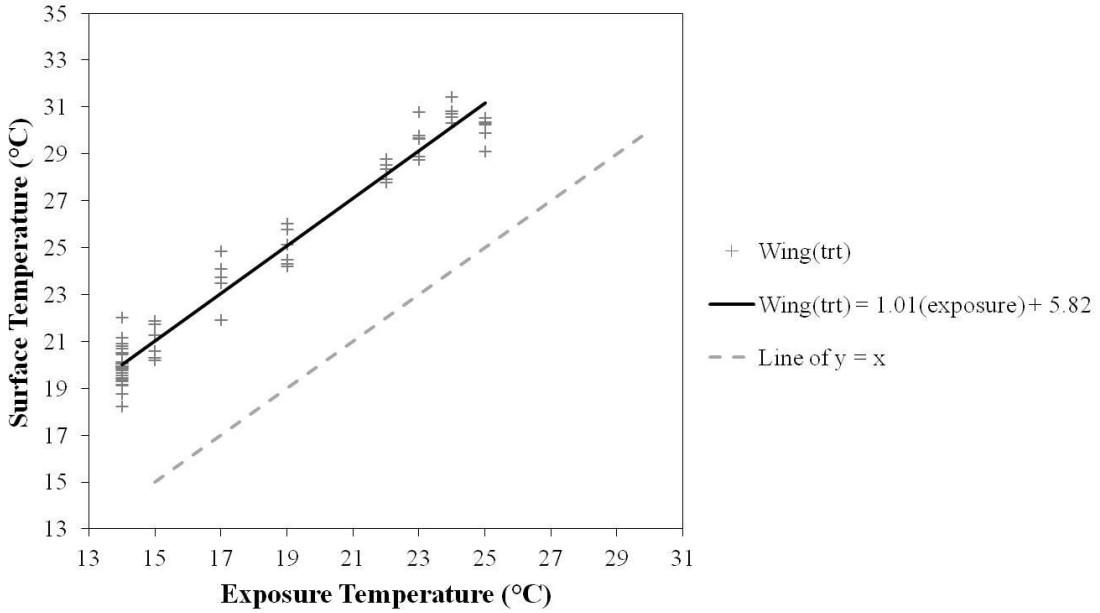

Figure 4.27. Regression analysis of the wing temperatures for Hybrid Converter tom turkeys grown from 1 - 12 weeks of age exposed to 4°C below the standard temperature curve. The solid line represents the regression equation for the treatment wing data [$\mathbf{T_{wing}^{trt}}$ = 1.01(exposure temperature) + 5.82]. The dotted line represents a regression equation where the slope is 1 and the y-intercept is 0.

CHAPTER 5: Discussion

5.1. Surface Temperatures at Specific Ambient Temperatures

The surface temperatures of the feathered locations appear to reflect changes in exposure temperature, seen through the strong, positive relationship between T^{con} or T^{trt} and T_{breast}, T_{drum} or T_{wing} (Table 4.2). There is a distinct, although not perfect, pattern to the decrease in feathered surface temperatures that follow the same decreasing pattern as the exposure temperature (Figure 4.1-4.3). A positive, approximate one-by-one linear relationship between T_{breast}, T_{drum} or T_{wing} and T^{con} or T^{trt} (Figure 4.22-4.28) further indicates that a change in exposure temperature results in a similar change in surface temperature.

A current study by Cangar *et al.* (2008) also illustrates a similar pattern of surface temperatures decreasing to the same approximate degree as the exposure temperature. In this study, growing broiler chickens subjected to an average decrease in exposure temperature of 1.2°C every 7 days, from 3 to 37 days of age, showed a decrease in surface wing temperature of approximately 2°C during this same time period. A true reflection in temperature occurred between days 22 to 37 with the wing temperature and the exposure temperature decreasing at the same rate. The change in the measured surface drumstick temperature by Cangar *et al.* (2008) was found to be in contrast with the change in T_{drum} measured in this study. As the exposure temperature decreased, the temperature of the drumstick remained relatively constant compared to T_{drum} within the current study which decreased in temperature. The two studies show an even greater difference in the change of the measured breast temperatures as the Cangar *et al.* (2008) study illustrates a dramatic rise and fall in breast temperature with the decrease in exposure temperature.

The difference in these patterns may be due to the measurement techniques, facilities and species worked with between these two studies. Chickens have a lower feather density on the breast compared to turkeys (Lucas & Stettenheim, 1972) and thus, provide less insulation. This reduction in insulation may cause the measured temperature to reflect the temperature of the skin more than the exposure temperature in the study by

Cangar *et al.* (2008). Further, the temperature measurement for the breast was obtained from an image taken at an angle below the bird. Should the birds piloerect their feathers (feathers standing vertical to the body) the resulting temperature would potentially consist of both feather and skin temperatures due to the angle of the image, consequentially giving an inaccurate final temperature reading.

Both studies attempted to reduce measurement errors by taking the images as quickly as possible; however, the study by Cangar *et al.* (2008) randomly selected birds from a large flock at each testing period. This stopped the birds from being able to acclimate to the measurement process. Handling birds elevates their internal and skin temperatures as well as their heart rate (Cabanac & Guillemette, 2001). Allowing birds to become acclimated to handling lowers the rise in temperature (Cabanac & Guillemette, 2001) making the measured temperatures more representative of the actual surface temperature. This may explain some of the differences in the temperature patterns observed over the course of the two studies.

From a facility perspective, Cangar *et al.* (2008) testing chickens under commercial housing conditions, allows the birds to express thermal regulating behaviours, an example being huddling, not available to birds in the current study. It is possible that a lack of response in the breast and drumstick temperatures to the change in exposure temperature may be due to the reduction in the surface area exposed to the environment when birds are in close proximity to one another. Heat transfer through convection to the surrounding environment cannot occur if the surfaces are not exposed. When the birds are in contact with one another, heat will be transferred by conduction and the surfaces will represent the temperature of the bird(s) beside them as opposed to the exposure temperature.

This study found that the temperatures of the featherless locations remained relatively constant while exposure temperature decreased (Figure 4.4-4.7). This pattern of constant surface temperatures of featherless locations is confirmed by Cangar *et al.* (2008) as head and shank temperatures remained constant over the study period. The temperature under the wing decreased by approximately 3°C during the second last

measurement period, while remaining relatively the same for the remaining measurement periods. These featherless locations are used for thermal regulation and help to maintain a constant internal temperature (Giloh *et al.*, 2012). It is expected then, that as the exposure temperature changes the temperature of these surface locations will change in reflection to the exposure temperature. No clear mathematical explanation (regression analysis) can be provided to accurately explain a relationship between T^{con} or T^{trt} and T_{core}, T_{logger}, T_{head} or T_{shank} (Section 4.3). This may be due to the exposure temperatures of both studies, remaining within the turkeys' thermal neutral zone. At these temperatures the turkeys are at a comfortable thermal state, not requiring any additional heat loss or retention. The movement of heat to and from the birds would therefore, be constant and at a neutral temperature compared to the temperatures of the surfaces when the birds are attempting to either lose or retain heat.

5.2. Comparison of Weekly Body Temperatures at Specific Ambient Temperatures

Natal down (termed 1st generation feather growth) covers chickens from hatch to a maximum of 56 days of age, though most down is lost between 14 and 28 days (Lucas & Stettenheim, 1972). Starting around 14 days of age, adult feather growth occurs with the development of 2nd generation feather growth over the body and wings (Lucas & Stettenheim, 1972). Measured temperatures of the feathered locations were found to be the same during the first 3 wks for T_{breast} and the first 2 wks for T_{drum} and T_{wing} when exposed to either T^{con} or T^{trt} (Figure 4.8-4.10). T_{breast}(difference), for both the control and treatment group, increased from wk 1 to wk 3, while T_{drum}(difference) and T_{wing}(difference) were shown to be the same during the first two wks (Figure 4.8-4.10). This demonstrates that the surface temperatures decreased during the first few wks of study. As down is a poor insulator compared to adult feathers (Lucas & Stettenheim, 1972), the surface temperatures measured over the first 2 to 3 wks are affected to a greater degree by the skin temperature rather than the exposure temperature. The response at wk 3 for T_{breast}(difference) which is not seen for T_{drum}(difference) and T_{wing}(difference), may be due to the lower feather density over the breast compared to the drum and wing during this wk (Lucas & Stettenheim, 1972).

Feather cover is continually changing throughout a bird's life (Lucas & Stettenheim, 1972); however, a complete cover of adult feathers occurs around 56 days of age (Lucas & Stettenheim, 1972). T_{breast}, T_{drum} and T_{wing} exposed to T^{con} or T^{trt} fluctuated slightly during the last 6 wks of study yet still remained relatively constant (Figure 4.8-4.10). During this time, T^{con} and T^{trt} were held constant from wk 8 to wk 12 and were only 1°C higher at wk 7 compared to the final 5 wks. Further evidence that the surface temperatures were constant is in T_{breast}(difference), T_{drum}(difference) and T_{wing}(difference) over this period (Figure 4.8-4.10). The exposure temperature and body temperature remained constant during the last 4 wks, leaving the difference calculation to also be constant during this period. Constant T_{breast}, T_{drum} and T_{wing} are therefore, most likely due to the birds being fully feathered in combination with the exposure temperature remaining constant, during the last 6 wks of study. From this it can be concluded that feathered body locations can only be used as indicators of temperature stress during the first 3 wks of growth when feather coverage is minimal.

Young poultry are unable to maintain a constant core temperature during the first 10 days of life (Weytjens, 1999; Yardimci *et al.*, 2006) and must rely on external sources of heat. This was seen in the first wk of study as T_{core}^{con} and T_{core}^{trt} were roughly 40°C for wk 1 compared to 41°C for the remaining 11 wks (Figure 4.11). Similar patterns occurred, with T_{logger}^{con}, T_{logger}^{trt} and T_{shank}^{con} having lower temperatures during the first 2 wks and T_{shank}^{trt} having a lower temperature during the first wk, compared to the remaining wks of study (Figure 4.13-4.14). The skin at the juncture between the wing and the shoulder region on the underside of the wing and the shank are locations of thermal regulation for poultry and are used to maintain a constant internal temperature (Giloh *et al.*, 2012). It is possible, that the lower surface temperatures during the first few wks of growth are due to an attempt at restricting heat loss; however, poultry are poikilotherm (Weytjens, 1999; Yardimci *et al.*, 2006) during this time and the functionality of these thermal regulation locations is not wholly developed. The turkeys therefore, become reliant on the exposure temperature to maintain their body temperature. As T_{core}, T_{logger} and T_{shank} are low during the first wk of growth it is acceptable to believe that T^{con} and T^{trt} were too cold for maintaining a proper body temperature.

Young birds are continually improving their ability to regulate their body temperature over the second wk of growth (Phillips & Sanborn, 1995). At the end of the first wk the extra warmth from the heat lamp was removed, causing the turkeys to rely on thermal regulating behaviours. Within the home pen the birds are able to express the thermal regulating behaviour of huddling to share body heat through conduction and reduce the loss of heat through convention. During the trial periods the poults were housed individually, thus stopping them from being able to huddle together and share body heat. Due to this, the poults would have to reduce the movement of heat to the surrounding environment through the thermal regulating locations. The surface temperatures of the skin at the juncture between the wing and the shoulder region on the underside of the wing and the shank would therefore decrease. This development in thermal regulation may explain why T_{logger} and T_{shank} are lower during the first 2 wks of growth.

Lower surface temperatures were not found to occur during the first few wks of study for T_{head} and this location therefore does not follow the pattern expressed by the other featherless locations (Figure 4.12) even though it is also used for thermal regulation (Giloh *et al.*, 2012). The head is highly vascularised as the brain requires a significant supply of blood to provide the quantities of oxygen needed for proper brain function (Whittow, 1998). Blood travels directly from the heart to the brain carrying the oxygen as well as a supply of heat. It is possible that the direct movement of blood from the internal body to the brain resulted in a continual transfer of heat from the core of the bird to the surface of the head resulting in the higher T_{head} during the first 2 wks.

Another unexpected pattern emerged with T_{head}, T_{logger} and T_{shank} exposed to either T^{con} or T^{trt}, with the surface temperatures peaking at 3 (T_{head} and T_{shank}) or 4 (T_{logger}) wks-of-age before decreasing in temperature for the remainder of the study (Figure. 4.12-4.14). T_{head}(difference), T_{logger}(difference) and T_{shank}(difference) expand upon this finding as, the difference between the exposure temperature and the surface temperatures decrease during wks 8 to 12 when the exposure temperature is held constant (Figure 4.12-4.14). The difference between the highest and lowest temperature was 1.59°C for T_{logger}^{con}

and 2.03°C for T_{logger}^{trt} (between wks 4 and 12), 2.20°C for T_{head}^{con} (between wks 3 and 10) and 2.23°C for T_{head}^{trt}, 1.47°C for T_{shank}^{con} and 1.61°C for T_{shank}^{trt} (between wks 3 and 11).

It is expected that the surface temperatures of the thermal regulating locations will change in refection to the exposure temperature. In order to maintain a constant internal temperature at low exposure temperatures the movement of heat will be reduced through the thermal regulating locations. This is accomplished by reducing the movement of heat from the core to the surface of the bird resulting in lower skin temperatures. It is therefore, reasonable to observe decreases in T_{head}, T_{logger} and T_{shank} from 3 to 7 wks-of-age as the exposure temperature decreases during this time. Unexpectedly, the surface temperature of these featherless locations decreased from 8 to 12 wks-of-age when the exposure temperatures remain constant.

By the aforementioned explanation, a lack of change in exposure temperature should be reflected by a lack of change in the thermal regulating responses. In addition, the ability to regulate internal temperature has been shown to increase with an increase in body size (Phillips & Sanborn, 1994). This further confirms that the older, larger turkeys should be able to maintain a constant temperature at the thermal regulating locations when the exposure temperature is not changed. The deviation away from this expectation is therefore unexplainable and requires further investigation.

5.3. Comparison of Body Temperatures at Different Ambient Temperatures

A reduction in exposure temperature of 4°C decreased the surface temperatures of the feathered locations. The average difference between T_{breast}^{con}(week) and T_{breast}^{trt}(week) is 2.12°C and 1.75°C between T_{drum}^{con}(week) and T_{drum}^{trt}(week) as well as T_{wing}^{con}(week) and T_{wing}^{trt}(week), with the temperature of the control group being higher (Figure 4.15-4.17). The difference between the feathered surface temperatures and the exposure temperature had T_{breast}^{trt}(week-difference), T_{drum}^{trt}(week-difference) and T_{wing}^{trt}(week-difference) always significantly larger compared to T_{breast}^{con}(week-difference), T_{drum}^{con}(week-difference) and T_{wing}^{con}(week-difference) (Figure 4.15-4.17). These calculated differences indicate that the

surface temperatures of the control group are closer to T^{con} than the surface temperatures of the treatment group are to T^{trt}.

The higher temperatures observed in the control group are expected as feathers act as insulation, resisting the transfer of heat from one side of the feathers to the other, resulting in the surface temperature of the feathers to be closer to that of the exposure temperature than the internal bird temperature (Yahav *et al.*, 2005). A study by Shinder *et al.* (2007) has demonstrated that a significant decrease in exposure temperature results in a significant decrease in surface body temperature. This suggests that a small difference in surface temperature, as seen between the 2 treatment groups, is acceptable as there was only a small change in the exposure temperature. It is interesting to note the greater effect changing the exposure temperature had on T_{breast}(week) compared to T_{drum}(week) and T_{wing}(week). This may be due to the orientation of the birds while they were being subjected to the different exposure temperatures.

During the 2-h exposure period, it was observed that the turkeys faced towards the inward flow of air. It is unclear if this orientation was due to the measurement technique used or whether the birds were expressing a thermal regulating behaviour. Regardless of the cause, this orientation placed the breast perpendicular to the air flow, while the drum and wing were parallel. Extrapolating the flow of air over the curved edge of an airplane's wing, it can be theorized that air will flow in a similar manner over the body of a turkey when the air is moving in the direction of head to tail as viewed from overhead (refer to Figure 6.1). In this scenario, air contacts the breast first before moving down around the sides of the bird and making contact with the drum and wing. Heat lost through convection occurs as air moves over a solid object, in this instance, the turkey (section 2.2.1). The movement of heat occurs in the direction of high temperature, the surface of the bird, to low temperature, the air. In the current study, air contacting the breast would obtain heat as it moves along its surface. The same situation occurs for the drum and wing; however, air contacting the drum and wing is now warmer as it previously obtained heat from the breast. It is acceptable then to believe that the transfer of heat from the drum and wing would be reduced due to the surface and air temperatures being closer together. As the drum and wing are not in line with each other, air from the breast would

have contacted them individually, potentially affecting the two locations to the same degree. This theory may explain why there is a greater difference between T^{con}_{breast}(week) and T^{trt}_{breast}(week)

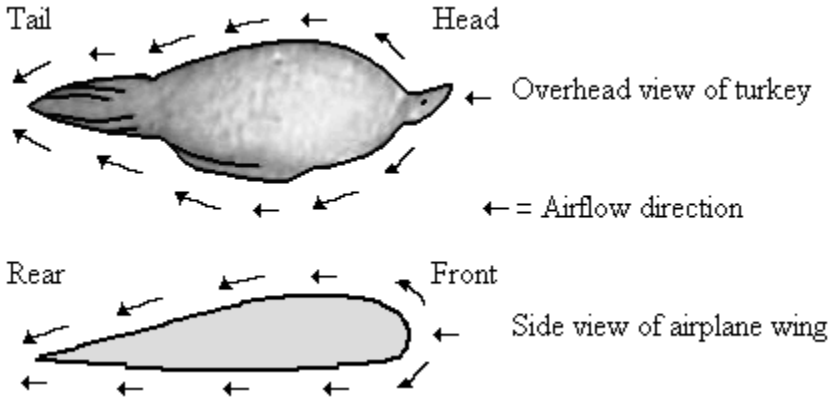

Figure 5.1. The movement of air over the wing of an airplane from the side view and the extrapolated movement of air over the body of a turkey from the top view using the air movement from the airplane wing as a reference.

compared to the difference between T^{con}_{drum}(week) and T^{trt}_{drum}(week) as well as T^{con}_{wing}(week) and T^{trt}_{wing}(week). It also helps to explain why the differences between T^{con}_{drum}(week) and T^{trt}_{drum}(week) as well as T^{con}_{wing}(week) and T^{trt}_{wing}(week) are the same.

No significant difference in temperature was found between T^{con}_{breast}(week) and T^{trt}_{breast}(week) as well as T^{con}_{wing}(week) and T^{trt}_{wing}(week) for wks 6 and 9. The same occurred for the difference between T^{con}_{drum}(week) and T^{trt}_{drum}(week) with the addition of wk 2. Testing of the turkeys was moved from the daylight hours to the dark hours at wk 6 in an attempt to utilize a lower environmental temperature and reduce the strain on the cooling system. Internal temperatures are lower during the dark hours (Lacey & Hamrita, 1999) due to reduced movement and metabolism of the birds. Having been acclimated to the presence and movement of the tester during the light hours the change in schedule resulted in the birds being awake and active during the dark hours. This in turn increased bird movement as well as feed consumption, and therefore metabolism, causing their internal temperature not to decrease. The change in internal temperature and behaviour may have had an effect on the surface temperatures and resulted in no difference being

observed between T^{con}_{breast}(week) and T^{trt}_{breast}(week), T^{con}_{drum}(week) and T^{trt}_{drum}(week) as well as T^{con}_{wing}(week) and T^{trt}_{wing}(week) during the 6th wk of study. No equally significant event occurred at wk 2 or wk 9, making the lack of a difference unexpected and unexplainable.

Lowering the exposure temperature by 4°C was shown not to cold stress the turkeys as there was no difference in T_{core}(week) (Figure 4.18). The similarity in temperature is further illustrated by the difference between T^{con}_{core}(week-difference) and T^{trt}_{core}(week-difference) being 4°C, the same difference as between T^{con} and T^{trt}. Had the birds been cold, T^{trt}_{core}(week) would have been seen to decrease while the difference between surface temperature and exposure temperature increased. A drop in internal temperature has been illustrated in neonatal broiler chicks exposed to a decrease in exposure temperature of 12 (Shinder *et al.*, 2002) or 10°C (Mujahid & Furuse, 2008). Smaller differences of 7°C, in 2 day-old-layer chicks (Weytjens, 1999), and 6°C, in 6 day-old-broiler chicks (Baarendse *et al.*, 2006), have also demonstrated that lowering the exposure temperature decreases the internal temperature of chickens. Older birds are also negatively affected by a decrease in exposure temperature with 8-wk-old turkeys having lower internal temperatures when exposed to 10°C compared to 20°C (Yahav, 2002). In the current study, the decrease of 4°C seems to have had no negative effect on internal temperature, suggesting that T^{trt} was within poultry's thermal neutral zone and the birds were therefore able to easily regulate their internal temperature.

For the remaining three featherless locations, there was no significant difference between the two treatment groups for most wks (Figure 4.19-4.21). As these are areas of thermal regulation and respond to changes in exposure temperature a difference in temperature is expected. A decrease of 4°C should therefore, result in a decrease in surface temperatures of the treatment group compared to the control group. It is possible that a difference of 4°C is not dramatic enough to require a significant alteration in thermal behaviours and responses compared to the standard recommended exposure temperature. If this is true, the thermal regulating locations of the treatment group would express similar temperatures as the thermal regulating locations of the control group, a result seen to occur for most of the study wks. Some differences were observed between

the temperatures of the 2 treatment groups during wks 3, 4 and 9 for T_{logger}(week) and during wks 1, 2 and 5 for T_{head}(week) and T_{shank}(week), with the addition of wk 11 for T_{shank}(week) (Figure 4.19-4.21).

A decrease in temperature below the skin under the wings of 8-wk-old turkeys was observed when they were exposed to 10°C compared to 20°C (Yahav, 2002). A drop of 10°C, therefore, has the ability to alter skin temperatures under the wing. It is questionable though whether a decrease of 4°C would have the same effect as a decrease of 10°C. During the last 4 wks of trials the exposure temperature was the same within each treatment group. Taking this into consideration, it seems unlikely that a decrease of 4°C would affect 1 wk, while having no effect on the remaining 3 wks when exposure temperature remained constant. This appears to indicate that a drop of 4°C is not significant enough to cause a change in T_{logger}(week).

An increase in body weight may be responsible for the different temperatures between the control and treatment group during wk 9, as larger body masses retain more heat (Phillips & Sanborn, 1994) due to increases in the insulation of the body tissues. It is possible that the bird's body mass at wk 9 was enough to require a significant alteration in thermal regulation in order to maintain a constant internal. This same explanation can be applied to the difference observed in the temperatures of control and treatment groups for T_{shank}(week) at wk 11. This seems less logical when you consider that the difference in surface temperatures observed between the treatment groups for T_{logger}(week) and T_{shank}(week) occur at different wks. Should a change in thermal regulation be required would not all of the thermal regulation locations be affected? An alternative is, the other locations were being affected during these wks but the change in surface temperature was too small to be registered by the infrared camera and therefore did not appear significant.

The difference in surface temperature observed for T_{head}(week) during the first 2 wks of growth is more easily accepted as a decrease of approximately 7°C has been demonstrated to reduce the facial temperature of neonatal chicks (Yahav *et al.*, 1998). It is reasonable to believe a similar effect would occur with a difference of 4°C as seen with a difference of 7°C. The lower surface temperatures observed in the treatment group may

be due to an attempt at maintaining the turkey's internal temperature. Heat produced by the birds would be contained by reducing the movement of heat to the thermal-regulating locations. This, in turn, would reduce the temperatures at these locations while the internal temperature would remain the same. This explanation may also provide the reason for the difference in surface temperatures observed for T_{shank}(week) during the same 2 wks of growth.

Considering this, it would then be expected that T_{logger}, also an area of thermal regulation, would be significantly different during wks 1 and 2. The surface temperatures between the 2 treatment groups for T_{logger}(week) were not found to be different at these wks; rather they were different during wks 3 and 4. Poult size over the first few wks of life is small making it reasonable to accept that the internal temperature of the bird would not be different from the temperature under the wing. As the two body locations are physically close together, the continual conductive flow of heat between the two would explain the lack of difference. As the birds become larger, the physical distance between the core of the turkey and the surface under the wing would increase. Body tissue is deposited in this distance impeding the conductive flow of heat from one body location to the other. This causes the surface temperature of the wing to no longer be an extension of the internal temperature. The main form of heat transfer from the core to the underside of wing would change to be transported through blood vessels, the same as the head and legs.

Poultry are considered to be homoeotherms beginning at approximately 10 days of age (Weytjens, 1999; Yardimci *et al.*, 2006) though their ability to regulate their body temperature is still continuing to develop. It is therefore possible that during the 3rd and 4th wks of growth, poultry utilize their head and shank for heat loss more than the underside of their wings. This would leave the location under the wings as a secondary location for thermal regulation compared to the head and shank which are more easily exposed to the environment. The secondary thermal regulation status in combination with the physical proximity of the surface under the wing to the core also helps to explain why T_{logger} is closer to T_{core} compared to T_{head} and T_{shank} during all 12 wks of growth.

The difference in surface temperatures between the control and treatment groups for T_{head}(week) and T_{shank}(week) at wk 5 is more complicated. During this week, it was difficult to obtain the required exposure temperatures as the environmental temperature drawn from outside the barn was around 20.5°C to 23.4°C (Environment Canada, 2012). This resulted in the cooling system being used sporadically and causing unexpected noise and commotion. Though it cannot be proven, it is possible that this had a negative effect on some birds causing them to draw heat away from their extremities in a fight-or-flight response. Without the additional heat from the body, exposure temperature would have had a greater effect on the measured surface temperatures of the turkeys, resulting in the significant difference observed between the two groups.

CHAPTER 6: Conclusion

To conclude, the findings of this study will be discussed in two parts. The first part will present the conclusions for objective 1, determine the thermal (surface temperature) response of turkeys to ambient temperature and objective 2, determine the thermal (surface temperature) response of turkeys weekly over the first 12 weeks of production. The second part will present the conclusions for objective 3, compare the change in thermal (surface temperature) response of turkeys at two different ambient temperature regimes over the first 12 weeks of production.

6.1. Thermal Response of Growing Turkeys

Exposure temperature was found to significantly affect the temperature of feathered areas in turkeys, while having a smaller effect on featherless areas. This is demonstrated through the correlation and regression analyses by the strong relationship between feathered surface temperatures and the temperature to which they were exposed, and a weak relationship (on average) between the temperatures of featherless surfaces and the temperature to which these turkeys were exposed.

In this study, the surface temperatures of the feathers decreased from 1 wk to the next when the exposure temperature decreased. This effect is confirmed by similar results found within the literature. While the feathered surface temperatures were observed to decrease in both studies, it is important to note that they never became equivalent to the exposure temperature. Within this study the temperatures of featherless regions were observed to decrease minimally starting from the 3rd wk and going until the end of the 12-wk growth period. It is arguable that these temperatures remained relatively constant, a pattern which is also found within the literature.

The response in feather temperature is most likely due to the extent of insulation provided by feather cover. Feather cover is determined by the age of a bird and the part of the body being covered. As poultry age, adult feathers grow to form a continuous layer of insulation around the birds. Due to this layer of feathers, air warmed by the body is trapped next to the skin reducing but not completely stopping the loss of heat into the environment. Body locations such as the wings are more densely covered by feathers than

others such as the breast. The more uniform and dense the feather cover is, the greater the insulation capacity; as a consequence more heat is lost from the surface of the breast compared to the wing. Surface temperatures of the feathers are therefore, subject to the changes in feather type and cover quality as well as exposure temperature.

The responses of the featherless locations are dependent on their physical position. Lower cloacal temperatures during the first wk of growth, supports the current literature by further demonstrating that poultry are poikilotherm at a young age. After the first wk the turkeys were able to effectively regulate their internal temperature as shown by the constant cloacal temperatures and therefore would be classified as homoeotherms.

Responses of the remaining featherless locations are more complicated to explain as they are affected by exposure temperature as well as a constant internal temperature. The head, legs and skin under the wings are locations of thermal regulation and as such are subject to changes in internal body temperature. During this study, these locations slowly decreased in temperature while the exposure temperature decreased and the internal temperature stayed constant. Even though this affect is not seen within the literature it is not unexpected as a decrease in exposure temperature may require the retention of heat within the body to maintain internal temperature, resulting in a reduction of heat flow to the thermal regulation locations.

6.2. Thermal Response of Turkeys to Different Exposure Temperatures

Lowering the exposure temperature by 4°C reduced the surface temperatures of the feathers for most wks, an effect also found in the literature. In the current study, differences in T_{breast}(week) between the birds subjected to the standard temperature and 4°C below the standard temperature were larger than the differences in T_{drum}(week) and T_{wing}(week). During the data collection period the turkeys faced towards the inflow of air resulting in the breast being subjected to the exposure temperature first. This potentially may have caused a change in the temperature of the exposure air altering the effect placed on the drum and wing. Alternatively, feather density over the breast is lower than that of the drum and wing, which may have resulted in more heat being lost from the breast compared to the other two feathered locations. Changing the exposure temperature by as

little as 4°C alters the surface temperature of the feathers with greater effects occurring at locations subjected to the exposure temperature first or locations with reduced feather density.

Changing the exposure temperature by 4°C had very little effect, in comparison, on the featherless surface temperatures. No difference in T_{core} was seen between the two temperature exposure groups for any of the 12 wks. This is inconsistent with the literature as changes in exposure temperatures from 6 to 12°C have resulted in reduced internal temperatures. With no change occurring for T_{core}(week) the thermal regulation behaviours expressed by the turkeys was clearly sufficient to cope with a difference in exposure temperature of 4°C.

Some differences in featherless surface temperatures between the two exposure temperature groups were found to occur. T_{logger}(week) was seen to have different temperatures at wks 3, 4 and 9, while T_{head}(week) and T_{shank}(week) were observed to have different temperatures at wks 1, 2 and 5. A difference in featherless surface temperature due to changes in exposure temperature is seen within the literature. The change in exposure temperature for these studies, however, was around 10°C and it is unclear whether the effect seen at this difference can be extrapolated to the smaller difference in exposure temperature of 4°C.

In addition, the wks showing differences in featherless surface temperatures take place when the turkeys are young and the birds are poikilothermic. Due to this, they are more susceptible to exposure temperature; illustrated by the turkeys exposed to 4°C below the standard rearing temperature having the lower surface temperatures. Once the birds mature and are able to regulate their internal temperature there were no differences found between the featherless surface temperatures of the two exposure groups. A decrease in exposure temperatures of 4°C for a short period of time is therefore, still within the thermal neutral comfort zone.

CHAPTER 7: Recommendations

7.1. Suggestions on the Experiment

Exposure temperature is the most important factor in this study. To that end, it is imperative that the system used to alter exposure temperature is accurate. The utilization of a cooling system that relies on human management adds the possibility of human error when it could be otherwise avoided. While the addition of crushed ice seems a simple enough task there are many variables that need to be taken into consideration. The two main factors being: the quantity and frequency at which the ice needed to be added to the circulating water. Due to the range in environmental temperature, and the inconsistency of the ice supply, a few times the circulating water exceeded the maximum temperature level determined to maintain the required exposure temperature. When this occurred the exposure temperature rose and a few minutes elapsed before the appropriate temperature was again reached. Even though these problems can be solved to allow the continuation of human input it seems unnecessarily complicated when a simple air conditioning unit will easily remove the problems and any potential human error.

Another factor that should have been monitored and controlled throughout the experiment is RH. Panting and gular flutter are thermal regulating behaviours that are greatly influenced by the level of RH present. High levels of RH reduce the transfer of heat from within a bird to the external environment impeding the loss of body heat and altering the bird's thermal responses. The objectives of this study are to determine the normal thermal responses of current production turkeys and therefore, alterations in these responses will result in misleading data resulting in incorrect conclusions.

A second environmental affect that can alter thermal responses is wind chill. Convectional heat loss uses air as a medium to transfer heat away from the body into the surrounding environment. The speed at which the warmed air is drawn away from the body helps to determine the rate of heat loss. Faster speeds would therefore, increase the loss of heat from the body. The speed at which air was drawn through the test chamber was selected with the belief that it would have no negative impact of the birds. This

belief, however, was not tested resulting in the apparent temperatures responded to and the experimental exposure temperatures to be potentially different.

7.2. Suggestions on future work

One reason pilot studies are conducted is to assess whether an experimental design is appropriate or not. These studies are performed on a small scale in order to reduce time spent and costs associated with a full-scale study. This study was used to determine the feasibility of measuring surface temperatures using infrared technology. It was also used to ascertain the sensitivity of the infrared measurements and which surface body locations are most suitable for measuring. An exposure temperature difference of 4°C was found to result in a measureable difference at the same surface location on Hybrid Converter Tom turkeys (refer to Section 4), indicating that a FLIR (model S60) infrared camera was sensitive enough to pick up significant differences in surface temperatures. This camera was also user friendly, requiring little set-up and has a simple point and shoot image capturing procedure.

Measureable locations that provided clear results and are therefore recommendable for future studies were the breast, cloaca, external ear opening and the feathered outer surface of the wing. Each location was unobstructed from the exposure temperature and thus provided a clear response. The skin measured under the wing was continually covered by a strip of self-adhesive bandaging tape (Vetwrap) bringing to question the accuracy of the measurement due to the two different exposure temperatures. In contrast, this location is used for thermal regulation by poultry and thus may not require direct exposure to external temperatures to provide a clear and meaningful response. Measuring the skin temperature under the wing showed a similar response to that of the cloaca indicating that this location may in future be used to indirectly indicate internal temperature of birds.

Temperature measurements of the drumstick and the shank were less reliable and not recommendable for future studies. These locations are subject to behaviours that limit or alter their exposure to the surrounding environment. This mainly occurs with the wing being extended to cover the drumstick and the birds laying down and covering their legs.

In this study, the results obtained from these locations did not appear to be negatively affected, however, as they did not provide extra information compared to the body locations previously mentioned; the drumstick and the legs can be regarded as unnecessary for measurement.

A potential reason for the inclusion of the skin under the wing, drumstick and legs within future studies is the increased potential for an investigator to see differences in patterns. Should a temperature or comparison of temperatures be different at a location it is easier to determine if it is meaningful or not when there are more location temperatures with which to compare it. In other words it is easier to identify if the data contains 'noise' or is indicating something of value. Examples of potential noise within this study are: no significant difference occurring at wk 2 for T_{drum} while the other feathered locations were significant and significant differences occurring at wk 9 for T_{logger}, wk 5 for T_{head} and wks 5, 8 and 11 for T_{shank} when the other featherless locations were non-significant.

Expanding upon the idea of how valuable information is, it is important to note that the data provided by the aforementioned study are only relevant when poultry are subjected to changes in temperature once a week for a 2-h period of time. In order to determine whether the current temperature management practices should be changed, at minimum, an experiment must be conducted comparing body temperatures of birds exposed to the different temperatures for their entire growth period. By doing this, possible effects such as thermal conditioning, unlikely to have occurred in this study, are able to have an effect resulting in more accurate and relevant information.

Changes in body temperature, however, are only part of the story. Biological adaptations to the insulation capacity of poultry, such as increases in feather density or tissues beneath the skin may also occur with continual temperature exposure and should be examined. Changes to thermal regulating processes may also take place, potentially altering how birds respond behaviourally to ambient temperatures. It is also possible that production traits such as feed consumption, growth rate and carcass yield will change under continual temperature exposure. All of these factors will influence whether it is beneficial to change rearing temperatures, as they can have negative impacts on

production costs and returns, ultimately lower incomes for producers. Production management practices must result in profitability, and if reductions in barn temperatures impede this, even if they improve bird welfare, it is unlikely that producers will be inclined to make the change.

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Appendix

Appendix A. Feeding schedule for Hybrid Converter tom turkeys provided during the first 12 weeks of growth

Product Code	Age (weeks)	Diet Phase	kg/Bird	Cumulative (kg)
5015	1-3	28% Starter #1	1.10	1.10
5025	4-6	26% Starter #2	3.20	4.30
5035	7-9	24% Grower #1	6.31	10.61
5045	10-11	22% Grower #2	4.90	15.51
5255	12-14	21% Finisher #1	9.30	24.81

Appendix B. Nutrient content of the five different diet phases provided to Hybrid Converter tom turkeys throughout the first 12 weeks of growth

Nutrient (as fed)	Starter #1	Starter #2	Grower #1	Grower #2	Tom Finisher #1
Moisture (%)	10.20	10.00	9.90	9.80	9.80
AME (kcal/kg)	2,780	2,900	3,000	3,152	3,185
Crude Protein (%)	28.30	26.34	24.51	22.00	20.18
Arginine - Total (%)	1.92	1.74	1.61	1.40	1.25
Arginine - Dig. (%)	1.74	1.57	1.46	1.27	1.14
Lysine - Total (%)	1.84	1.70	1.56	1.36	1.20
Lysine - Dig. (%)	1.60	1.46	1.33	1.14	1.01
Methionine - Total (%)	0.75	0.68	0.61	0.61	0.57
Methionine - Dig. (%)	0.70	0.63	0.56	0.56	0.52
Total Sulfur AA - Total (%)	1.25	1.15	1.06	1.03	0.97
Total Sulfur AA - Dig. (%)	1.13	1.02	0.93	0.90	0.86
Threonine - Total (%)	1.20	1.10	1.01	0.91	0.82
Threonine - Dig. (%)	1.03	0.94	0.86	0.76	0.69
Tryptophan - Total (%)	0.33	0.31	0.28	0.24	0.22
Tryptophan - Dig. (%)	0.28	0.26	0.24	0.20	0.19
Isoleucine - Total (%)	1.25	1.15	1.05	0.93	0.86
Isoleucine - Dig. (%)	1.10	1.01	0.92	0.82	0.76
Valine - Total (%)	1.36	1.25	1.14	1.03	0.97
Valine - Dig. (%)	1.19	1.10	0.99	0.90	0.85
Crude Fat (%)	4.00	6.10	7.45	9.45	9.48
Linoleic Acid (%)	1.23	1.32	1.48	1.70	1.72
Crude Fibre (%)	3.71	4.14	4.44	4.45	4.62
Calcium (%)	1.50	1.36	1.26	1.20	1.10
Phosphorus - Available (%)	0.75	0.69	0.63	0.60	0.55
Phosphorus - Total (%)	1.06	1.00	0.94	0.91	0.85
Sodium (%)	0.15	0.15	0.16	0.17	0.16
Chloride (%)	0.26	0.27	0.27	0.28	0.27
Potassium (%)	1.05	0.98	0.92	0.80	0.75

Appendix C. Vitamin content within the five different diets provided to Hybrid Converter tom turkeys throughout the first 12 weeks of growth

Nutrient (as fed)	Starter #1	Starter #2	Grower #1	Grower #2	Tom Finisher #1
Vitamin A (IU/kg)	14,900	13,360	13,360	12,500	11,000
Vitamin D3 (IU/kg)	5,000	5,000	5,000	5,000	4,400
Vitamin E (IU/kg)	100	70	70	50	45
Vitamin K (mg/kg)	3.65	2.60	2.60	2.00	1.76
Thiamine - Total (mg/kg)	7.40	6.42	6.60	5.86	5.68
Riboflavin - Total (mg/kg)	28.97	16.38	17.05	9.07	8.14
Niacin - Total (mg/kg)	162.67	133.89	139.13	119.60	113.59
Pantothenic Acid - Total (mg/kg)	36.76	29.41	29.70	24.53	22.51
Pyridoxine - Total (mg/kg)	10.83	9.05	8.80	7.55	6.77
Biotin - Total (mg/kg)	0.74	0.59	0.60	0.48	0.44
Folic Acid - Total (mg/kg)	4.06	2.67	2.58	1.67	1.38
Vitamin B12 - Total (mg/kg)	41.92	30.98	30.87	23.02	19.95
Choline - Total (mg/kg)	2,405	2,340	2,285	2,098	2,065

Appendix D. Temperatures for each week of the 12 weeks of growth at the feathered locations for Hybrid Converter tom turkeys exposed to either, the standard rearing temperature curve (Con) or 4°C below the standard temperature curve (Trt). P<0.05; n=48

Week	Breast (°C)				Drumstick (°C)				Wing (°C)			
	Con	Trt	SEM	P value	Con	Trt	SEM	P Value	Con	Trt	SEM	P Value
1	30.50	28.11	0.21	<.0001	32.19	30.44	0.39	0.0075	32.11	30.09	0.20	<.0001
2	31.14	29.01	0.26	0.0002	31.05	29.93	0.67	0.2564	31.99	30.80	0.21	0.002
3	30.91	29.01	0.29	0.001	28.69	27.52	0.28	0.0123	30.69	29.60	0.29	0.0234
4	28.79	26.03	0.55	0.0043	27.63	26.12	0.33	0.0077	29.46	28.28	0.32	0.0236
5	25.23	22.75	0.15	<.0001	25.64	23.65	0.28	0.0003	27.12	25.01	0.32	0.001
6	22.40	21.00	0.65	0.1638	22.94	22.05	0.68	0.3814	23.84	23.34	0.63	0.6114
7	21.44	19.28	0.24	0.0001	22.22	20.30	0.26	0.0004	22.83	21.00	0.27	0.0008
8	20.62	18.58	0.30	0.0008	21.89	19.37	0.38	0.0007	21.97	19.65	0.32	0.0004
9	19.98	18.48	0.62	0.1288	21.65	20.06	0.58	0.0799	21.70	20.01	0.60	0.087
10	20.63	18.49	0.30	0.0004	21.77	19.10	0.36	0.0002	22.33	19.85	0.34	0.0003
11	20.57	18.23	0.10	<.0001	21.14	18.91	0.57	0.0151	22.43	20.28	0.26	0.0001
12	20.93	18.79	0.20	<.0001	21.21	19.53	0.39	0.0104	22.46	20.01	0.30	0.0002

Appendix E. Temperatures for each week of the 12 weeks of growth at the featherless locations for Hybrid Converter tom turkeys exposed to either, the standard rearing temperature curve (Con) or 4°C below the standard temperature curve (Trt). P<0.05; n=6 for core, n=480 for logger and n=48 for head and shank

Week	Core (°C)				Logger (°C)				Head (°C)				Shank (°C)			
	Con	Trt	SEM	P Value	Con	Trt	SEM	P Value	Con	Trt	SEM	P Value	Con	Trt	SEM	P Value
1	39.87	39.72	0.26	0.685	39.37	38.19	0.43	0.079	34.45	32.86	0.24	0.001	33.50	31.18	0.45	0.005
2	41.00	40.57	0.14	0.060	40.33	39.63	0.29	0.114	34.65	33.62	0.19	0.003	35.05	32.59	0.65	0.023
3	40.97	40.85	0.13	0.556	40.86	40.13	0.19	0.024	34.28	33.89	0.18	0.163	35.41	34.83	0.27	0.154
4	41.13	40.95	0.09	0.181	40.94	40.19	0.20	0.028	33.90	33.70	0.26	0.593	34.56	34.38	0.42	0.774
5	40.82	40.97	0.14	0.463	.	.	.	.	33.24	32.56	0.21	0.045	34.86	33.85	0.31	0.044
6	40.95	40.93	0.14	0.935	40.73	40.11	0.23	0.084	32.73	32.51	0.30	0.624	34.95	34.38	0.28	0.190
7	40.90	40.95	0.09	0.736	.	.	.	.	32.68	32.16	0.29	0.241	35.00	34.30	0.35	0.192
8	41.03	41.02	0.10	0.910	40.70	40.03	0.22	0.062	32.58	32.06	0.22	0.127	34.85	33.97	0.14	0.001
9	40.82	40.70	0.10	0.447	40.78	39.94	0.25	0.035	32.23	32.09	0.20	0.608	34.53	33.87	0.25	0.093
10	40.80	40.82	0.10	0.901	40.46	39.99	0.20	0.135	32.09	31.69	0.25	0.272	34.30	33.65	0.23	0.075
11	40.96	40.77	0.08	0.158	40.49	39.86	0.21	0.063	32.19	31.66	0.18	0.068	33.95	33.21	0.20	0.026
12	40.77	40.66	0.14	0.580	40.41	39.85	0.23	0.112	32.53	32.05	0.20	0.123	34.39	33.22	0.39	0.057

Appendix F. Difference for each week of the 12 weeks of growth between the temperatures at the feathered locations (breast, drumstick and wing) for Hybrid Converter tom turkeys exposed to either, the standard rearing temperature curve (Con) or 4°C below the standard temperature curve (Trt), and the corresponding exposure temperatures. P<0.05; n=48

Week	Breast (°C)				Drumstick (°C)				Wing (°C)			
	Con	Trt	SEM	P value	Con	Trt	SEM	P Value	Con	Trt	SEM	P Value
1	1.50	3.11	0.21	0.0013	3.19	5.44	0.39	0.0006	3.11	5.09	0.20	<.0001
2	3.14	5.01	0.26	0.0013	3.05	5.93	0.67	0.0188	3.99	6.80	0.21	<.0001
3	3.91	6.01	0.29	0.0014	1.69	4.52	0.28	0.0008	3.69	6.60	0.29	<.0001
4	2.79	4.03	0.55	0.1762	1.63	4.12	0.33	0.0002	3.46	6.28	0.32	<.0001
5	2.23	3.75	0.15	0.0001	2.64	4.65	0.28	0.0028	4.12	6.01	0.32	0.002
6	1.40	4.00	0.65	0.0311	1.94	5.05	0.68	0.0105	2.84	6.34	0.63	0.0013
7	2.44	4.28	0.24	0.0008	3.22	5.30	0.26	0.001	3.83	6.00	0.27	0.0003
8	2.62	4.58	0.30	0.0018	3.89	5.37	0.38	0.0307	3.97	5.65	0.32	0.0056
9	1.98	4.48	0.62	0.0231	3.65	6.06	0.58	0.0211	3.70	6.01	0.60	0.0158
10	2.63	4.49	0.30	0.0018	3.77	5.10	0.36	0.0647	4.33	5.85	0.34	0.0152
11	2.57	4.23	0.10	<.0001	3.14	4.91	0.57	0.1182	4.43	6.28	0.26	0.0004
12	2.93	4.79	0.20	0.0003	3.21	5.53	0.39	0.0037	4.46	6.01	0.30	0.004

Appendix G. Difference for each week of the 12 weeks of growth between the temperatures at the featherless locations (core, head, logger and shank) for Hybrid Converter tom turkeys exposed to either, the standard rearing temperature curve (Con) or 4°C below the standard temperature curve (Trt), and the corresponding exposure temperatures. P<0.05; n=6 for core, n=480 for logger and n=48 for head and shank

Week	Core (°C)				Logger (°C)				Head (°C)				Shank (°C)			
	Con	Trt	SEM	P value	Con	Trt	SEM	P Value	Con	Trt	SEM	P Value	Con	Trt	SEM	P Value
1	10.87	14.72	0.26	<.0001	10.37	13.19	0.43	0.001	5.45	7.86	0.24	<.0001	4.50	6.18	0.45	0.029
2	13.00	16.72	0.14	<.0001	12.33	15.63	0.29	<.0001	6.65	9.62	0.19	<.0001	7.05	8.59	0.65	0.078
3	13.97	17.85	0.13	<.0001	13.86	17.13	0.19	<.0001	7.28	10.89	0.18	<.0001	8.41	11.83	0.27	<.0001
4	15.13	18.95	0.09	<.0001	14.94	18.19	0.20	<.0001	7.90	11.70	0.26	<.0001	8.56	12.38	0.42	0.0001
5	17.82	21.97	0.14	<.0001	.	.	.		10.24	13.56	0.21	<.0001	11.86	14.85	0.31	0.0001
6	19.95	23.93	0.14	<.0001	19.73	23.11	0.23	<.0001	11.73	15.51	0.30	<.0001	13.95	17.38	0.28	<.0001
7	21.90	24.95	0.10	<.0001	.	.	.		13.68	17.16	0.29	<.0001	16.00	19.30	0.35	<.0001
8	23.03	26.02	0.10	<.0001	22.70	26.03	0.22	<.0001	14.58	18.06	0.22	<.0001	16.85	19.97	0.14	<.0001
9	22.82	26.70	0.10	<.0001	22.78	25.94	0.25	<.0001	14.23	18.09	0.20	<.0001	16.53	19.87	0.25	<.0001
10	22.80	26.82	0.10	<.0001	22.46	25.99	0.20	<.0001	14.09	17.69	0.25	<.0001	16.30	19.65	0.23	<.0001
11	22.96	26.77	0.09	<.0001	22.49	25.86	0.21	<.0001	14.19	17.66	0.18	<.0001	15.95	19.21	0.20	<.0001
12	22.77	26.66	0.14	<.0001	22.41	25.85	0.23	<.0001	14.53	18.05	0.20	<.0001	16.39	19.22	0.39	0.001

Appendix H. Temperatures at the feathered locations (breast, drumstick and wing) for Hybrid Converter tom turkeys exposed to either, the standard rearing temperature curve (Con) or 4°C below the standard curve (Trt), weekly over the 12 weeks of growth for each of the two treatment groups. Common letters within individual columns indicate no statistical significance between values. $P<0.05$; n=48

Week	Breast (°C)		Drumstick (°C)		Wing (°C)		Ambient (°C)	
	Con	Trt	Con	Trt	Con	Trt	Con	Trt
1	30.52^{A}	28.20^{A}	32.25^{A}	30.60^{A}	32.12^{A}	30.07^{AB}	29	25
2	31.11^{A}	29.03^{A}	31.19^{A}	29.78^{A}	31.99^{A}	30.81^{A}	28	24
3	30.91^{A}	29.02^{A}	28.64^{B}	27.56^{B}	30.68^{B}	29.60^{B}	27	23
4	28.80^{B}	26.09^{B}	27.65^{B}	26.03^{C}	29.45^{C}	28.28^{C}	26	22
5	25.24^{C}	22.74^{C}	25.65^{C}	23.64^{D}	27.12^{D}	24.99^{D}	23	19
6	22.40^{D}	21.00^{D}	22.98^{D}	22.05^{E}	23.86^{E}	23.34^{E}	21	16
7	21.44^{E}	19.28^{E}	22.22^{DE}	20.30^{F}	22.83^{F}	21.00^{F}	19	15
8	20.62^{F}	18.58^{F}	21.89^{E}	19.37^{G}	21.97^{G}	19.65^{H}	18	14
9	19.98^{F}	18.48^{F}	21.65^{E}	20.06^{FG}	21.70^{G}	20.01^{GH}	18	14
10	20.63^{F}	18.49^{F}	21.85^{E}	19.10^{G}	22.33^{FG}	19.85^{GH}	18	14
11	20.57^{F}	18.23^{F}	21.25^{E}	18.91^{G}	22.43^{FG}	20.28^{G}	18	14
12	20.93^{EF}	18.79^{EF}	21.21^{E}	19.51^{FG}	22.46^{FG}	20.01^{GH}	18	14
SEM	0.20	0.19	0.30	0.31	0.21	0.18		
P value	0.001	0.001	0.001	0.001	0.001	0.001		

Appendix I. Temperatures at the featherless locations (core, head, logger and shank) for Hybrid Converter tom turkeys exposed to either, the standard rearing temperature curve (Con) or 4°C below the standard curve (Trt), weekly over the 12 weeks of growth for each of the two treatment groups. Common letters within individual columns indicate no statistical significance between values. P<0.05; n=6 for core, n=480 for logger and n=48 for head and shank

Week	Core (°C)		Logger (°C)		Head (°C)		Shank (°C)		Ambient (°C)	
	Con	Trt	Con	Trt	Con	Trt	Con	Trt	Con	Trt
1	39.87^{B}	39.72^{B}	39.35^{G}	38.16^{G}	34.46^{A}	32.80^{B}	33.52^{C}	31.14^{D}	29	25
2	41.00^{A}	40.57^{A}	40.30^{F}	39.77^{F}	34.65^{A}	33.65^{A}	35.07^{AB}	32.75^{C}	28	24
3	40.97^{A}	40.85^{A}	40.86^{B}	40.13^{AB}	34.29^{AB}	33.89^{A}	35.42^{A}	34.83^{A}	27	23
4	41.13^{A}	40.95^{A}	40.94^{A}	40.19^{A}	33.91^{B}	33.57^{A}	34.50^{B}	34.38^{AB}	26	22
5	40.82^{A}	40.97^{A}	.	.	33.25^{C}	32.54^{BC}	34.86^{AB}	33.82^{B}	23	19
6	40.94^{A}	40.93^{A}	40.73^{C}	40.11^{B}	32.75^{D}	32.51^{BC}	34.96^{AB}	34.38^{AB}	21	16
7	40.90^{A}	40.95^{A}	.	.	32.68^{D}	32.16^{C}	35.00^{AB}	34.30^{AB}	19	15
8	41.03^{A}	41.02^{A}	40.70^{C}	40.03^{C}	32.58^{DE}	32.06^{CD}	34.85^{AB}	33.97^{B}	18	14
9	40.82^{A}	40.70^{A}	40.70^{C}	39.94^{D}	32.24^{E}	32.09^{CD}	34.53^{B}	33.87^{B}	18	14
10	40.80^{A}	40.82^{A}	40.46^{DE}	39.99^{CD}	32.09^{E}	31.68^{D}	34.30^{B}	33.65^{B}	18	14
11	40.97^{A}	40.77^{A}	40.49^{D}	39.86^{E}	32.19^{E}	31.66^{D}	33.95^{BC}	33.21^{BC}	18	14
12	40.77^{A}	40.68^{A}	40.41^{E}	39.85^{E}	32.53^{DE}	32.04^{CD}	34.39^{CB}	33.22^{BC}	18	14
SEM	0.14	0.15	0.20	0.23	0.13	0.18	0.16	0.23		
P value	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001		

Appendix J. Difference between temperatures at the feathered locations (breast, drumstick and wing) of Hybrid Converter tom turkeys exposed to either, the standard temperatures curve (Con) or 4°C below the standard temperatures curve (Trt), and the corresponding exposure temperature weekly over the 12 weeks of growth for the two treatment groups. Common letters within individual columns indicate no statistical significance between values. $P<0.05$; n=48

Week	Breast (°C)		Drumstick (°C)		Wing (°C)		Ambient (°C)	
	Con	Trt	Con	Trt	Con	Trt	Con	Trt
1	1.52^{D}	3.20^{D}	3.25^{AB}	5.60^{AB}	3.12^{B}	5.07^{C}	29	25
2	3.11^{B}	5.03^{B}	3.19^{AB}	5.78^{AB}	3.99^{AB}	6.81^{A}	28	24
3	3.91^{A}	6.02^{A}	1.64^{B}	4.56^{B}	3.68^{B}	6.60^{AB}	27	23
4	2.80^{B}	4.09^{C}	1.65^{B}	4.03^{B}	3.45^{B}	6.28^{AB}	26	22
5	2.24^{C}	3.74^{CD}	2.65^{AB}	4.64^{B}	4.12^{AB}	5.99^{B}	23	19
6	1.40^{D}	4.00^{C}	1.98^{B}	5.05^{B}	2.86^{B}	6.34^{AB}	21	16
7	2.44^{C}	4.28^{BC}	3.22^{AB}	5.30^{AB}	3.83^{AB}	6.00^{B}	19	15
8	2.62^{BC}	4.58^{BC}	3.89^{A}	5.37^{AB}	3.97^{AB}	5.65^{BC}	18	14
9	1.98^{C}	4.48^{BC}	3.65^{A}	6.06^{A}	3.70^{AB}	6.01^{B}	18	14
10	2.63^{BC}	4.49^{BC}	3.85^{A}	5.10^{B}	4.33^{A}	5.85^{B}	18	14
11	2.57^{BC}	4.23^{C}	3.25^{AB}	4.91^{B}	4.43^{A}	6.28^{AB}	18	14
12	2.93^{B}	4.79^{BC}	3.21^{AB}	5.51^{AB}	4.46^{A}	6.01^{B}	18	14
SEM	0.20	0.19	0.31	0.37	0.21	0.18		
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		

Appendix K. Difference between temperatures at the featherless locations (core, head, logger and shank) of Hybrid Converter tom turkeys exposed to either, the standard temperatures curve (Con) or 4°C below the standard temperatures curve (Trt), and the corresponding exposure temperature weekly over the 12 weeks of growth for the two treatment groups. Common letters within individual columns indicate no statistical significance between values. P<0.05; n=6 for core, n=480 for logger and n=48 for head and shank

Week	Core (°C)		Logger (°C)		Head (°C)		Shank (°C)		Ambient (°C)	
	Con	Trt	Con	Trt	Con	Trt	Con	Trt	Con	Trt
1	10.87^{H}	14.72^{H}	10.35^{H}	13.16^{H}	5.46^{I}	7.80^{I}	4.52^{I}	6.14^{G}	29	25
2	13.00^{G}	16.57^{G}	12.30^{G}	15.77^{G}	6.65^{H}	9.65^{H}	7.07^{H}	8.75^{F}	28	24
3	13.97^{F}	17.85^{F}	13.86^{F}	17.13^{F}	7.29^{H}	10.89^{G}	8.42^{G}	11.83^{E}	27	23
4	15.13^{E}	18.95^{E}	14.94^{E}	18.19^{E}	7.91^{G}	11.57^{F}	8.50^{G}	12.38^{E}	26	22
5	17.82^{D}	21.97^{D}	.	.	10.25^{F}	13.54^{E}	11.86^{F}	14.82^{D}	23	19
6	19.94^{C}	23.93^{C}	19.73^{D}	23.11^{D}	11.75^{E}	15.51^{D}	13.96^{E}	17.38^{C}	21	16
7	21.90^{B}	25.95^{B}	.	.	13.68^{D}	17.16^{C}	16.00^{CD}	19.30^{B}	19	15
8	23.03^{A}	27.02^{A}	22.70^{A}	26.03^{A}	14.58^{A}	18.06^{A}	16.85^{A}	19.97^{A}	18	14
9	22.82^{A}	26.70^{A}	22.70^{A}	25.94^{B}	14.24^{BC}	18.09^{A}	16.53^{AB}	19.87^{A}	18	14
10	22.80^{A}	26.82^{A}	22.46^{B}	25.99^{A}	14.09^{C}	17.68^{B}	16.30^{BCD}	19.65^{AB}	18	14
11	22.97^{A}	26.77^{A}	22.49^{B}	25.86^{C}	14.19^{C}	17.66^{B}	15.95^{D}	19.21^{B}	18	14
12	22.77^{A}	26.68^{A}	22.41^{C}	25.85^{C}	14.53^{AB}	18.04^{A}	16.39^{BC}	19.22^{B}	18	14
SEM	0.14	0.15	0.20	0.23	0.13	0.18	0.16	0.23		
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		

Appendix L. Weekly average quantity of feed and water consumed during a 2-h ambient temperature exposure period by Hybrid Converter tom turkeys exposed to one of two ambient temperature curves, the standard ambient temperature curve (Con) or 4°C below the standard (Trt) for the first 12 weeks of growth

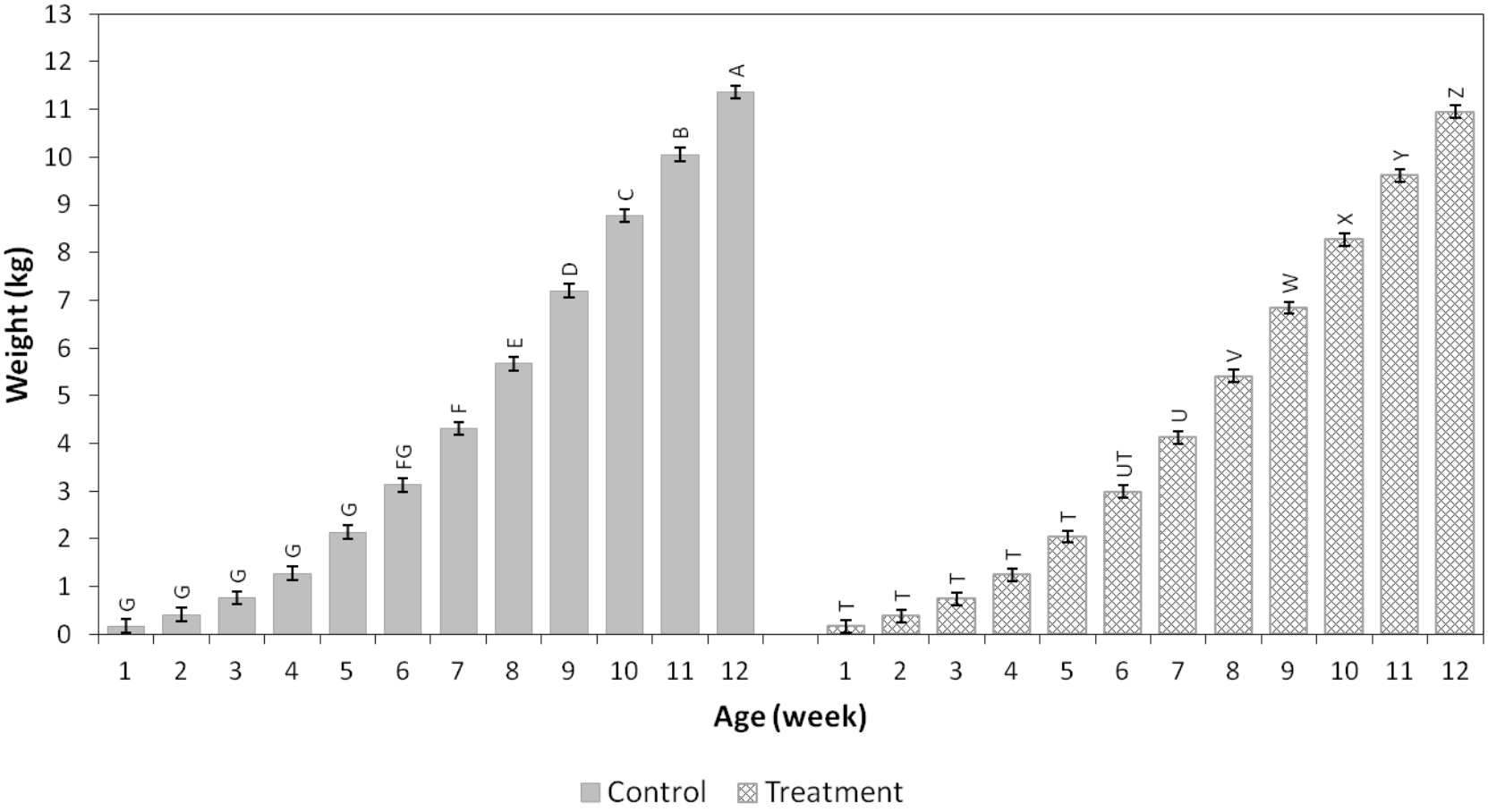
Week	Feed (kg)		Water (kg)		Ambient (°C)	
	Con	Trt	Con	Trt	Con	Trt
1	0.007	0.003	0.012	0.013	29	25
2	0.005	0.005	0.015	0.030	28	24
3	0.010	0.007	0.017	0.013	27	23
4	0.028	0.010	0.048	0.025	26	22
5	0.017	0.010	0.017	0.012	23	19
6	0.017	0.015	0.017	0.018	21	16
7	0.022	0.018	0.020	0.018	19	15
8	0.018	0.025	0.007	0.010	18	14
9	0.122	0.047	0.015	0.007	18	14
10	0.020	0.005	0.040	0.062	18	14
11	0.018	0.017	0.028	0.055	18	14
12	0.022	0.023	0.057	0.030	18	14
SEM	0.024	0.010	0.014	0.018		
P value	0.0691	0.1440	0.2535	0.3300		

$P<0.05$; n=6

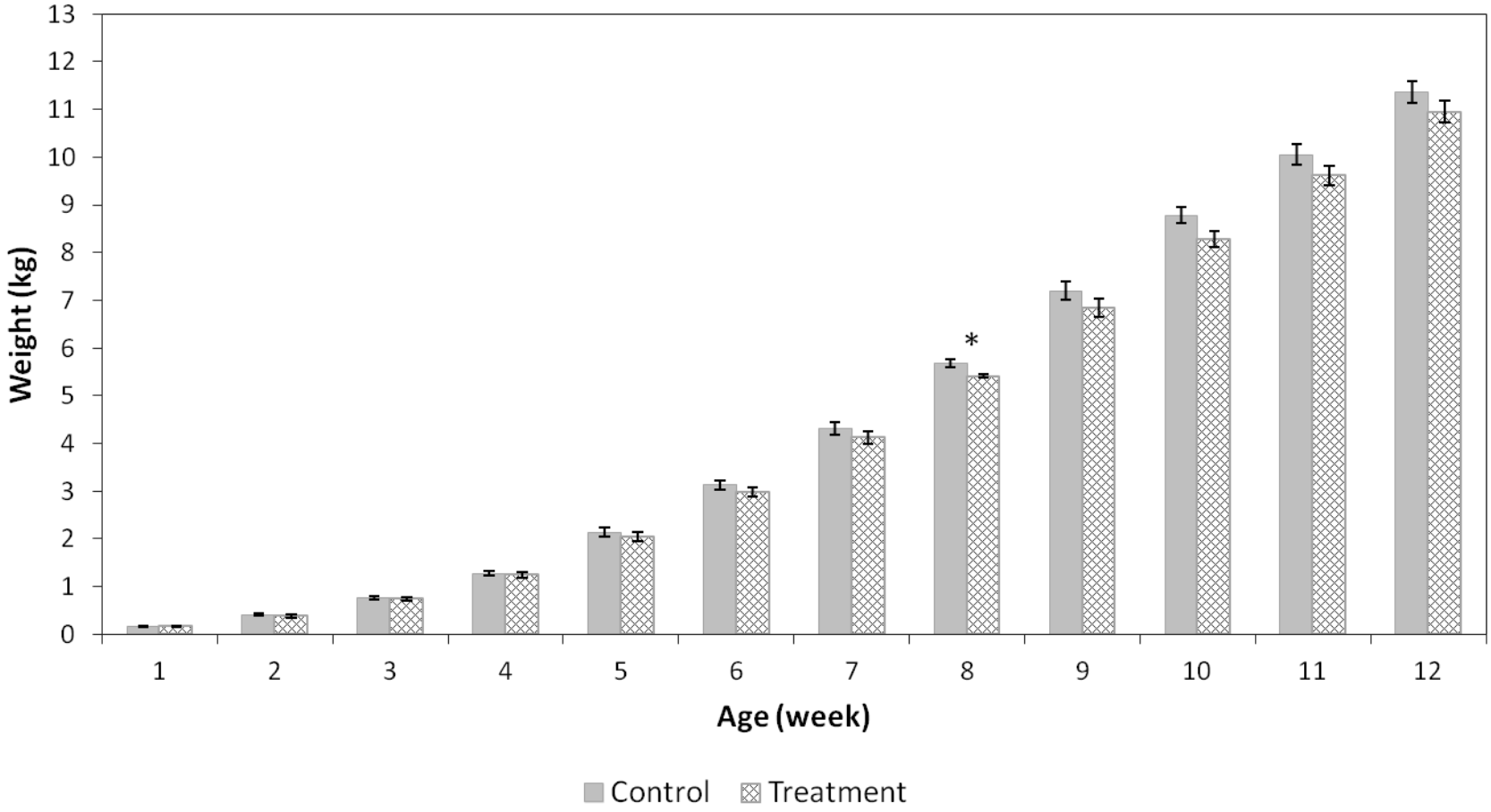
Appendix M. Average quantity of feed and water consumed during a 2-h ambient temperature exposure period each week by Hybrid Converter tom turkeys exposed to one of two ambient temperature curves, the standard ambient temperature curve (Con) or 4°C below the standard (Trt) for the first 12 weeks of growth

Week	Feed (kg)				Water (kg)				Ambient (°C)	
	Con	Trt	SEM	P value	Con	Trt	SEM	P value	Con	Trt
1	0.002	0.003	0.002	0.6618	0.012	0.013	0.003	0.8636	29	25
2	0.005	0.005	0.002	1.0000	0.015	0.030	0.013	0.3720	28	24
3	0.010	0.007	0.002	0.2897	0.017	0.013	0.005	0.5527	27	23
4	0.028	0.010	0.011	0.3269	0.048	0.026	0.020	0.4082	26	22
5	0.017	0.010	0.003	0.2897	0.017	0.012	0.007	0.4386	23	19
6	0.017	0.015	0.005	0.5960	0.017	0.018	0.008	0.8743	21	16
7	0.022	0.018	0.006	0.7554	0.020	0.018	0.013	0.7300	19	15
8	0.018	0.025	0.010	0.6087	0.007	0.010	0.004	0.2452	18	14
9	0.122	0.047	0.053	0.2553	0.015	0.007	0.006	0.3291	18	14
10	0.020	0.005	0.005	0.1138	0.040	0.062	0.032	0.4854	18	14
11	0.018	0.017	0.011	0.9885	0.028	0.055	0.021	0.3317	18	14
12	0.022	0.023	0.015	0.8343	0.057	0.030	0.021	0.3194	18	14

$P<0.05$; $n=6$



Appendix N. Weekly live body weights of Hybrid Converter tom turkeys exposed to one of two rearing temperature regimes, the standard exposure curve (control) or 4°C below the standard (treatment) during the first 12 weeks of growth. Common letters indicate no significant difference between weeks. $P<0.0001$, $n=6$



Appendix O. Live body weights for each week of Hybrid Converter tom turkeys exposed to one of two rearing temperature curves, the standard exposure curve (control) or 4°C below the standard (treatment) during the first 12 weeks of growth. A significant difference between weights of the control and treatment groups is indicated by an "*". $P<0.0001$, $n=6$