COMPARING SUBCUTANEOUS SITES TO DEEP BODY TEMPERATURE IN BROILER CHICKENS

by

MATTHEW RYAN HICKS

(Under the Direction of Brian Fairchild)

ABSTRACT

Research was conducted to compare subcutaneous sites to deep body temperature (DBT) in broilers chickens. The study was conducted in field and lab trials using market age broilers (40-55 days) under summer conditions. Temperature data loggers were surgically implanted in the broilers to record temperatures in the neck, back, and deep body. A logger was also introduced into the upper gastrointestinal tract (UGI) during the lab trials. At the conclusion of the trials, the birds were euthanized and the temperature loggers were retrieved. When the subcutaneous temperatures were compared to DBT, the correlation coefficients were statistically significant ($P \leq 0.05$). In the lab trials, the UGI site was found to be a better representation of DBT than implantation in the lower abdominal cavity. This study shows that subcutaneous sites in broilers can be used as an indicator of DBT.

INDEX WORDS: Deep Body Temperature, Broiler, Heat Stress, Subcutaneous Temperature

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CHAPTER 1

LITERATURE REVIEW

Thermoregulation

A homeothermic organism is one that regulates its body temperature. The system works to keep a constant deep body temperature independent of its environment. Whether the environment be tropical or artic conditions, the homeotherm uses physiological and behavioral responses to maintain the body temperature. Adult birds are homeothermic organisms and broilers, in particular, normally have a deep body temperature (DBT) of 41-42°C (Prinzinger et al. 1991; Kettlewell et al., 1997; Cooper and Washburn, 1998). Chicks are poikilothermic when they hatch and develop the ability to regulate their body temperature by 10 days of age (Nichelmann and Tzschentke, 2002; Shinder et al., 2007). Birds have mechanisms for controlling their body temperature as the environment around them changes which include panting, changes in feed and water consumption, ruffling of feathers, and activity level. These mechanisms change according to breed, age of the bird, and degree of environmental change (Reece and Lott, 1982; El-Gendy and Washburn, 1995; Lacey et al. 2000a; Deeb and Cahaner, 2002; Shinder et al. 2007; Nääs et al., 2010).

Cabanac (1975) says the term "temperature regulation" means that there are mechanisms defending the temperature of one or several definable regions of the body with the result that these temperatures remain within a restricted range. A bird regulates its body temperature by managing the heat gained and removed through evaporation, conduction, convection, and radiation (Dawson and Whittow, 2000).

When air is cooled through the evaporation of water into the air, the bird is losing heat through evaporation (Czarick and Fairchild, 2008). Since a bird does not perspire, evaporation usually occurs through the respiratory system. The bird can also remove heat through the evaporation occurring during surface wetting where water is dispersed from the ceiling using a sprinkler system. Conduction is the transfer of heat through a solid medium by direct contact. Broilers lose a minimal amount of heat from conduction because of the insulation properties of their bedding material, so this form of heat transfer is negligible. A bird loses heat by convection when heat is transferred through a moving liquid or gas. Convection occurs in the poultry industry in the form of air velocity. Radiation is when heat is transferred from a warm object to a cold object through electromagnetic waves which may be negligible due to small temperature gradient between the bird's surface temperature and the inside surfaces of the poultry house (Czarick and Fairchild, 2008).

The heat gained and removed can be divided into two major categories which are sensible heat and latent heat (Wathes and Clark. 1981; Simmons et al., 1997; Genç and Portier, 2005). Simmons et al. (1997) describes sensible heat as the heat added or gained from the air passing over any warm object and latent heat as the heat associated with the phase change of water. Latent heat is also called the heat of evaporation. Sensible and latent heat can be added together to calculate the total heat production of a bird which can be quantified using a calorimeter. The calorimeter is a box with two openings allowing air to enter and exit. An animal is placed within the box where the temperature and enthalpy are measured on the air entering and exiting the box. By taking these measurements, the total heat production of the animal can be calculated and used to determine the effect of environmental change and different feed diets on the bird.

Heat production is important when trying to keep birds in a thermal neutral state. A heat balance equation can be used to determine the thermoregulatory condition of a bird. The bird body temperature will remain unchanged and in a thermal neutral state if the heat gains and heat losses equal zero which is referred to as thermal equilibrium (Furlan et al., 2000). If the heat gains are higher than the heat losses, the bird's body temperature will increase above the thermal neutral state which can lead to hyperthermia. The bird's body temperature will decrease below the thermal neutral state if the heat losses are greater than the heat gained which could result in hypothermia.

Environmental factors that affect body temperature

Bird body temperatures stay relatively constant, but certain environmental factors lead to body temperature fluctuations. Some of the main environmental factors that affect body temperature are feeding, lighting, bird density, air velocity, ambient temperature, and relative humidity (Rh). Minor changes in body temperature can be maintained through mechanisms to regulate their DBT such as regulating feed intake, panting, and spreading their wings (Lacey et al., 2000a).

Feed intake helps a bird grow and maintain their body, but feed digestion results in the production of metabolic heat which can have negative impacts during ambient temperatures above 32°C (Christensen et al., 2012; Lara and Rostagno, 2013). Integrators and researchers have used feed restriction to decrease heat production and body temperature (Koh and MacLeod, 1999). Christensen et al. (2012) showed that birds fasted for 6 hours or more have a significantly lower body temperature of approximately 1°C when compared to birds having free access to feed. The reduction in body temperature may be caused by decreased productive metabolism.

Nutritional deprivation in chickens depresses protein synthesis which would lower the heat production associated with the process and contribute to lowering the body temperature.

Intermittent or discontinuous lighting is a common practice in the poultry industry for improved feed conversion, lower electricity costs, and lower heat and moisture production (Blair et al., 1993; Xin et al., 1994; Aerts et al., 2000). Xin et al. (1996) found that there is a 25-26% reduction in total heat production in broilers when switching from light to darkness. The shorter dark periods in effect lowers activity levels and feed intake making it easier for a broiler to maintain thermal equilibrium. Broiler environmental control systems need to take into account the dynamic nature of these changes while trying to maximize performance.

The goal of poultry producers is to maximize kg of broilers produced per square meter (Abudabos et al., 2013). Stocking density plays an important role in the performance of a broiler and commercial densities range from 0.046 to 0.12 m^2/bird (Deaton et al., 1968; Freddes et al., 2002; Uzum and Toplu, 2013). The higher stocking densities result in lower performance due to the reduction in air flow at bird level which reduces body heat dissipation to the air, poor air quality, and reduced access to feed and water (Freddes et al., 2002). The lower stocking densities allow air to flow between the birds and increases the surface area for heat removal. The bird densities also have an effect on the body temperature of the broiler. Abudabos et al. (2013) found that the surface body temperature significantly increases by approximately 0.5°C when in a medium to high (0.037 to 0.030 m^2/bird) stocking density.

Tunnel ventilation achieves total air exchange in the house in approximately a minute or less, with air velocities in the range of 2.03 to 2.53 m/s, as a result the total heat production of the bird shows little change at an ambient temperature of 20-25°C (Simmons et al.,1997). At higher air velocities, the broiler relies less on evaporative cooling for heat dissipation and more on sensible heat removal (Simmons et al., 1997; Lott et al., 1998). Since sensible heat removal occurs when air moves over a warm object, the higher air velocities provide relief to the broiler due to the “wind chill” factor (Drury, 1966; Drury and Siegel, 1966). Fulan et al. (2000) found the higher air velocities decrease the body temperature by almost 1°C and also reduces the time a broiler takes to reach thermal equilibrium. When ventilating properly, a broiler can reach thermal equilibrium within the first 10 minutes of exposure to the air velocity.

An elevated ambient temperature affects the bird’s heat production by decreasing the difference between the bird’s body temperature and the surrounding environment (Dawson and Whittow, 2000; Genç and Portier, 2005). As ambient temperature increases, the sensible heat removal decreases and latent heat removal increases (Simmons et al., 1997; Genç and Portier, 2005). When temperatures increase to 35°C or above and air velocity is 0 m/s, sensible heat loss decreases to zero (Genç and Portier, 2005). As a bird ages, feathers grow and eventually cover a majority of the body. Deeb and Cahaner (1999, 2002) found that the naked neck genotype are able to endure elevated ambient temperatures because of their lack of feathers or insulation factor which allows them to remove heat more effectively. Younger birds share a similar ability to remove heat because of their lack of feathers. Latent heat removal is the only way the bird is able to handle the high temperatures, in the absence of airspeed, which results in increased stress to the broilers and increased body temperatures (Lacey et al., 2000a). Breed and age play a role in the effect of elevated ambient temperatures on birds. (Brown-Brandl et al., 1997).

Evaporative cooling through latent heat removal is an important mechanism for controlling elevated body temperatures in poultry. Yahav et al. (1995) states the driving force for evaporative cooling is the gradient between the body surface and water vapor density found in the air which is referred to as Rh. As Rh increases, the gradient becomes smaller and reduces the effectiveness of evaporative cooling. Since a bird relies heavily on latent heat removal to maintain thermal equilibrium, it is crucial that Rh is maintained within the poultry house. The effects high Rh combined with elevated ambient temperatures are devastating to the bird. Genç and Portier (2005) found that at environmental conditions of 35°C, 50% Rh, and no air velocity, the broiler relies solely on latent heat removal to establish thermal equilibrium. At environmental conditions of 35°C and 70% Rh or above, the bird's heat removal was zero. The conditions were too much for the bird to handle. If these conditions exist for an extended period of time, body temperature would rise and mortality is expected to increase.

Environmental control and house management

Poultry house management and environmental control are crucial when raising poultry, especially during the summer months. The birds need to be kept cool and in a thermal neutral state to maximize weight gain and feed efficiency. The method commonly used to remove heat in hot climates is tunnel ventilation which means air velocity is used to remove heat along the length of the poultry house. The poultry house is designed as a narrow, long pipe where fans are installed in one end wall of the house and on the other end wall, there are tunnel inlets. The number of fans and amount of tunnel inlets varies depending on the house dimensions and size of the bird being grown and the desired air velocity.

When the fans are turned on, they create a negative pressure that pulls air into the house through the tunnel inlets. The average air speed in a poultry house is between 2-3 m/s (Dozier et al., 2005). To add extra cooling to the poultry house, evaporative cooling can be added to the tunnel inlet end of the house. The evaporative cooling system consists of a water pumping system and evaporative cooling pads. When air enters the house, it passes through the evaporative cooling pads and then through the tunnel inlets. Water can be introduced into the top of the pads where the water evaporation cools the air as it enters the house. The pads are made of fluted cardboard to allow for maximum air movement while minimizing the work needed to pull the air through the pad.

The evaporative cooling system and fans can be programmed to run at different temperatures using the environmental controller in the poultry house. By programming the controller, it can maximize heat removal while keeping the birds cool. The combination of tunnel ventilation and evaporative cooling systems is an effective tool for cooling birds, but if managed improperly, the results could include wet litter, birds with elevated body temperature, and the worst case would be increased mortality.

Heat stress

Deep body temperature will remain consistent when the environmental conditions are within the thermal neutral zone (Tao and Xin, 2003). Once the amount of heat gained exceeds the amount of heat removed, the broiler begins to experience the early stages of heat stress (Lara and Rostagno, 2013). Heat stress conditions usually occur during the summer months when ambient temperatures exceed 32°C and Rh exceeds 70% (Cooper and Washburn 1998; Genç and Portier, 2005). High lethal body temperature for birds is around 47°C (Moreng and Shaffner, 1951). The heat stress conditions are detrimental to the poultry industry due to reduced weight gain, decreased feed efficiency, increased mortality, and decreased meat quality (Yahav et al., 1995; Cooper and Washburn, 1998; Lara and Rostagno, 2013; Uzum and Toplu, 2013). It is estimated these losses due to heat stress cost the broiler industry approximately $60 million dollars annually (St-Pierre et al., 2003).

Determining heat stress

Heat stress can be determined by indirect observations or by directly monitoring the bird's reaction to the environment. Indirect observation can be viewed by the grower and researcher through tracking feeding and water consumption, and also watching the bird to determine any changes in behavior which include panting, spreading of wings, and heat prostration. Broilers will decrease their feed consumption and increase water consumption to combat the effects of heat stress (Cooper and Washburn, 1998; Koh and MacLeod, 1999; Lara and Rostagno, 2013). The downside to tracking feed and water consumption in a commercial setting is that mortality may increase before a change is noticed.

Activity is a behavioral response that can be viewed firsthand. When ambient temperatures increase, broilers will reduce their activity to produce less heat (Koh and MacLeod, 1999). Broilers will rely heavily on latent heat removal during increased temperatures. Latent heat removal works through respiration and increased heat causes this response to increase in the form of panting. Toyomizu et al. (2005) found that chickens exposed to an ambient temperature of 38°C had an increased respiratory rate from 61 breaths/min to 261 breaths/min after 60 minutes of heat exposure. Blood samples showed a significant increase in pH and a significant decrease in pCO_2 and bicarbonate. In a commercial setting, scientific equipment is not readily available and the grower uses strict observation to notice signs of heat stress. Growers usually monitor poultry heat stress through panting which can be subjective.

Environmental conditions can be monitored to determine the onset of heat stress by monitoring house temperature and Rh. Commercial poultry houses are equipped with an environmental controller that can be programmed to keep the house at optimal growing conditions. The environmental conditions are monitored through temperature sensors along the length of the house and an Rh sensor located about midway down the house. The downside is that sometimes the temperature and Rh sensors are not placed in the optimal positions, therefore giving an inaccurate reading. The other downside is most commercial houses are only controlled by temperature sensors. Rh should be monitored because this could affect the bird's latent heat removal and cause higher mortality if conditions become too harsh for the birds to cope with. Rh is not usually monitored because the sensors are not as reliable and are more prone to failure.

Direct observation can also be used as a determination of heat stress and includes monitoring bird body temperature. Body temperature can be monitored using DBT and surface temperature (Richards, 1970; May et al., 1987; El-Gendy and Washburn, 1995; Cooper and Washburn, 1998; Lacey et al., 2000a,b,c; Toyomizu et al., 2005). Monitoring bird body temperature ensures the data accurately describes how the bird is interacting with the environment. Direct body temperature monitoring allows the researcher or grower to change the conditions to minimize the effects of heat stress on production and performance.

Monitoring body temperature

Body temperature has been measured several different ways in previous research which include rectal thermometers, telemetry, thermocouples, thermistors, and infrared thermography. The type of tool used relied heavily on the technological capabilities of the time and the focus of the research.

The most common method to monitor bird DBT was using a thermometer because of lower costs and ease of use. The thermometer is usually inserted between 25-60 mm into the cloaca to monitor DBT (May et al., 1987; Cooper and Washburn, 1998; Furlan et al., 2000; Cabanac and Aizawa, 2003; Christenson et al., 2013). Yahav et al. (1995) also used a thermometer to measure subcutaneous temperature by inserting the thermometer through a small skin puncture underneath the wing. Regardless of the site, in order to obtain body temperature via thermometer, the researcher had to handle the bird. The handling can cause the bird DBT and stress levels to increase when handled continuously for more than three minutes (Cabanac and Aizawa, 2003). While being handled, the bird also experienced an initial peripheral vasoconstriction, as shown by a drop in skin temperature. The bird's body reacted differently to handling and could skew measurements depending on which site was being monitored.

Telemetry systems have been used as a way to monitor DBT without handling the bird and to continuously monitor the bird without disrupting normal activity (Hamrita et al., 1998). These systems implement a temperature logger that was surgically implanted and the data were retrieved by a radio frequency receiver connected to a computer (Kadono and Besch, 1978; Kettlewell et al., 1997; Hamrita et al., 1998; Lacey et al., 2000a,b,c; Hamrita and Hoffacker, 2008). The researchers used several techniques to implant the temperature logger which include deep body implantation, introducing the logger into the upper gastrointestinal tract, and applying the logger directly to the skin.

Kettlewell et al. (1997) used a radio telemetry system for remote monitoring and recording of ECG, heart rate, and deep body temperature. The temperature logger and heart rate monitor were wired together, making the system large, weighing 105 g. The recording devices were secured to the abdominal sidewall via silk sutures in an attempt to prevent movement of the system while in the abdominal cavity. The system was tested on birds in a laboratory setting under different environmental conditions. The results proved that the system worked and could be adapted for future projects.

Most of the temperature loggers used in previous studies were implanted within the abdominal cavity and allowed to freely move. Hamrita et al. (1998) used a temperature logger weighing 3 g and having dimensions of 6 mm x 15 mm. This research was conducted in a laboratory setting on individually caged birds. The goals of the study were to determine the effect of ambient temperature changes. The temperature logger was able to accurately record body temperatures continuously. The average bird DBT was 40°C at an ambient temperature of 27°C. The downside to this method is the life of the temperature logger battery was only 100 days which could potentially put a time constraint on research and also could increase the cost of a study.

Temperature loggers have also been introduced into the upper gastrointestinal tract by inserting the logger through the mouth into the esophagus. Brown-Brandl et al. (2003) used temperature loggers with dimensions of 12 mm x 25 mm and a battery life of only 15 days. The loggers were dipped in vegetable oil and placed in the bird's mouth, so the logger could be swallowed by the bird. The logger would reach the gizzard after 4-6 house and remain there for the duration of the study. Occasionally the loggers stayed in the crop, but a gentle stroke allowed the logger to move to its appropriate location in the gizzard. The downside to this method is the degradation of the temperature logger over time. This research was conducted on layer hens whose diets consists of a high calcium content. The combination of the calcium and the grinding action of the gizzard causes the removal of the epoxy coating which shortens the life span of the temperature logger.

Richards (1970, 1971) used thermocouples and thermistors to measure body temperature in chickens. Thermistors were inserted into the cloaca and attached to the bird via rubber bands over the back and wings. Thermocouples monitored the surface temperature at multiple locations which were separated into feathered and naked skin. Feathered skin included the back, thigh, and under the wing while the naked skin included the foot, comb, and shank. The thermocouples were attached to the skin locations with surgical tape to prevent movement. The birds were introduced to ambient temperatures of 20°C, 30°C, and 40°C and the body temperatures were recorded. The feathered skin varied in temperature by 2-5°C over the three ambient temperatures while the naked skin varied by as much as 20°C (comb). This method may have some variation due to how the loggers were attached to the bird.

Infrared thermography has improved over the years to where it is a viable method of measuring bird skin temperature to correlate to DBT (Cangar et al., 2008; Nääs et al., 2010; Giloh et al., 2012; Nascimento et al., 2014). The thermal images show the heat distribution over the surface of the bird and surface temperatures are greatly affected by the amount of feather cover. Cangar et al. (2008) found that areas with little to no feathering showed the greatest temperature gradients. This research focused on using thermal images to evaluate the surface temperature gradient of birds. To obtain the images, the birds were placed on a wooden plate and a top, side, and bottom view were taken of the bird using an infrared camera. The images were used to find temperature ranges of certain body parts which included the cheek, skull, neck, crop, breast, wing, thigh, drumstick, shank, pelvis, and cloaca. Giloh et al. (2012) found that the facial surface temperature was found to show the highest positive correlation to DBT.

CHAPTER 2

STATEMENT OF PURPOSE

Temperature logger technology has made drastic changes to increase accuracy, data capacity, and durability while decreasing size, weight, and cost. These changes help expand the methods of bird body temperature monitoring. Previous research has used thermometers, telemetry, thermistors, thermocouples, and infrared thermography to measure the surface temperature and DBT of broilers.

These methods of monitoring bird body temperature are effective, but have some limitations and negative impacts. New measurement techniques and locations should be evaluated to see if there are any sites in the body that can provide an accurate and less invasive representation of DBT during heat stress conditions. With today’s technology, subcutaneous methods might be used to determine if a broiler is heat stressed instead of using deep body implantation. The objective of this study was to compare subcutaneous temperatures from various sites with deep body temperature during summer conditions in field and lab settings.

CHAPTER 3

MATERIALS AND METHODS

Temperature loggers

Body temperatures were recorded using DST-NANO-T temperature loggers (Star-Oddi, Reykjavík, Iceland). The loggers measure 6 mm x 17 mm, weigh 1 g, have a 10 month battery life, and are capable of recording 43,477 measurements with an accuracy of +/- 0.2°C and a resolution of 0.032°C. Star-Oddi provided a certificate of calibration with each logger, but the loggers were placed in a 41.5°C water bath for two hours to validate the calibration. The standard deviation was 0.06°C between the 17 loggers for the duration of the water bath which is within the accuracy of the logger (Figure 1).

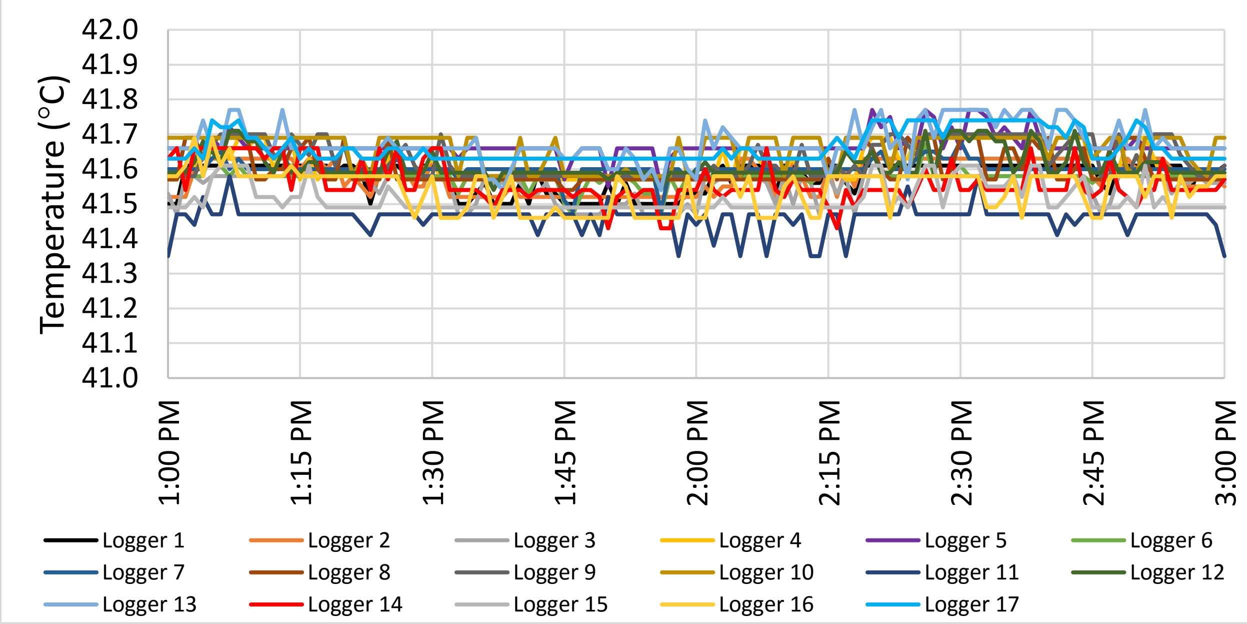

Figure 1: The logger temperatures had a standard deviation of 0.06°C for the duration of the 41.5°C water bath.

Surgery procedure

The sites chosen for comparing body temperatures in this study included the neck, back, and deep body. The site for the neck implant was located on the left side of the neck, approximately 7 cm anterior to the base of the neck. The second implantation site was located in the medial aspect of the back, approximately halfway between the left and right scapula. The site for the deep body implant was located on the right side of the lower abdomen, between the keel and pubic bones, passing through the skin and the thin abdominal musculature into the shallow abdominal cavity.

Male broilers of similar size were selected from each farm which, depending on farm bird age, ranged from 2 to 3 kg. The birds were weighed using a BW-2050 poultry weighing system (Weltech International Ltd., Saint Ives, United Kingdom). While holding the bird in place on the surgical table, the incision site was cleaned of feathers and debris. Betadine followed by ethanol was used to clean and sanitize the site. The temperature loggers were sterilized by being submerged in 70% Isopropyl Alcohol. A subcutaneous injection of local anesthetic (Lidocaine 2%, 0.3 ml) was administered to the incision area. An incision was made in the skin and the temperature logger was inserted. The incision was sutured with an absorbable suture material (Ethilon black 18" PC-3 conventional cutting) for the neck, and back sites. For the deep body site, the abdominal musculature was sutured along with the skin for the side incision. Neosporin® triple antibiotic ointment (Johnson and Johnson, NJ, United States) and Blu-Kote® germicidal antiseptic spray (Dr. Naylor®, NY, United States) were applied to help prevent infection.

The birds were placed in a recovery pen for approximately one hour. Before returning the birds to the study environment, neon paint was applied to the back and wings for identification purposes which did not draw attention from the other birds. All experimental procedures for the broiler temperature measurements were approved by the University of Georgia Animal Care and use Committee.

Field trials

The field trials were conducted to observe broilers in a commercial setting and to test the body temperature monitoring method. The field trials were conducted in modern 15 m x 152 m totally enclosed tunnel-ventilated broiler houses from three different integrators in Northeast Georgia. The house environment was managed according to the integrator guidelines. The birds started the trials ranging in age from 40-55 days. The trial length ranged from 6-13 days and ended either the day prior to market age or the day of market age depending on when the flock was removed from the house. Farm visits were conducted every two days to check on the status of the test broilers and equipment. At the end of each trial, the birds containing the temperature loggers were euthanized using cervical dislocation and the loggers were removed from the bird. The loggers were not sutured in placed and could change position within the site, so the final location of the logger was noted as it was removed.

Field trials: Equipment setup

An anemometer pole was used to monitor the air velocity of the house. There were three anemometers (Chore-time, IN, United States) per pole and the anemometers were connected to a HOBO H22-001 data energy logger (Onset Computer Corporation, MA, United States). The top anemometer was 0.66 m from the ceiling. The bottom anemometer was 0.66 m from the floor. The middle anemometer was placed equidistance from the top and bottom. The house temperature and Rh were recorded using two U23 Pro v2 loggers (Onset Computer Corporation, MA, United States). The house temperature and Rh loggers were secured to a feedline, 1.3 m from the floor and 4.5 m from the wall. The anemometer pole and house temperature/Rh loggers were placed 50 m from the fan end of the house and launched to record data every one minute.

Field trial: Farm 1

A limited number of temperature loggers were available for implantation during the initial farm trial due to manufacturing issues. It was decided that rather than placing temperature loggers in all three sites (neck, back, and deep body) in three birds that only two loggers would be implanted in five birds at the neck and deep body sites (Table 1). The temperature loggers were set to record data every one minute. The male birds from Integrator A were 55 days old at the onset of the six day trial (July 8-13, 2015) and weighed on average 3 kg. After their post-surgical recovery period, the study birds were placed in the same house within 2 m of the anemometer pole.

Field trial: Farm 2

The manufacturer was able to increase production and more loggers were available for Farm 2. Eight birds were used on Farm 2 and two loggers were placed in each bird (neck and deep body). The male birds from Integrator A were 50 days old at the onset of the ten day trial (July 15-24, 2015) and weighed on average 2.75 kg. These birds were placed in the house according to the parameters stated in Farm 1.

Field trial: Farm 3

More temperature loggers were ordered for the remainder of the study. Since more loggers were available, the back site was added for the remainder of the field trials. Five birds were used on Farm 3 and three loggers were placed in each bird (neck, back, and deep body). The male birds from Integrator B were 40 days old at the onset of the 11 day trial (August 3-13, 2015) and weighed on average 2 kg. These birds were placed in the house according to the parameters stated in Farm 1. The birds on Farm 3 were observed three times a day for the duration of the trial to determine bird activity.

Field trial: Farm 4

Six birds were used on Farm 4 and three loggers were placed in each bird (neck, back, and deep body). The male birds from Integrator A were 49 days old at the onset of the 13 day trial (August 14-26, 2015) and weighed on average 2.5 kg. The six birds were divided between two houses that were adjacent to each other on the farm. The equipment and three birds were placed in each house according to the parameters described in Farm 1.

Field trial: Farm 5

Six birds were used on Farm 5 and three loggers were placed in each bird (neck, back, and deep body). The male birds from Integrator C were 54 days old at the onset of the nine day trial (August 31-September 8, 2015) and weighed on average 3 kg. This farm had the same set up as described in Farm 4.

Table 1: The logger sites for each farm during the field trials.

Farm	Neck	Back	Deep body	Bird (n)
1	X		X	5
2	X		X	8
3	X	X	X	5
4	X	X	X	6
5	X	X	X	6

Lab Trial: Trial 1

The first lab trial was conducted to examine the variation in temperature at each implant site. The first trial was conducted in a 10 m x 16 m room in a research poultry house. Two 49 day old broilers were used and placed in a 1.16 m x 1.67 m pen with no other birds present. The pen contained 10 cm of dried pine shavings. Food and water were provided ad libitum. The house temperature and Rh were recorded using two U23 Pro v2 loggers (Onset Computer Corporation, MA, United States). The house temperature and Rh loggers were secured to the feeder 1.3 m from the floor. The loggers were set to record once every minute.

Multiple temperature loggers were placed at each implantation site and set to record data every one minute. Two loggers were placed directly beside each other in the neck and back. Four loggers were placed through the same incision leading into the deep body cavity in Bird 1. Bird 2 only received three loggers in the deep body cavity due to battery failure in one of the loggers. One logger was introduced into the upper gastrointestinal tract by inserting the logger through the mouth into the esophagus. This was referred to as the UGI site and only one logger was used for each bird due to the number of loggers available. The UGI site was not used in the field trials because of the risk that the logger would exit the gizzard and pass through the digestive system which would have resulted in the loss of the loggers in the litter within the house. In the lab trials, the loggers, if passed, could be retrieved due to the small pen size.

The trial ran for a period of 11 days (September 14-24, 2015) and the house environmental controller was set to a temperature of 18.3°C. The birds were monitored daily to make sure they were not experiencing any adverse effects from surgery which included inspecting the incision sites for infection. At the end of the trial, the birds were euthanized and necropsied to remove the loggers. During the necropsy, pictures were taken to document the final placement of the loggers.

<u>Lab trial: Trial 2</u>

In the second lab trial, the back and UGI sites were used to gather baseline data. The second trial was conducted in a 10 m x 16 m room in a research poultry house. The length of the trial was 5 days (October 22-26, 2015) and the set temperature was 15.6°C. Eight 59 day old broilers were used and placed in a three level, six cage battery system with two bird per cage on the top row and one bird per cage on the following two rows. The cage dimensions were 0.5 m x 0.5 m and had a wire mesh floor with a maure tray underneath. Food and water were provided ad libitum. The house temperature and Rh were recorded using an U23 Pro v2 logger (Onset Computer Corporation, MA, United States). The house temperature and Rh loggers were secured to each level of the battery system. Two temperature loggers (back and UGI) were used in each bird. The loggers were set to record once every minute. When the trial ended, the birds were euthanized and the temperature loggers were removed as described in Trial 1.

<u>Lab trial: Trial 3</u>

The third lab trial was conducted to determine the effect of cyclic temperature changes on the broiler body temperature. The trial was conducted in a 10 m x 16 m room in a research poultry house. The length of the trial was 5 days (October 28-November 1, 2015) and the set temperature was changed twice each day. At 10:00 am, the set temperature was increased to 26.7°C. At 7:30 pm, the set temperature was decreased to 15.6°C. Six 64 day old broilers were used and placed in a 1.16 m x 1.67 m floor pen with 0.14 m^2/bird. Food and water were given ad libitum. The house temperature and Rh were recorded using an U23 Pro v2 logger (Onset Computer Corporation, MA, United States). The house temperature and Rh loggers were secured to each level of the battery system. Two temperature loggers (back and UGI) were used in each bird. The loggers were set to record once every minute. When the trial ended, the birds were euthanized and the temperature loggers were removed as described in Trial 1.

Data Analysis

Once the temperature loggers were removed from the bird, the data were downloaded from the loggers via the Mercury software package from Star-oddi. The raw temperature data were then imported into a Microsoft Excel file for analysis. The data were condensed from 1 to 15 minute data and the first eight hours of data after the surgery were not used because this was considered the recovery period. The refined data were used for comparisons of the DBT and subcutaneous temperatures. A statistician was consulted to validate the statistical analysis.

JMP pro 12 was used to further analyze the 15 minute data. The temperature logger data were analyzed by farm/trial and by bird. Correlations coefficients (Pearson) were calculated to determine the strength of the linear relationship, but the coefficients (r) are sensitive to extreme outliers so coefficients of determination (R^2) were calculated to determine the amount of variation. R^2 is the proportion of the variation in a response variable that is explained by a fitted statistical model. Summary statistics were developed for every farm/trial which included mean, minimum, maximum, and standard deviation.

CHAPTER 4

RESULTS AND DISCUSSION

Temperature logger placement

The logger subcutaneous implantation sites needed to have a stable temperature while having no effect on the bird's normal activity. Different sites on the body were considered. The breast presented a large surface area to work with, but there were multiple disadvantages. First, the temperature would constantly fluctuate as a bird changed from a sitting to a standing position. Furthermore, since the breast has minimal feather coverage, it would be more affected by environmental conditions and likely to be less representative of DBT. Constant contact with the litter could also increase the likelihood of infection. Another site considered was underneath the wing. The disadvantage of this site was that the temperature could be affected by wing movement and had minimal feather coverage. Sites on the neck and back would provide full feather coverage and would be minimally affected by a bird's movement. For these reasons, the neck and back sites were selected for use in the study. A logger was surgically implanted in the abdominal cavity to acquire DBT which would serve as a reference temperature for the subcutaneous implantation sites.

Temperature logger retrieval

At the conclusion of each trial, the loggers were removed and the location of the loggers was documented. During removal of the loggers on the first three farms, there was slight infection at the neck (28%) and deep body site (50%) among the 18 birds. The infection was minor discoloration to the skin which should have minimal effect on the body temperature data that was recorded. There were no differences in temperature at the subcutaneous sites or DBT between broilers that exhibited slight infection around the incision site compared to those that had no infection. Additionally, the birds also showed no signs of distress when viewed during the bi-daily checks. For the remainder of the study, each bird was administered an intramuscular injection of antibiotic (Enroflaxin, 0.5 ml/kg) after surgery to prevent infection. The remaining farms only had a 25% infection rate at the deep body site which could be due to the near constant contact with the litter and manure. The deep body site was also more invasive than the neck and back because two incisions were required to insert the logger into the abdominal cavity. During the lab trials, no infection was noticed at any of the implantation sites which was possibly due to the cleaner conditions in the research rooms, better litter quality which would have reduced microbial challenge, and the antibiotic injection.

The movement of the loggers varied with implantation site. During the study, the back site had the least movement. The logger stayed within 1 cm of the initial implantation site. The lack of movement was expected due to the placement between the scapulas which tended to hold the logger in place. The logger at the neck site moved less than 3 cm from its initial implantation site which could possibly due to the range of motion associated with the neck.

When removing the deep body logger, the logger's location was more variable than the other implantation sites. A majority (63%) of the loggers remained in the lower abdominal cavity surrounded by the intestines. Some loggers (20%) were found in the thin abdominal musculature which was due to error in logger placement. These loggers did not pass through the second incision upon implantation. The other loggers (15%) floated to different locations along the length of the abdominal cavity. The loggers were found in between the heart and lungs, near air sacs, in the fat pad, and several loggers became lodged on the gizzard and liver.

When removing the UGI logger from the birds, all of the loggers were retrieved and found either in the gizzard (95%) or between the gizzard and proventriculus (5%). Upon retrieval, the exterior of the logger had a polished appearance which was due to the grinding action of the feed in the gizzard. After each trial, the loggers were placed in a water bath to determine if the accuracy was affected by the wear, but the results were similar to the initial water bath test with an average standard deviation ranging from 0.06°C.

Field trials: Bird location

On four of the farms (Farms 1, 2, 3, and 5), the birds remained within 10 meters of their initial placement when viewed during the bi-daily checks. On Farm 4, the birds moved the farthest from their initial placement due to the absence of migration fences which the others farms utilized. When doing the bi-daily checks, some birds were found 40 m from their initial placement. These birds were moved back to within 2 m of the anemometer poles, so the equipment could accurately monitor the bird's environment.

Field trial: Farm 1

Outside temperature ranged from 21-36°C and outside Rh ranged from 38-95%. The house operated in tunnel ventilation mode for the entire trial period. Air speeds ranged from 2.2-2.5 m/s (Figure 2). The house temperature ranged from 23-29°C and Rh ranged from 80-94%.

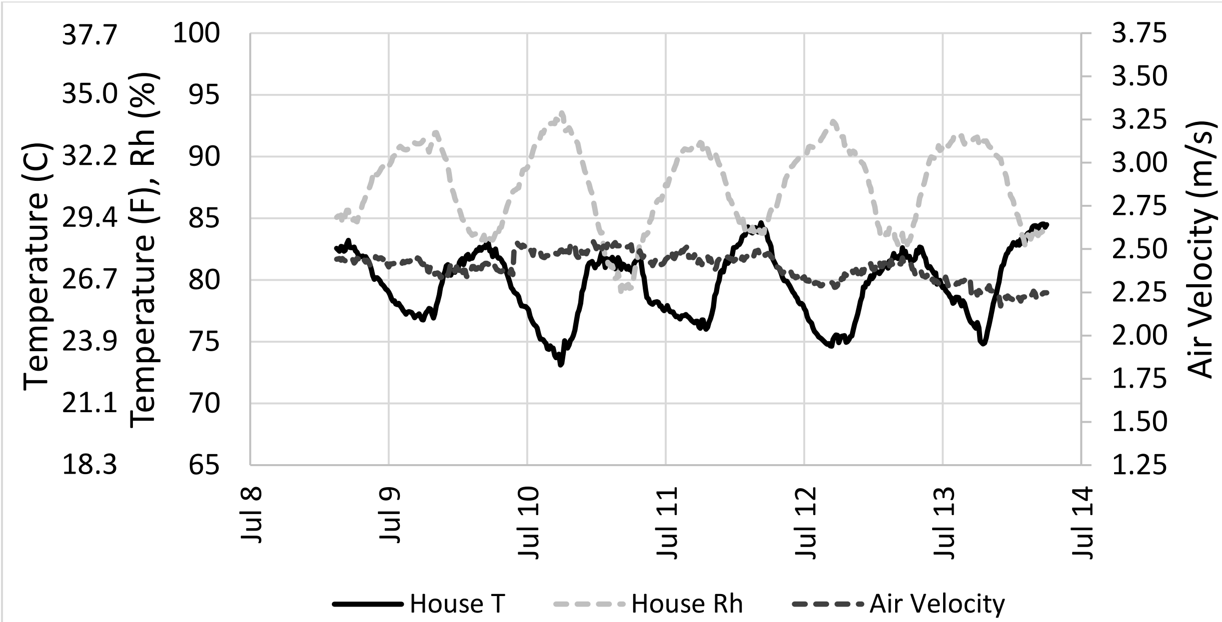

Figure 2: The house conditions for Farm 1 during the trial.

The range of individual bird DBT and neck temperature was 40.1-43.4°C and 39.7-42.9°C respectively (Figures 3 and 4). The average DBT and neck temperature was 41.7°C and 41.3°C respectively (Figure 5). When examining the individual bird DBT, bird 2 was above the average bird DBT 99% of the time and bird 5 was below the average bird DBT 97% of the time. A similar pattern can be seen when examining the neck temperatures. These variations could possibly be due to bird location within the house or difference in metabolic rates. Additionally the individual birds may have different levels in their ability to remove heat.

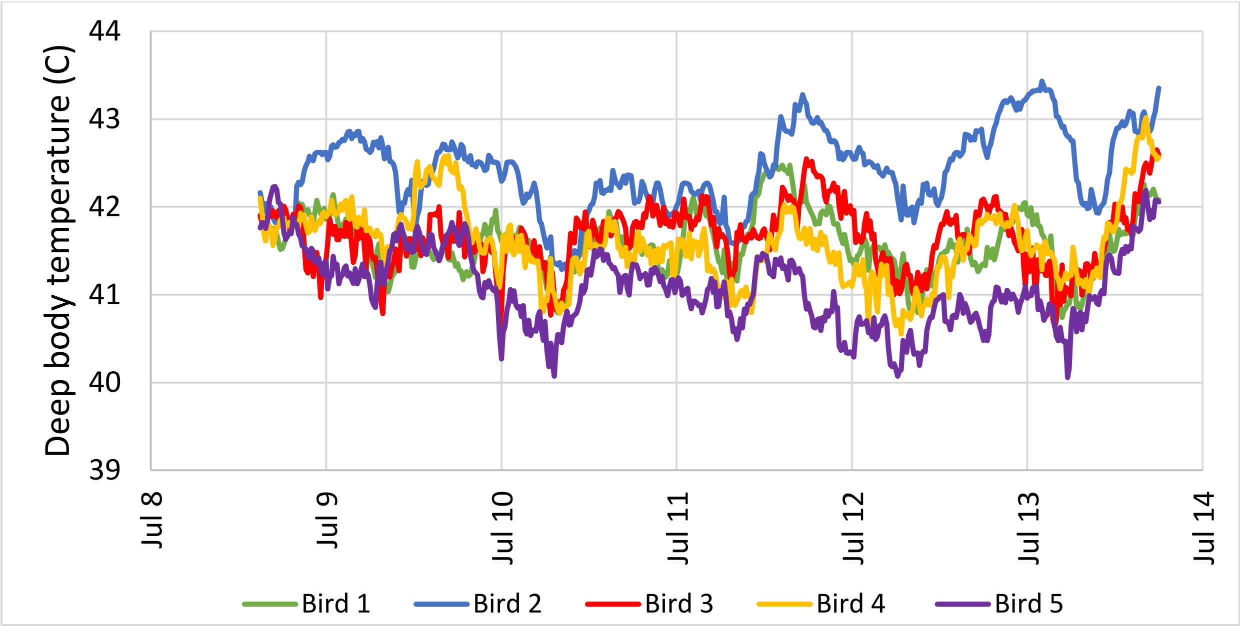

Figure 3: The individual bird DBT for Farm 1.

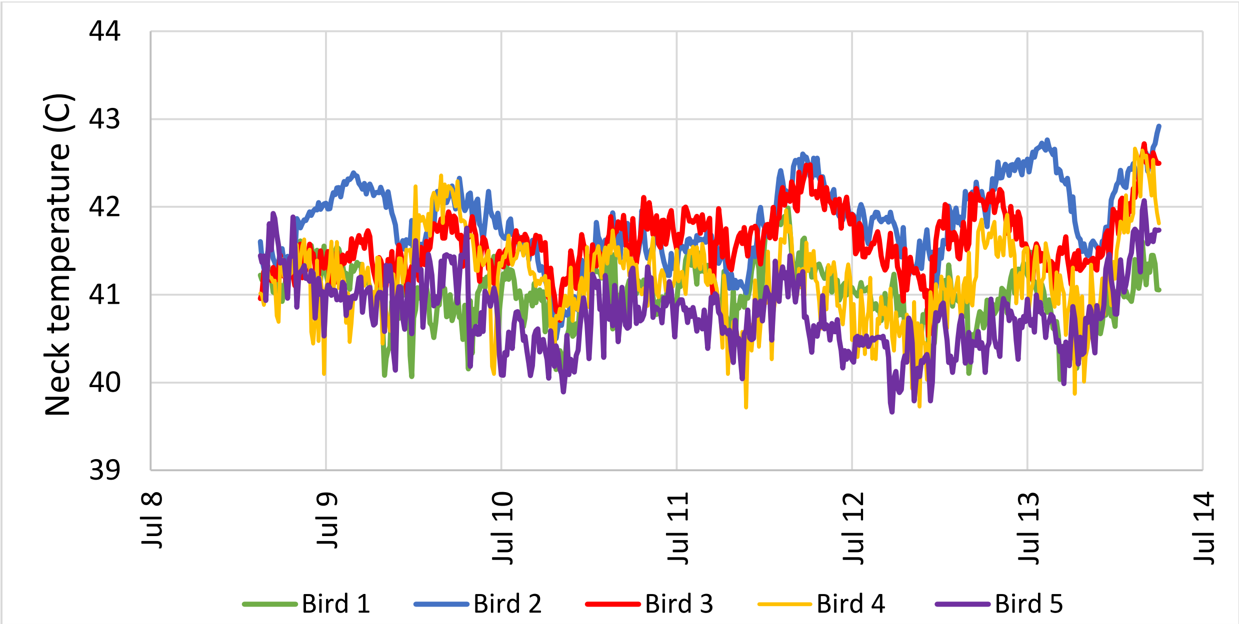

Figure 4: The individual bird neck temperatures for Farm 1.

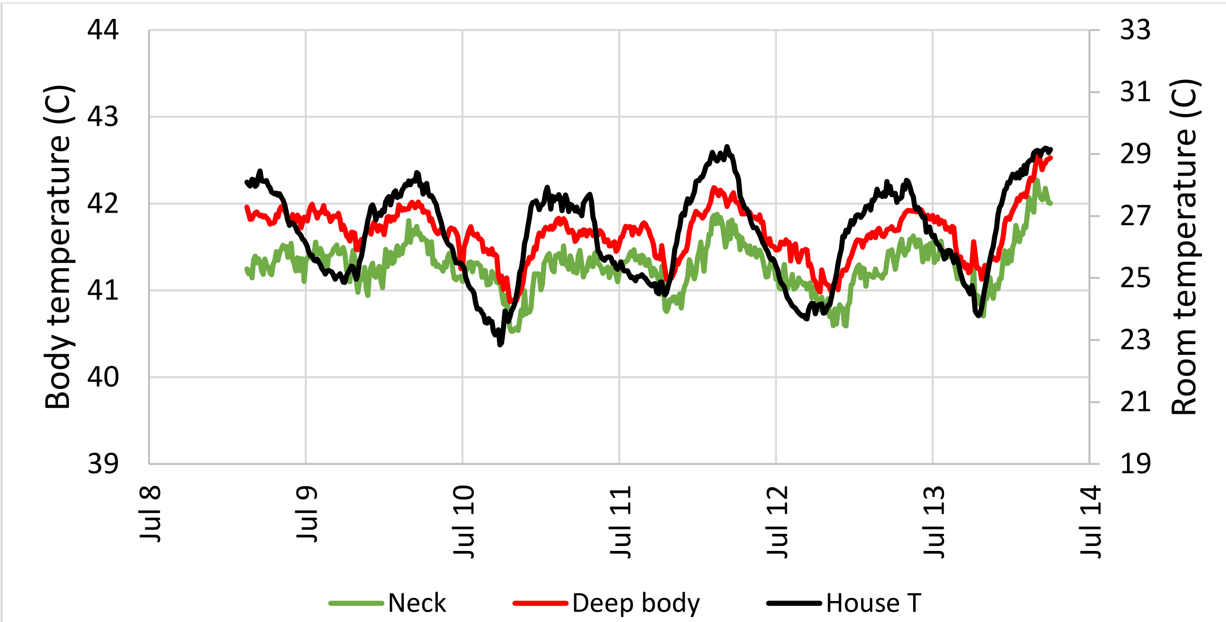

Figure 5: The average bird DBT and neck temperatures for Farm 1.

The deep body vs. neck had a correlation coefficient of 0.85 for all of the bird's temperatures combined. The correlations of deep body vs. neck for the individual birds ranged from 0.70-0.97 (Table 2). The correlation coefficients were statistically significant. The R^2 value for the deep body vs. neck was 0.73 for all of the bird's temperatures combined (Figure 6). This is similar to the research conducted by Giloh et al. (2012). Their infrared thermography research focused on correlating facial surface temperature to DBT which had individual bird R^2 values ranging from 0.75-0.89. Giloh's research was conducted in a laboratory setting, so less variation occurred which could explain the higher R^2 values.

Table 1: The individual bird correlation coefficients of the deep body vs. neck from Farm 1.

Bird	Deep body vs. Neck
1	0.84**
2	0.97**
3	0.70**
4	0.74**
5	0.84**
Combined	0.85**

**P ≤ 0.01

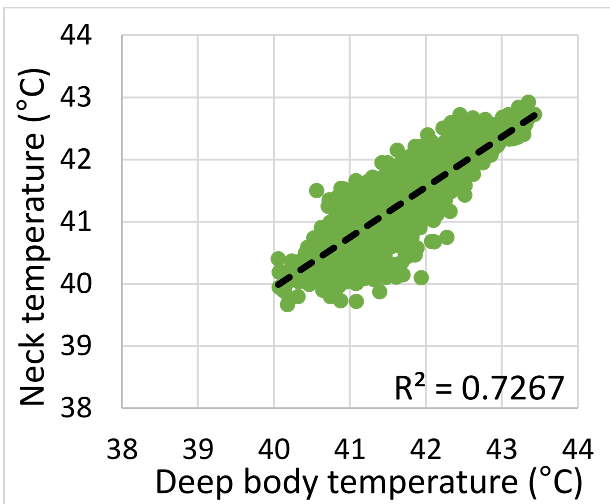

Figure 6: The relationship of DBT vs. neck temperature (n=5 birds) for Farm 1.

Field trial: Farm 2

Outside temperature ranged from 20-36°C and outside Rh ranged from 34-97%. The house operated in tunnel ventilation mode for the entire trial period. Toward the end of the study, the grower utilized more fans to maximize the sensible heat removal of the market age broilers. Air velocity ranged from 1.9-3 m/s for the entire trial (Figure 7). The house temperature ranged from 22-30°C and Rh ranged from 73-96%. The house temperature and Rh logger failed on July 20th due to battery corrosion.

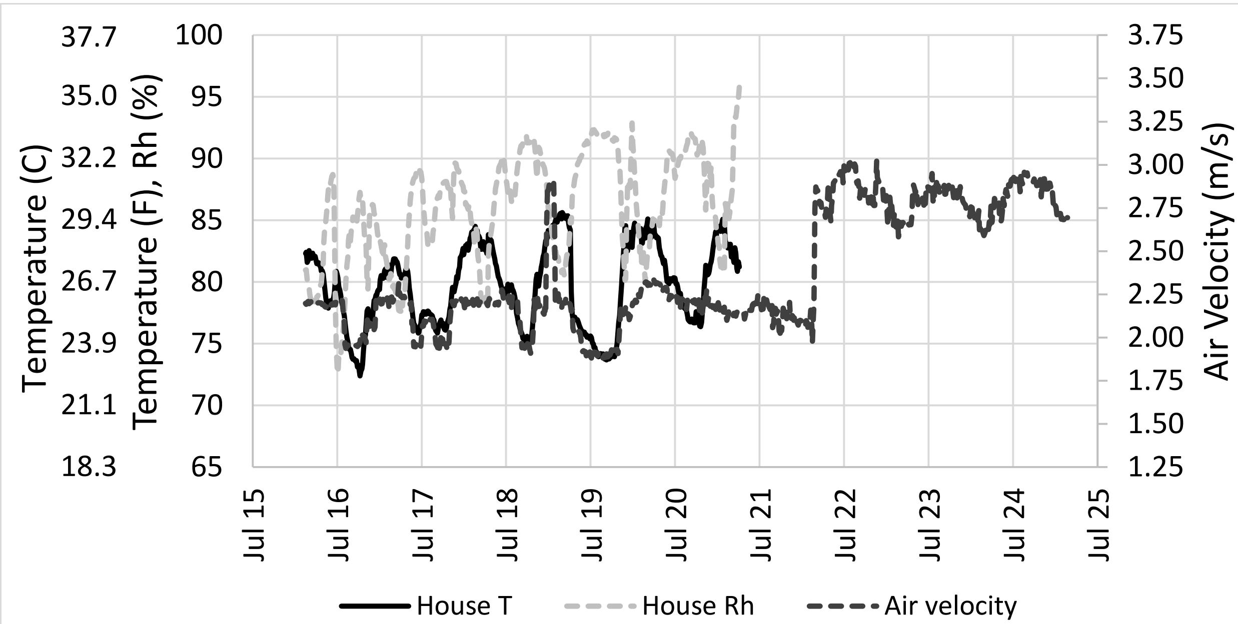

Figure 7: The house conditions for Farm 2 during the trial.

The range of individual bird DBT and neck temperature was 39.9-43.2°C and 37.9-42.9°C respectively (Figures 8 and 9). The average DBT and neck temperature was 41.5°C and 41.0°C respectively (Figure 10). When examining the individual DBT, bird 3 was below the average 99% of the time. When examining the individual neck temperatures, the standard deviation between temperatures was 0.46°C until July 21st. The standard deviation increased to 0.73°C on July 21st which coincided with an average air velocity change from 2.1 m/s to 2.8 m/s. This increase in air velocity could explain why there was an increase in standard deviation of the neck temperatures. The bird would be able to remove heat quicker from the neck than the deep body which would create a variation in the temperatures.

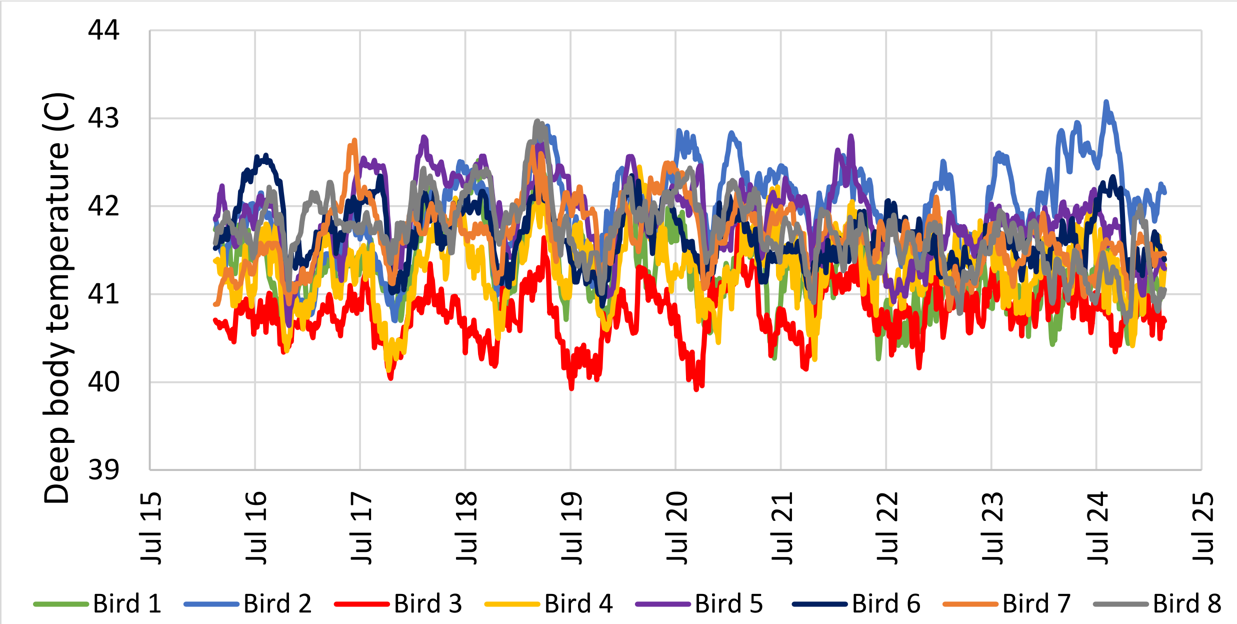

Figure 8: The individual bird DBT for Farm 2.

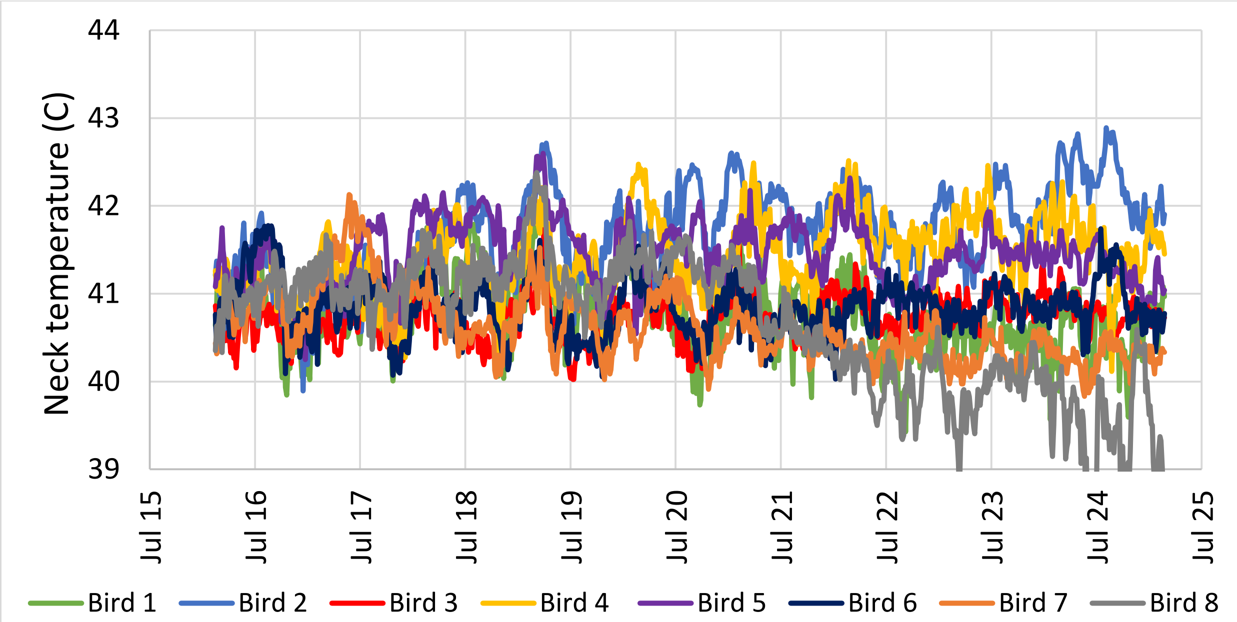

Figure 9: The individual bird neck temperatures for Farm 2.

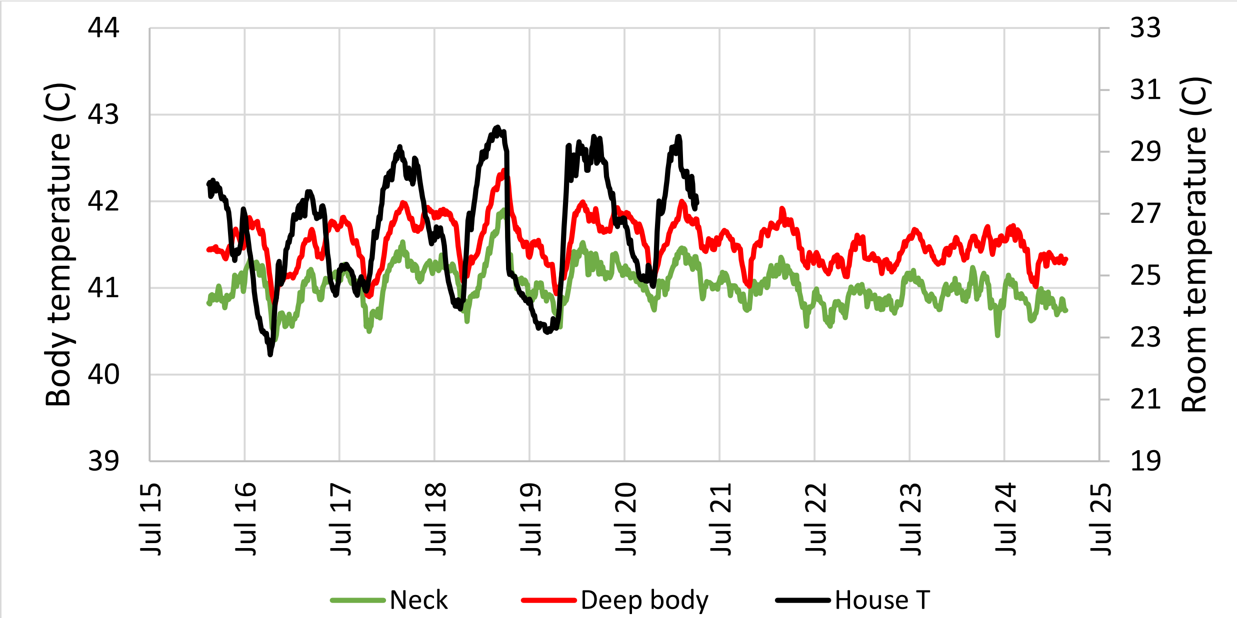

Figure 10: The average bird DBT and neck temperatures for Farm 2.

The deep body vs. neck had a correlation coefficient of 0.62 for all of the bird's temperatures combined. The correlations for the individual birds ranged from 0.66-0.94 (Table 3). The correlation coefficients were statistically significant. The R^2 value for deep body vs. neck was 0.38 for all of the bird's temperatures combined (Figure 11). The relationship between DBT and neck temperature is lower than observed on Farm 1 which may be due to the larger standard deviation in neck temperatures (0.73°C) compared to DBT (0.47°C) after the increase in air velocity.

Table 3: The individual bird correlation coefficients of the deep body vs. neck from Farm 2.

Bird	Deep body vs. Neck
1	0.80**
2	0.94**
3	0.83**
4	0.70**
5	0.86**
6	0.80**
7	0.66**
8	0.81**
Combined	0.62**

**P ≤ 0.01

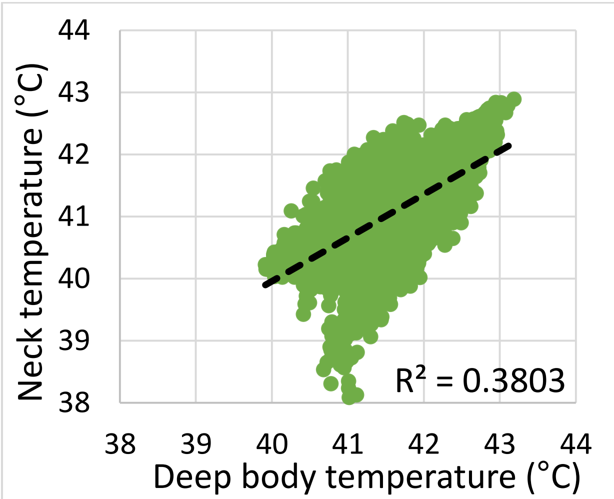

Figure 11: The relationship of DBT vs. neck temperature (n=8 birds) for Farm 2.

<u>Field trial: Farm 3</u>

Outside temperature ranged from 20-37°C and outside Rh ranged from 31-98%. The house operated in tunnel ventilation mode for the entire study period. Air speeds ranged from

1.3-2.4 m/s (Figure 12). The house temperature ranged from 24-30°C and Rh ranged from 65-94%.

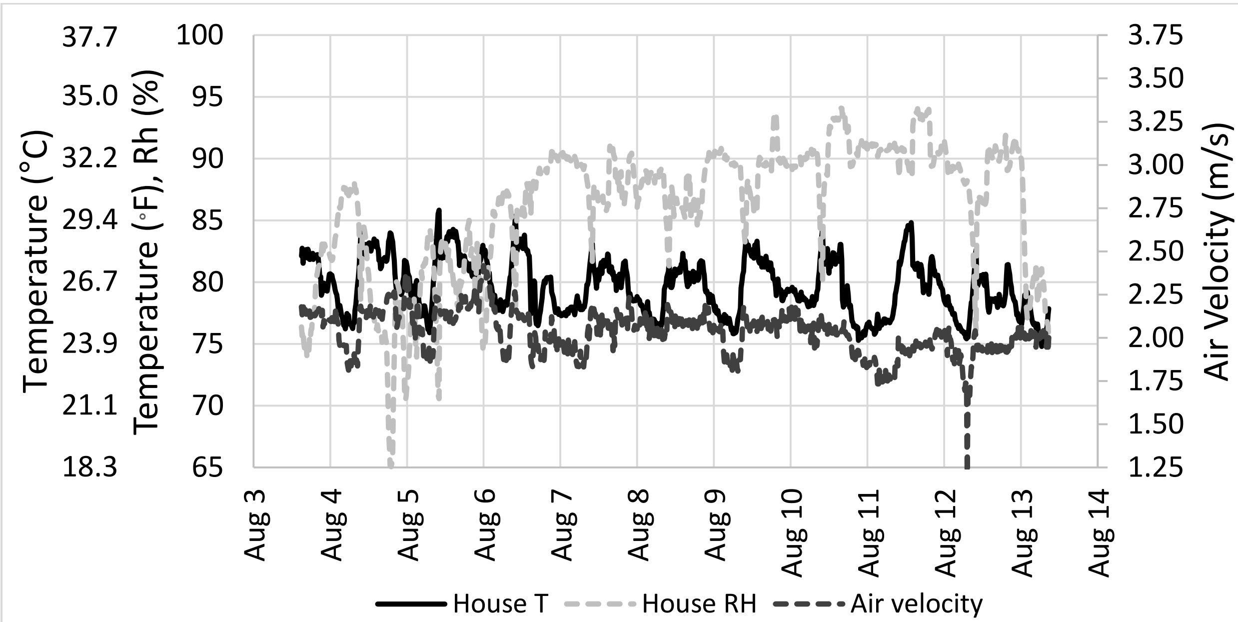

Figure 12: The house conditions for Farm 3 during the trial.

The range of individual bird DBT, neck, and back temperature was 39.5-43.1°C, 39.5-42.2°C, and 39.4-42.2°C respectively (Figures 13, 14, and 15). The average DBT, neck, and back temperature was 41.5°C, 40.9°C, and 40.8°C respectively (Figure 16). When examining the bird body temperatures, bird 1 had a back temperature (89%) and DBT (98%) that were consistently above the average respective temperature while the neck temperature was only over the average neck temperature 41% of the time. This variation may have occurred due to bird location and density. When observing the study birds, Bird 1 stayed in between the outside feedline and water line 90% of the time while the other birds stayed in the middle of the house 60% of the time.

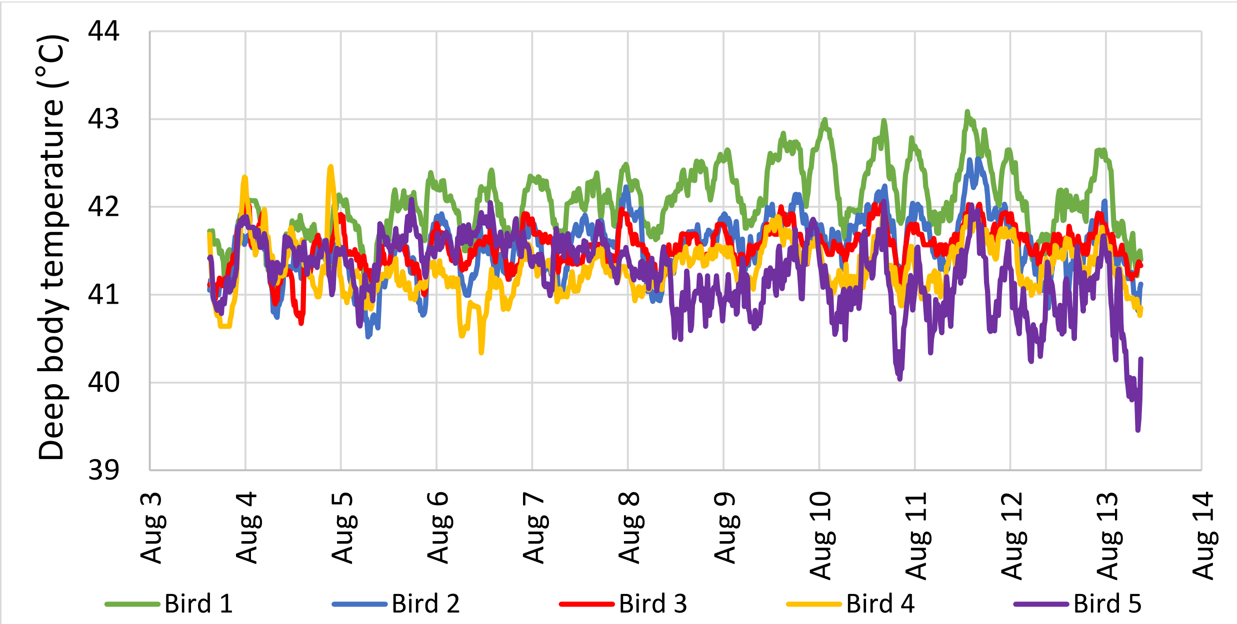

Figure 13: The individual bird DBT for Farm 3.

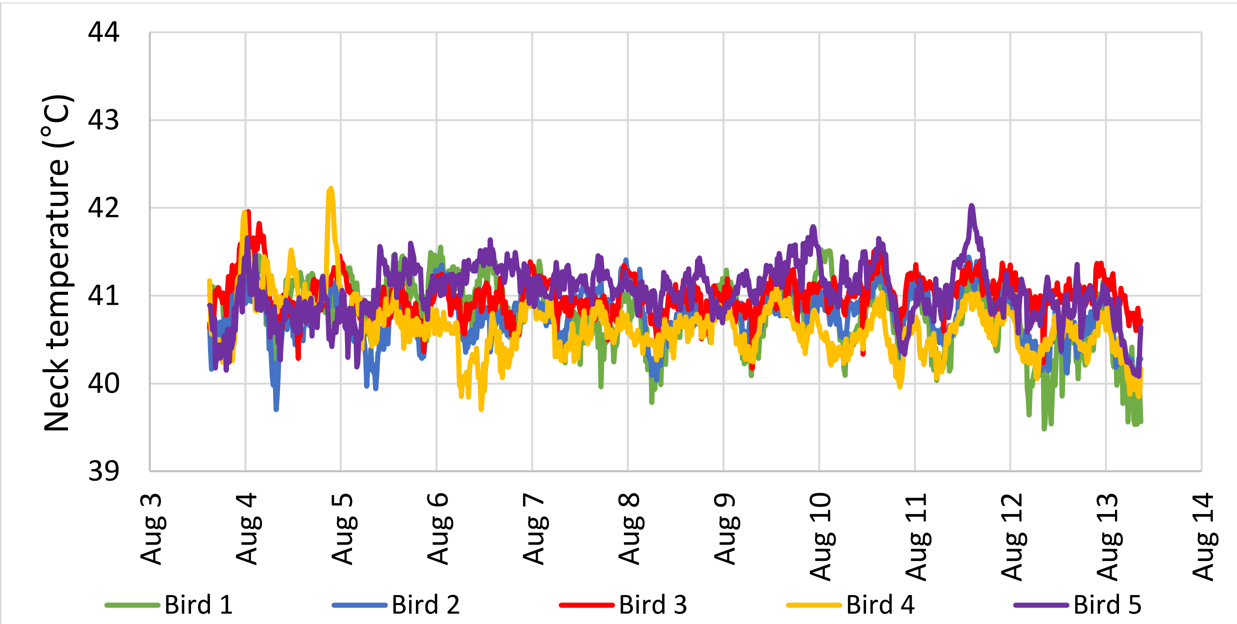

Figure 14: The individual bird neck temperatures for Farm 3.

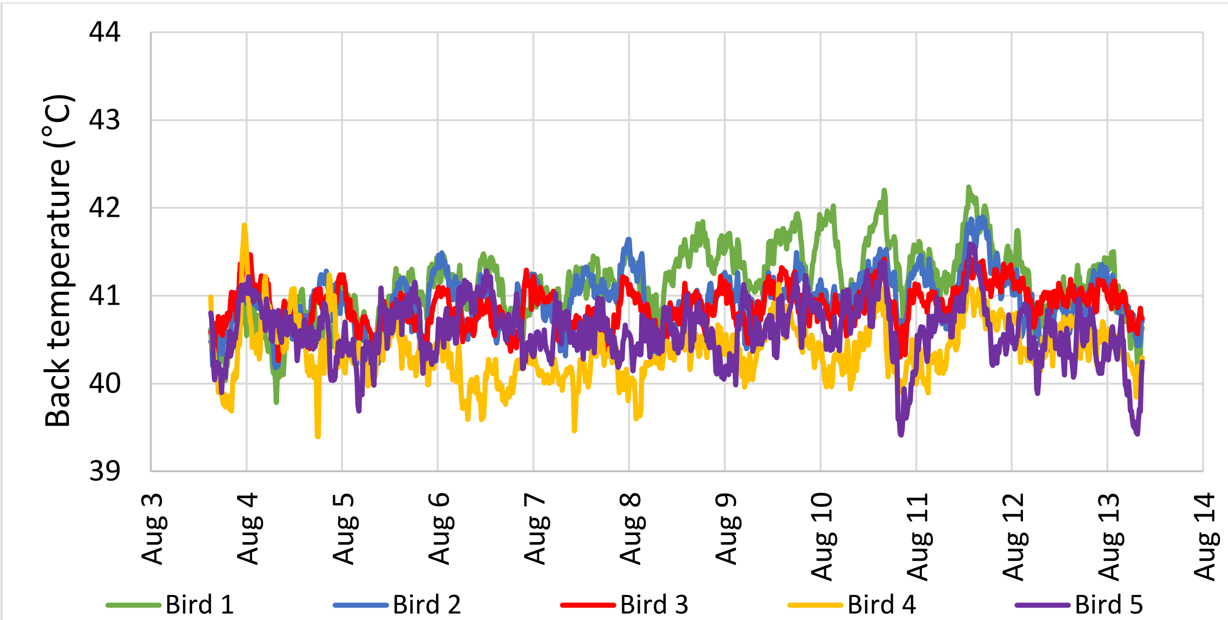

Figure 15: The individual bird back temperatures for Farm 3.

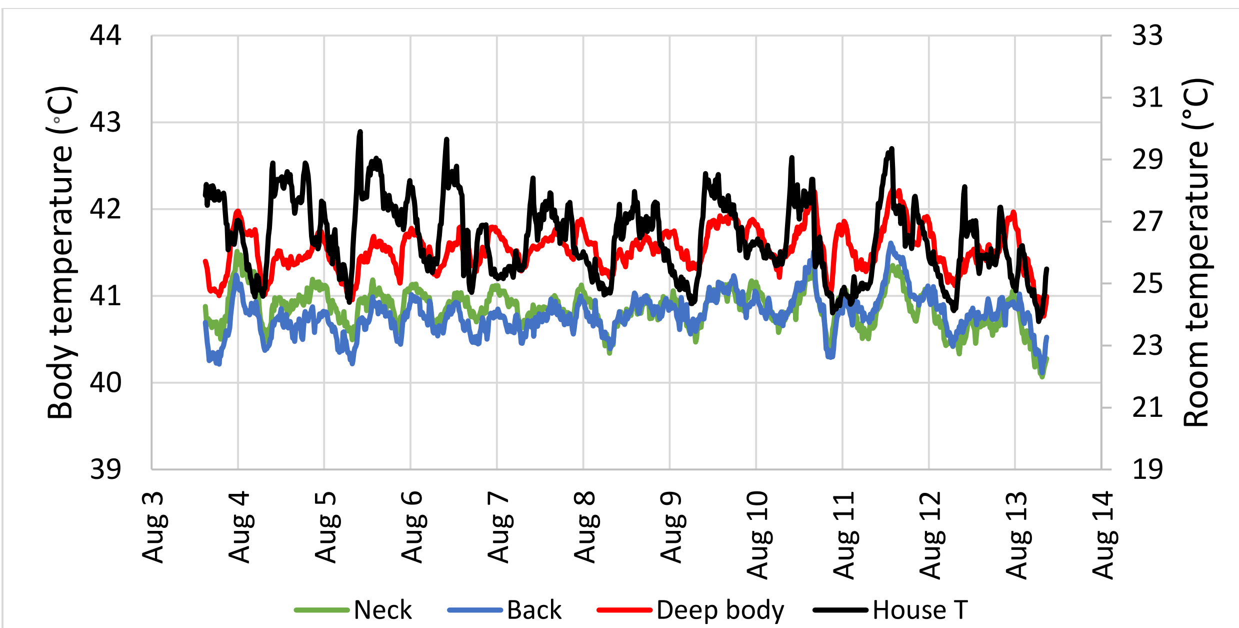

Figure 16: The average bird DBT and subcutaneous temperatures for Farm 3.

The deep body vs. neck and deep body vs. back had a correlation coefficient of 0.41 and 0.83 respectively with all of the bird's temperatures combined. The individual correlations for the deep body vs. neck ranged from 0.46-0.82. The individual correlations for the deep body vs. back ranged from 0.62-0.93 (Table 4). The correlation coefficients were statistically significant. The R^2 value for the deep body vs. neck and deep body vs. back was 0.16 and 0.70 respectively for all of the bird's temperatures combined (Figure 17).

Table 4: The individual bird correlation coefficients of the deep body vs. neck and deep body vs. back from Farm 3.

Bird	Deep body vs. Neck	Deep body vs. Back
1	0.46**	0.90**
2	0.82**	0.93**
3	0.73**	0.84**
4	0.75**	0.82**
5	0.65**	0.62**
Combined	0.41**	0.83**

**P ≤ 0.01

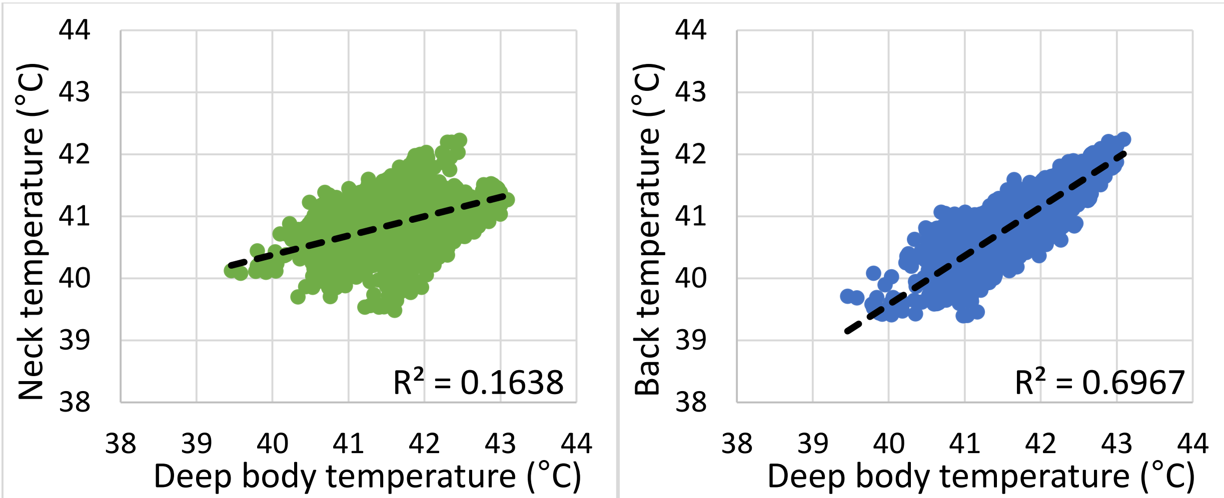

Figure 17: The relationships of the DBT vs. neck and DBT vs. back (n=5 birds) for Farm 3.

<u>Field trials: Farm 4</u>

Outside temperature ranged from 17-33°C and outside Rh ranged from 40-99%. The house operated in tunnel ventilation mode for the entire study period. Air speeds ranged from 2.1-3.1 m/s (Figure 18). The house temperature ranged from 26-31°C and Rh ranged from 74-97%.

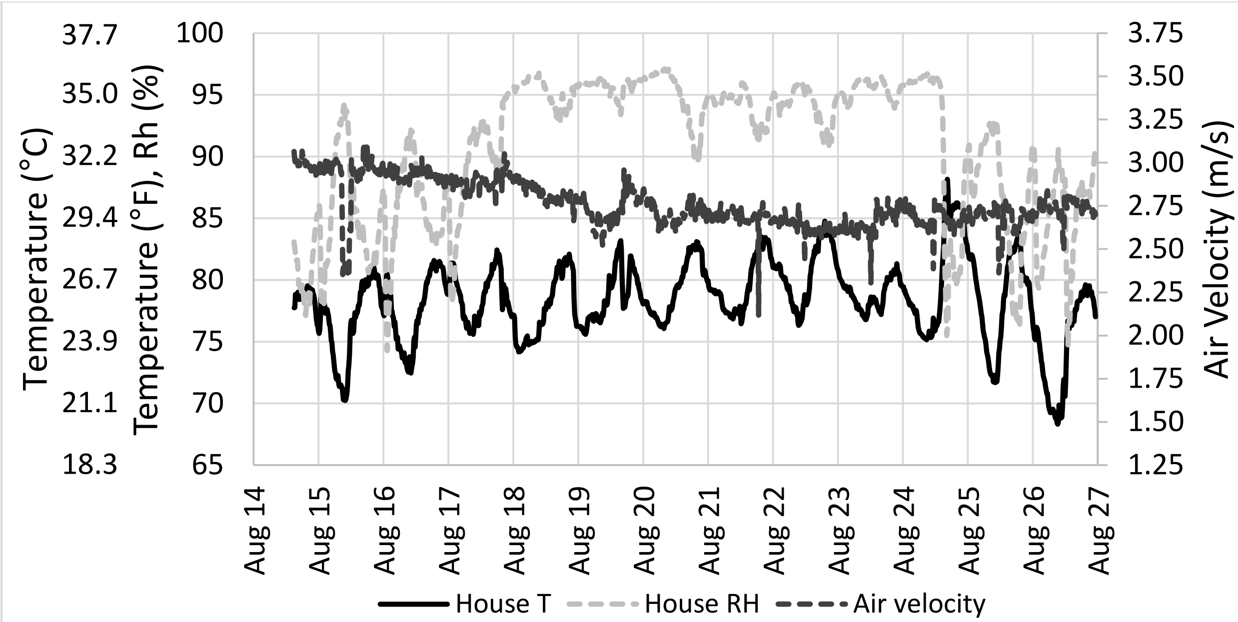

Figure 18: The house conditions for Farm 4 during the trial.

The range of individual bird DBT, neck, and back temperature was 39.3-43.2°C, 39.5-42.7°C, and 39.5-42.7°C and respectively (Figures 19, 20, and 21). The average DBT, neck, and back temperature was 41.3°C, 40.9°C, and 40.9°C respectively (Figure 21). On Farm 4, birds 1-3 were in house 1 and birds 4-6 were in house 2. When examining the individual bird body temperatures (neck, back, and deep body), birds 1-3 showed increased temperatures in all implant sites starting on August 21st and the grower's records showed an increased mortality in house 1 (500 birds/day) compared to house 2 (30 birds/day) on the August 24th and 25th. During the bi-daily checks, the birds showed no signs of distress and the conditions within the houses were similar. The standard deviation between house temperatures was 0.18°C. These differences may be associated with bird health issues as seen by the increased mortality, but the birds were never tested by the integrator for confirmation.

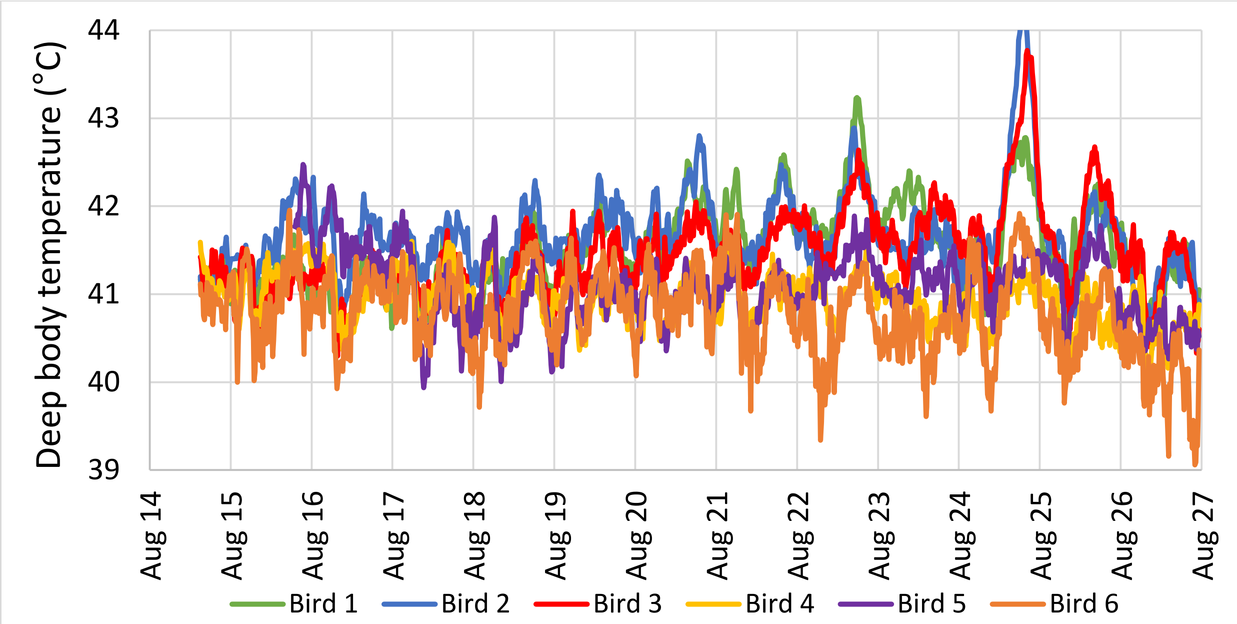

Figure 19: The individual bird DBT for Farm 4.

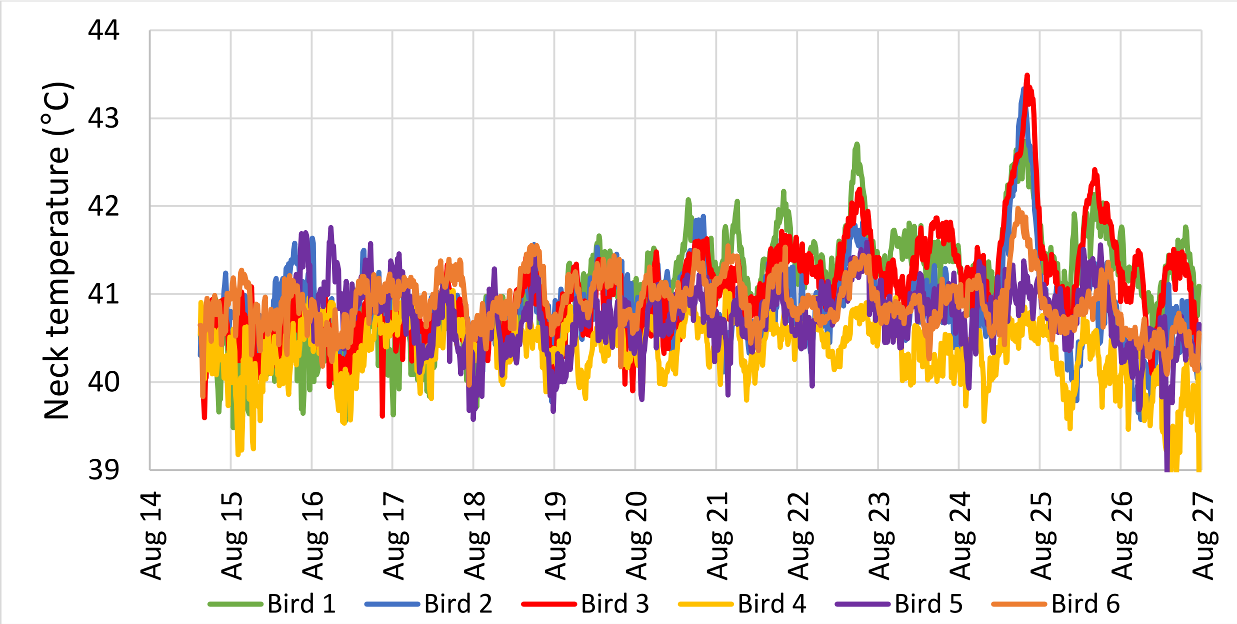

Figure 20: The individual bird neck temperatures for Farm 4.

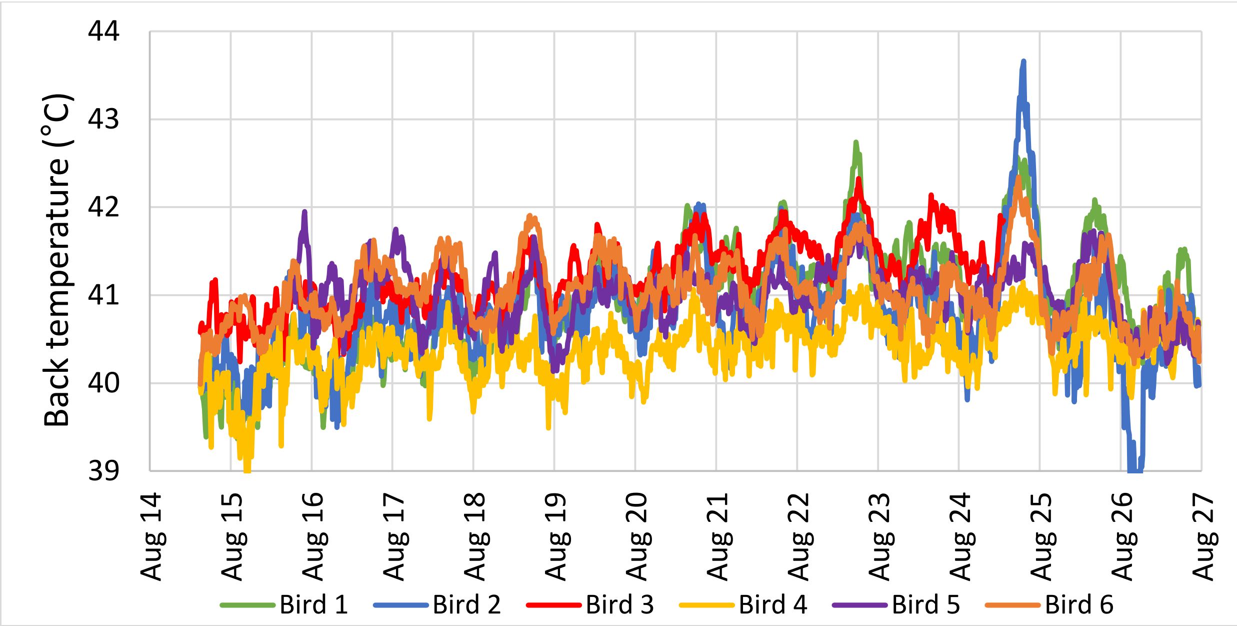

Figure 21: The individual bird back temperatures for Farm 4.

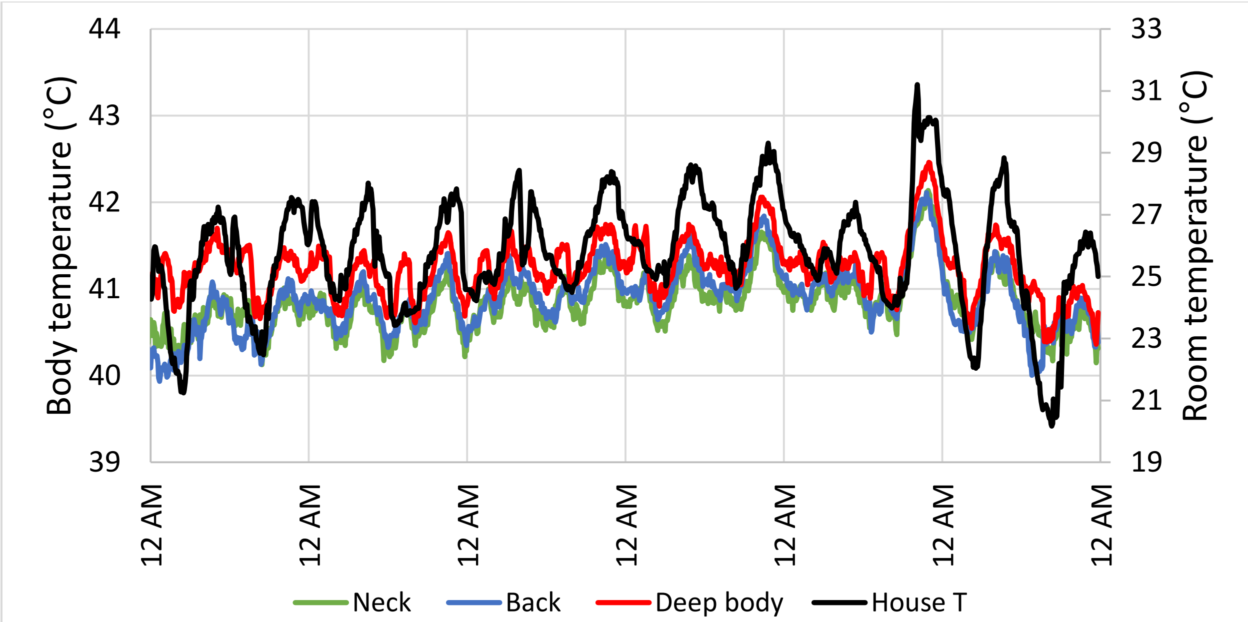

Figure 22: The average bird DBT and subcutaneous temperatures for Farm 4.

The deep body vs. neck and deep body vs. back had a correlation coefficient of 0.69 and 0.54 respectively with all of the bird's temperatures combined. The individual correlations for the deep body vs. neck ranged from 0.70-0.89. The individual correlations for the deep body vs. back ranged from 0.19-0.92 (Table 5). The correlation coefficients were statistically significant. The R^2 value for the deep body vs. neck and deep body vs. back was 0.48 and 0.30 respectively for all of the bird's temperatures combined (Figure 23).

Table 5: The individual bird correlation coefficients of the deep body vs. neck and deep body vs. back from Farm 4.

Bird	Deep body vs. Neck	Deep body vs. Back
1	0.89**	0.93**
2	0.88**	0.80**
3	0.88**	0.92**
4	0.86**	0.19**
5	0.71**	0.75**
6	0.70**	0.64**
Combined	0.69**	0.54**

**$P \leq 0.01$

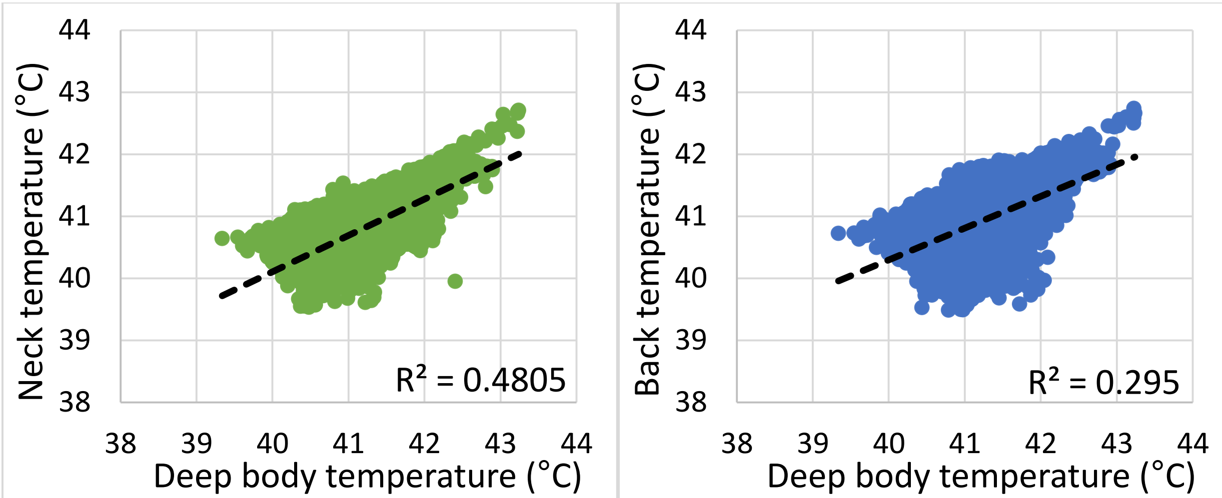

Figure 23: The relationships of the DBT vs. neck and DBT vs. back (n= 6 birds) for Farm 4.

<u>Field trials: Farm 5</u>

Outside temperature ranged from 18-25°C and outside Rh ranged from 44-83%. The house operated in tunnel ventilation mode for the entire study period. Air speeds ranged from 2.5-3.7 m/s (Figure 24). At the beginning of the trial, the fan capacity switched between ~70% at night and ~100% during the day. On September 5th, the fans capacity increased to between 85-95% for the remainder of the trial. The house temperature ranged from 20-27°C and the house Rh ranged from 84-98%.

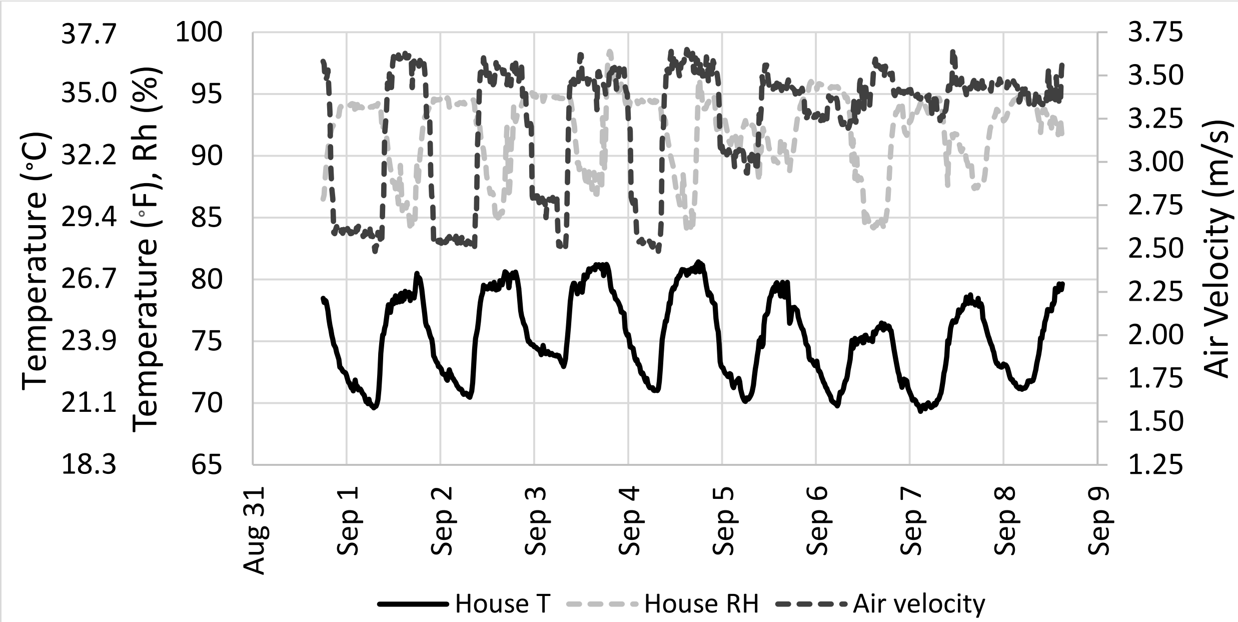

Figure 24: The house conditions for Farm 5 during the trial.

The range of individual bird DBT, neck, and back temperature was 39.5-43.4°C, 38.6-42.8°C, and 39.0-42.5°C respectively (Figures 25, 26, and 27). The average neck, back, and DBT was 40.5°C, 40.5°C, and 41.0°C respectively (Figure 28). Bird 5 had elevated body temperatures (neck, back, and deep body) on September 1-2. The temperatures returned to normal pattern on September 3 and continued for the remainder of the trial.

A temperature logger (bird 3, back) stopped recording due to battery failure and was undetectable until the data was downloaded. The data was retrieved until the failure occurred, and the logger was replaced for the following trials. This was the first time the failure occurred while the logger was in the bird. There were other battery failures, but these happened while launching the loggers.

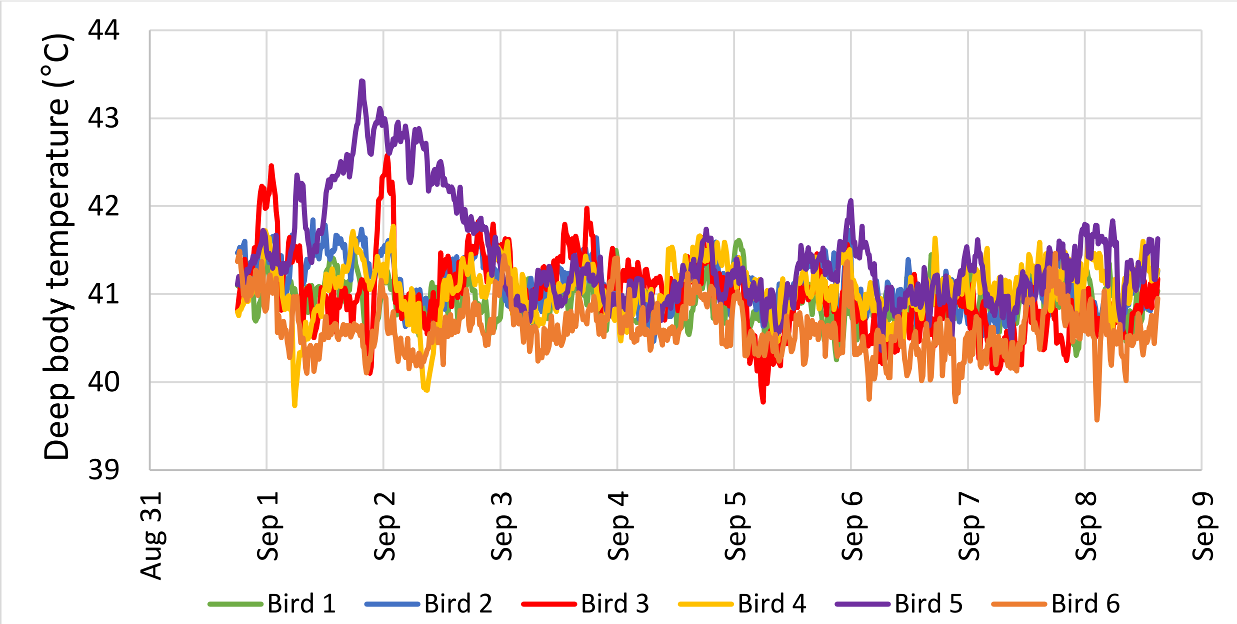

Figure 25: The individual bird DBT for Farm 5.

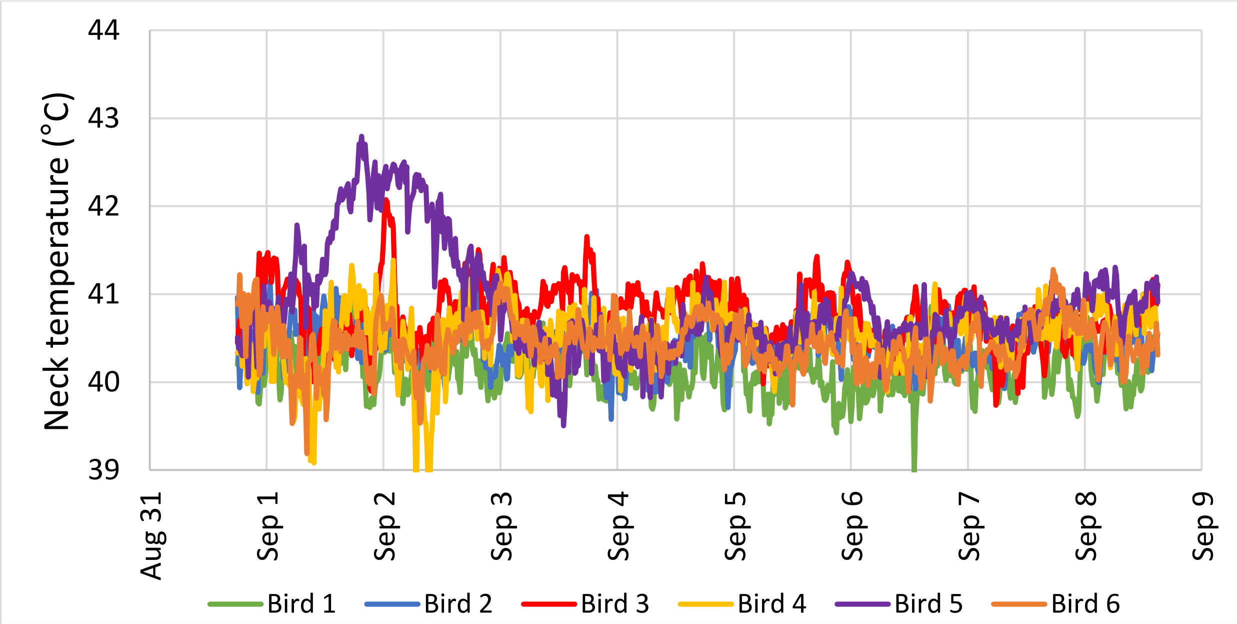

Figure 26: The individual bird neck temperatures for Farm 5.

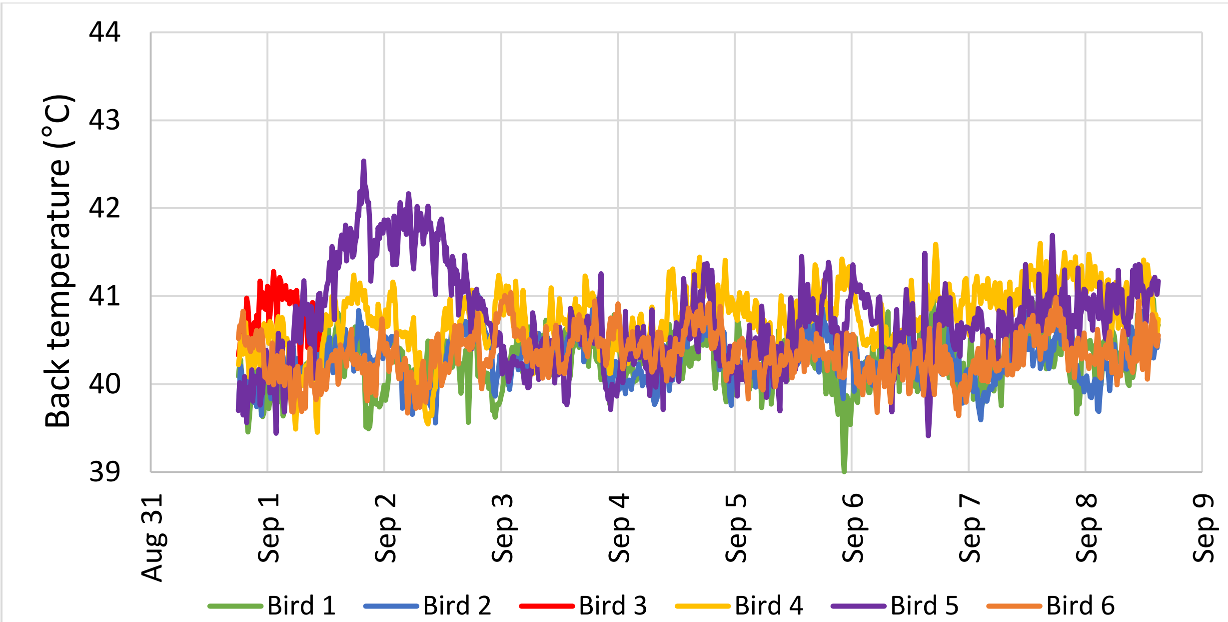

Figure 27: The individual bird back temperatures for Farm 5.

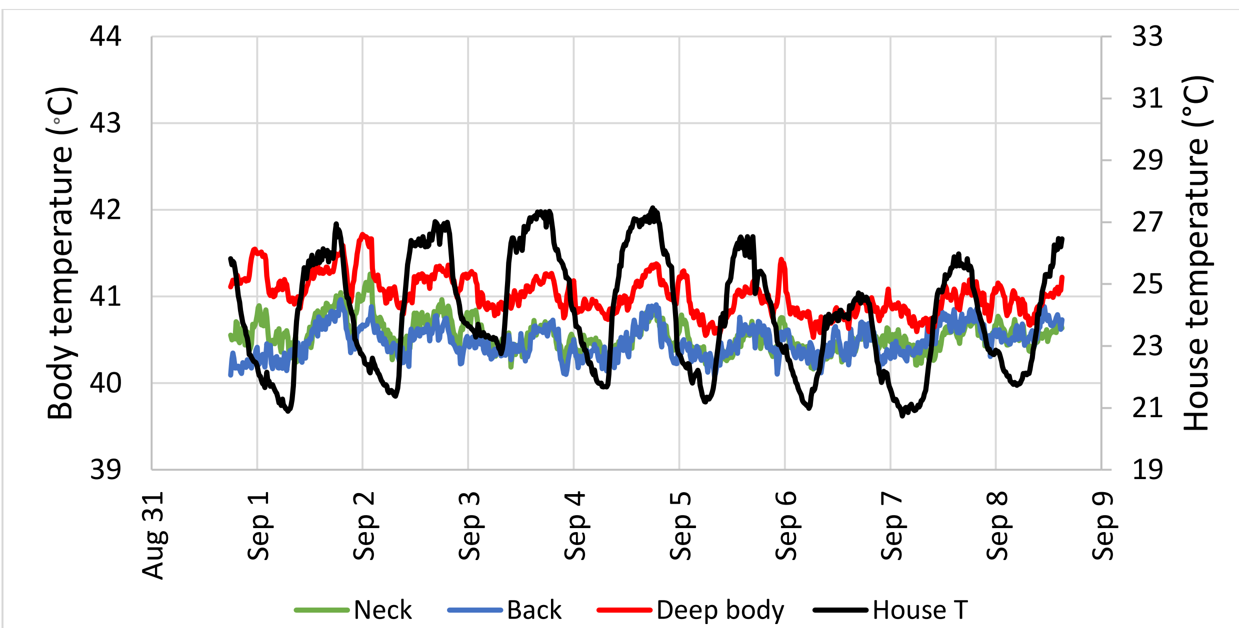

Figure 28: The average DBT and subcutaneous temperatures for Farm 5.

The deep body vs. neck and deep body vs. back had a correlation coefficient of 0.75 and 0.66 respectively with all of the bird's temperatures combined. The individual correlations for the deep body vs. neck ranged from 0.67-0.93. The individual correlations for the deep body vs. back ranged from 0.50-0.78 (Table 6). The correlation coefficients were statistically significant. The R^2 value for the deep body vs. neck and deep body vs. back was 0.57 and 0.43 respectively for all of the bird's temperatures combined (Figure 29).

Table 6: The individual bird correlation coefficients of the deep body vs. neck and deep body vs. back from Farm 5.

Bird	Deep body vs. Neck	Deep body vs. Back
1	0.86**	0.50**
2	0.67**	0.54**
3	0.82**	0.56**
4	0.76**	0.78**
5	0.93**	0.77**
6	0.68**	0.55**
Combined	0.75**	0.66**

**$P \leq 0.01$

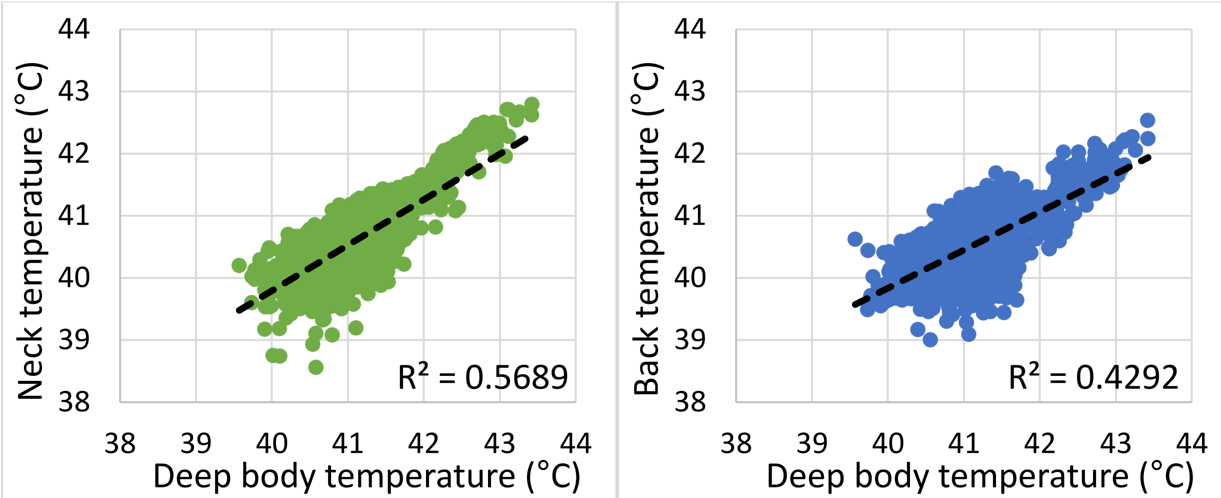

Figure 29: The relationships of the DBT vs. neck and DBT vs. back (n=6 birds) for Farm 5.

Field trials: All farms

Throughout the field trials the correlation coefficients between subcutaneous temperature and DBT were all statistically significant. When trying to determine which subcutaneous temperature had the best correlation with DBT, the most reliable implantation site varied from farm to farm. The bird temperature data from all of the farms was combined into a single data set and analyzed. The neck vs. deep body and back vs. deep body had a correlation coefficient of 0.69 and 0.65 respectively which are lower because of the variation associated with combining the field trial data. The correlations were statistically significant. The neck vs. deep body location had the highest correlation in the field trials, but due to possible logger migration within the abdominal cavity, the results were considered inconclusive as to which subcutaneous site had a higher correlation.

The data were split into different temperature ranges according to DBT to determine if the correlations improved as DBT increased. The DBT ranges were below 41°C, 41-42°C, and about 42°C. When DBT was below 41 C, the neck vs. deep body and back vs. deep body had a correlation coefficient of 0.20 and 0.12 respectively which are not strong correlations, but they are still significant. When DBT was in the range of 41-42 C, the neck vs. deep body and back vs. deep body had a correlation coefficient of 0.43 and 0.47 respectively. When DBT was above 42 C, the neck vs. deep body and back vs. deep body had a correlation coefficient of 0.51 and 0.61 respectively. The correlations suggest that as DBT increases the relationship to subcutaneous temperature increases which may be due to the subcutaneous temperatures being more influenced by environmental changes. As ambient temperature increases, the gradient between the environment and DBT decrease resulting in better correlations for the subcutaneous and DBT.

<u>Lab trial: Trial 1</u>

The house environmental controller was set to maintain a target temperature of 18.3°C. The house temperature ranged from 22-30°C and Rh ranged from 44-77%. Circulation fans were ran constantly to provide a uniform environment within the house.

The body temperature data was separated by implantation site and analyzed. The neck site had an average temperature of 40.9°C and a range of 40.0-41.9°C. The standard deviation between the loggers in bird 1 was 0.03°C while bird 2 have a standard deviation of 0.16°C (Figure 30). The standard deviation between all four of the loggers was 0.16°C.

There were two loggers placed at the back site in each bird. The back site had an average temperature of 40.8 C and a range of 39.7-41.8°C. The standard deviation for the loggers in bird 1 was 0.03°C while bird 2 have a standard deviation of 0.05°C (Figure 31). The standard deviation between all four loggers was 0.13°C.

There were four loggers placed in bird 1 and three loggers placed in bird 2 at the deep body site. The deep body site had an average temperature of 41.0°C and a range of 39.8-42.1°C.

The standard deviation for the loggers in bird 1 was 0.17°C while bird 2 have a standard deviation of 0.19°C (Figures 32 and 33). The standard deviation between all seven loggers was 0.22°C.

One logger was placed at the UGI site in each bird. The UGI site had an average temperature of 41.2°C and a range of 40.2-42.2°C. The standard deviation between the two loggers was 0.15°C (Figure 34).

The deep body site had the highest deviation between the loggers which was possibly due to logger migration as seen in the field trials. The back site had the least deviation between the loggers out of the four implantation sites based on the standard deviations.

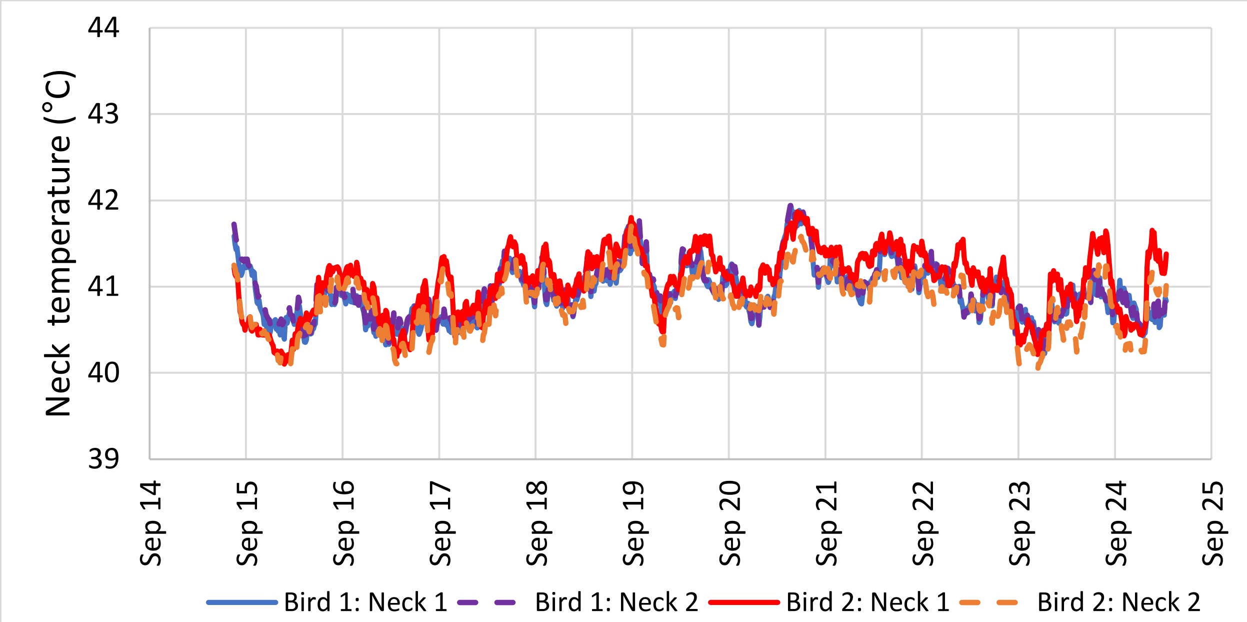

Figure 30: Comparing the neck temperatures of the birds from Trial 1.

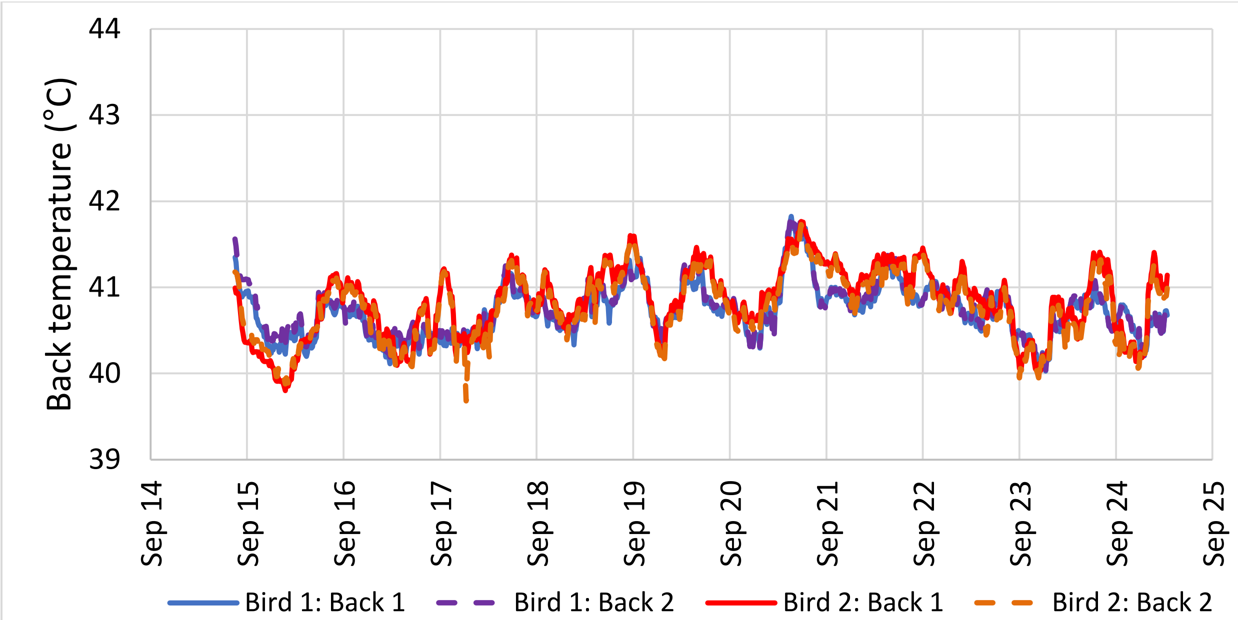

Figure 31: Comparing the back temperatures of the birds from Trial 1.

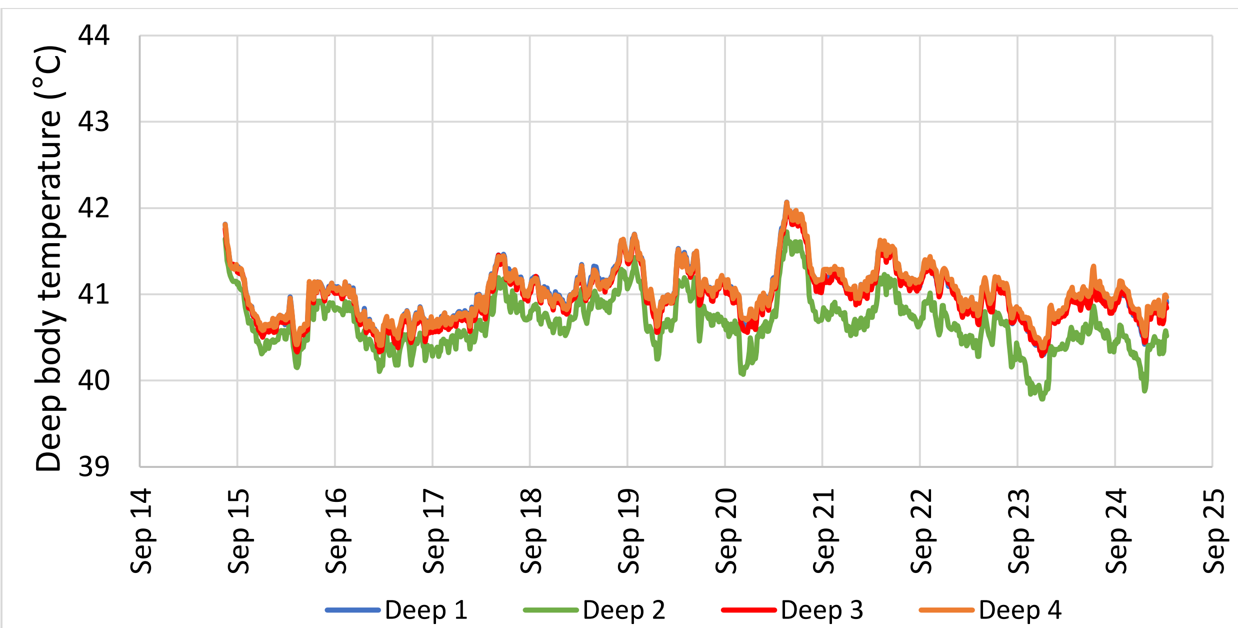

Figure 32: Comparing the DBT of Bird 1 from Trial 1.

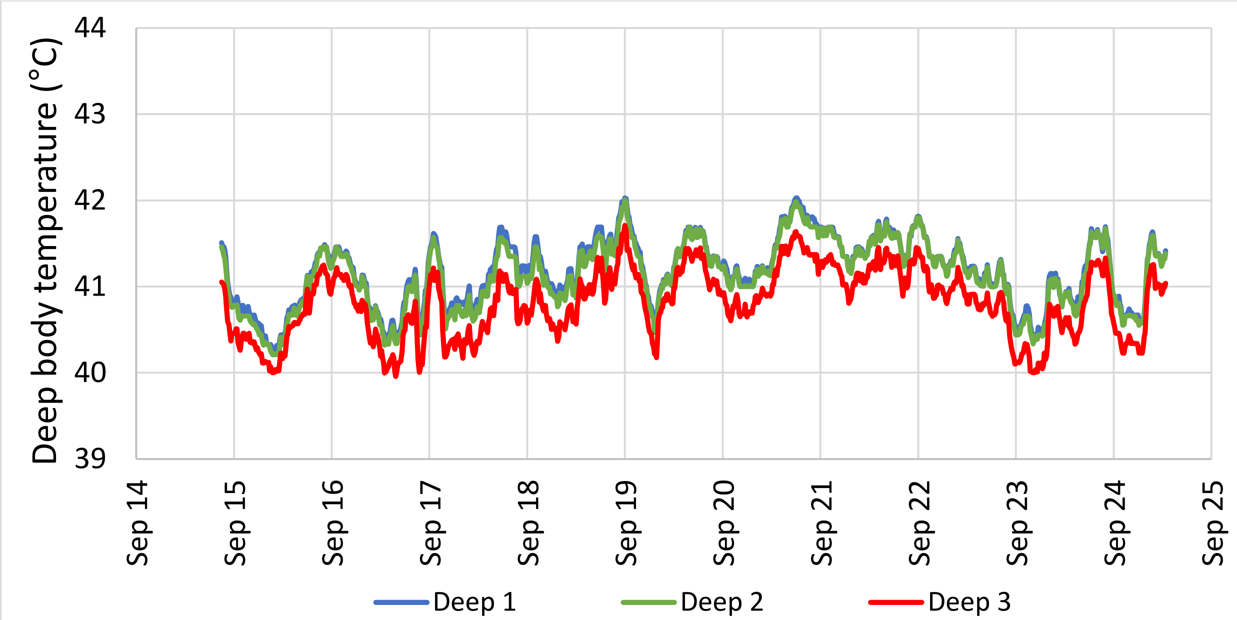

Figure 33: Comparing the DBT of Bird 2 from Trial 1.

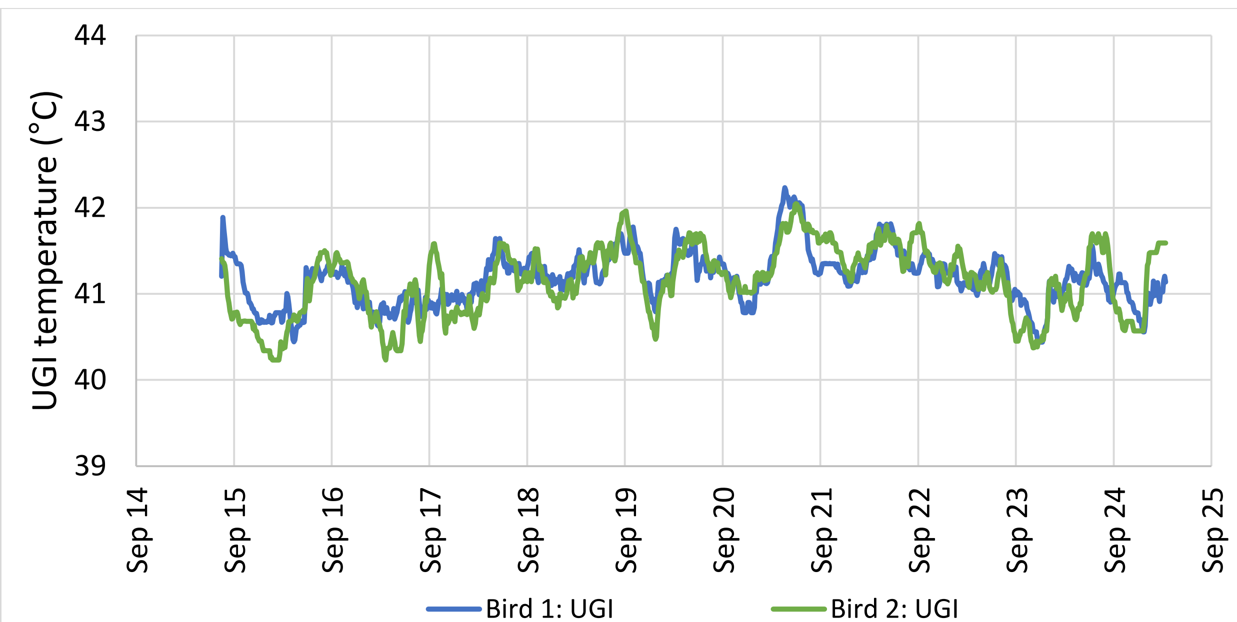

Figure 34: Comparing the UGI temperatures of the birds from Trial 1.

The deep body vs. neck and deep body vs. back had an average correlation coefficient of 0.90 and 0.93 respectively with both bird's temperatures combined (Table 7). The individual bird correlations for the neck vs. deep body and back vs. deep body ranged from 0.67-0.97 and 0.82-0.98 respectively. The neck vs. UGI and the back vs. UGI had an average correlation coefficient of 0.95 and 0.97 respectively with both bird's temperatures combined (Table 8). The individual bird correlations for the neck vs. UGI and back vs. UGI ranged from 0.93-0.98 and 0.96-0.98 respectively. Then the UGI was compared to the deep body location. The UGI vs. deep body had an average correlation coefficient of 0.92 and individual bird correlations ranging from 0.79 - 0.97.

Table 7: Average correlation coefficients of the neck vs. deep body and back vs. deep body from all of the birds for Trial 1.

Deep body	Neck vs. Deep body	Back vs. Deep body
Deep 1	0.92**	0.97**
Deep 2	0.78**	0.85**
Deep 3	0.93**	0.93**
Deep 4	0.97**	0.98**
Average	0.90**	0.93**

**$P \leq 0.01$

Table 8: Trial 1 correlation coefficients of the neck vs. UGI and back vs. UGI.

Bird	Neck vs. UGI	Back vs. UGI
Bird 1	0.94**	0.97**
Bird 2	0.97**	0.98**
Average	0.95**	0.97**

**$P \leq 0.01$

Lab trials: Trial 2

The house environmental controller was set to maintain a target temperature of 15.6°C. The house temperature ranged from 14-26°C and the house Rh ranged from 54-94%. Circulation fans ran constantly to provide a uniform environment within the house.

The range of individual bird UGI and back temperatures was 40.0-42.9°C and 38.9-42.4°C respectively (Figures 35 and 36). The average UGI and back temperature was 40.9°C and 40.3°C respectively (Figure 37). On October 23rd, the study birds showed elevated body temperatures which was possibly due to a max house temperature of 26°C as opposed to 24°C and below for the remainder of the trial.

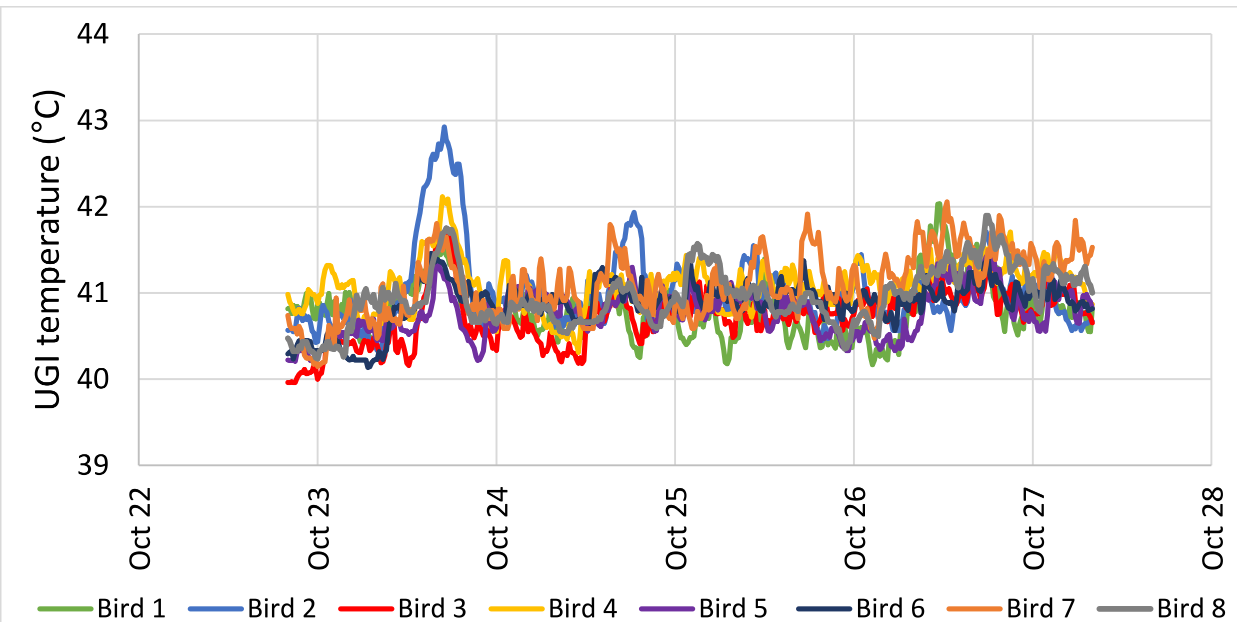

Figure 35: The individual bird UGI temperatures for Trial 2.

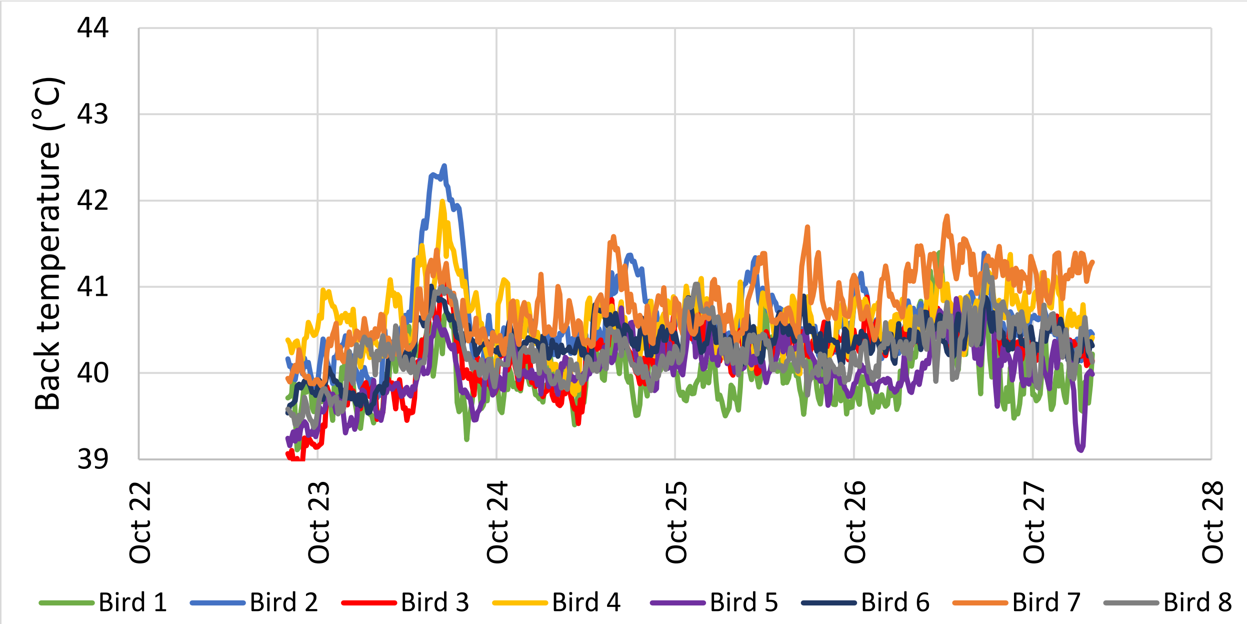

Figure 36: The individual bird back temperatures for Trial 2.

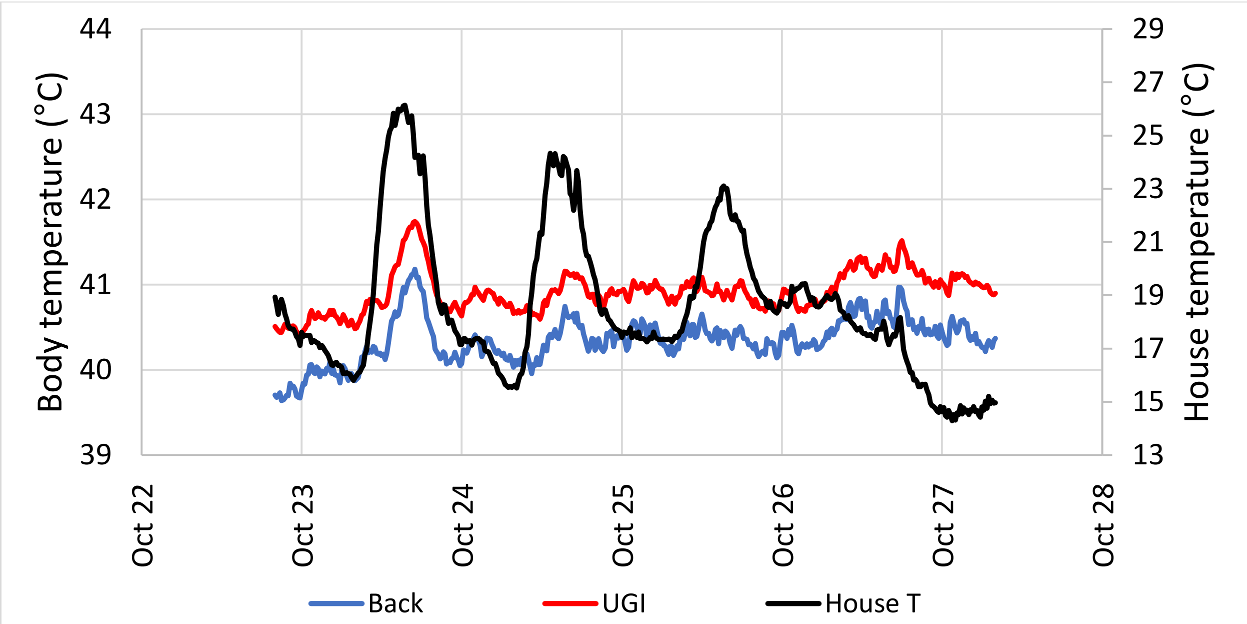

Figure 37: The average UGI and back temperatures for Trial 2.

The back vs. UGI had a coefficient of 0.87 with all of the bird's temperatures combined. The individual correlations for the UGI vs. back ranged from 0.83-0.95 (Table 9). The correlation coefficients were statistically significant. The R^2 value for the UGI vs. back was 0.76 with all of the bird's temperatures combined (Figure 38).

Table 9: Trial 2 correlation coefficients of the UGI vs. back.

Bird	UGI vs. back
1	0.83**
2	0.95**
3	0.90**
4	0.90**
5	0.84**
6	0.95**
7	0.95**
8	0.90**
Combined	0.87**

**P ≤ 0.01

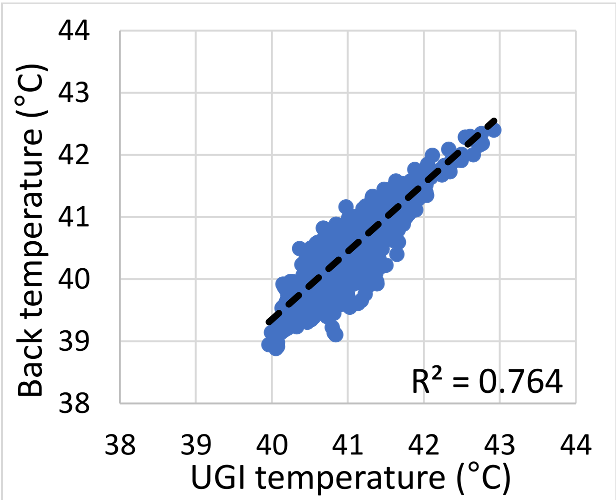

Figure 38: The relationship of the UGI vs. back for Trial 2.

Lab trials: Trial 3

The house environmental controller was set to cycle between 15.6°C and 26.7°C. The house temperature ranged from 15-27°C and the house Rh ranged from 45-93%. Circulation fans ran constantly to provide a uniform environment within the house.

The range of individual bird UGI and back temperatures was 40.2-43.2°C and 39.0-42.8°C respectively (Figures 39 and 40). The average UGI and back temperature was 41.4°C and 40.8°C respectively (Figure 41). When examining the UGI temperatures, the study birds experienced an average UGI temperature change of 1.6°C during the cyclic temperature changes. This UGI temperature rise occurred over a period of approximately 75 minutes after the set temperature was changed to 26.7°C. The UGI temperature remained elevated until the set temperature was decreased to 15.6°C. The UGI temperature decreased to the average over a period of approximately 90 minutes. The back temperature followed a similar pattern.

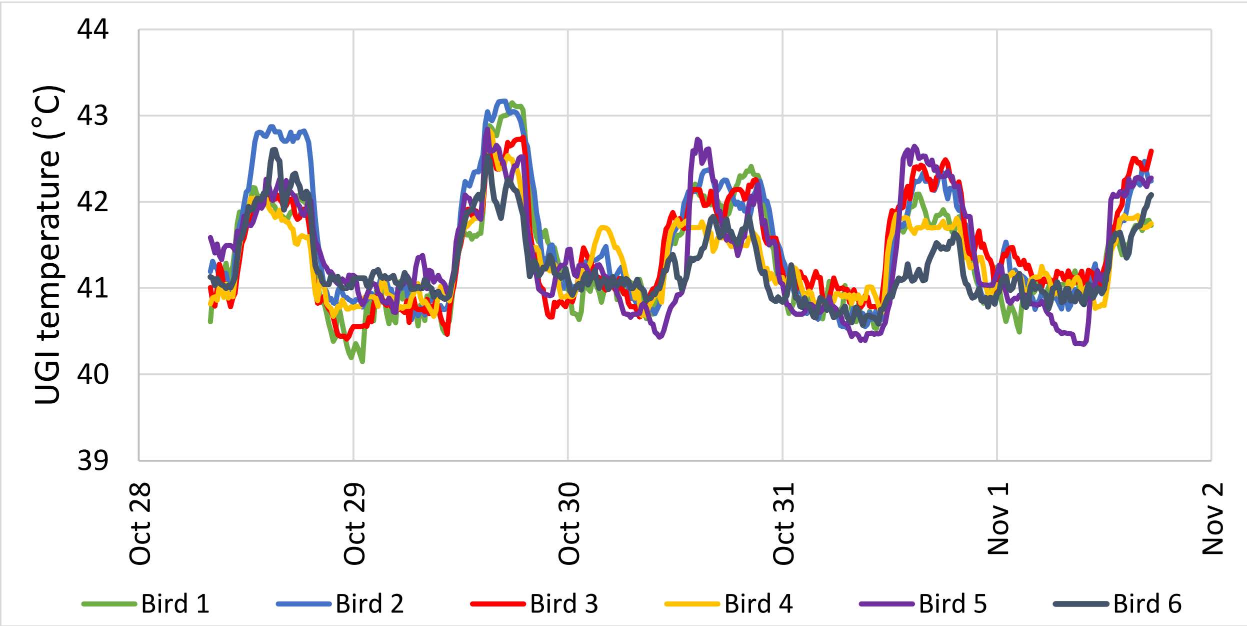

Figure 39: The individual bird UGI temperatures for Trial 3.

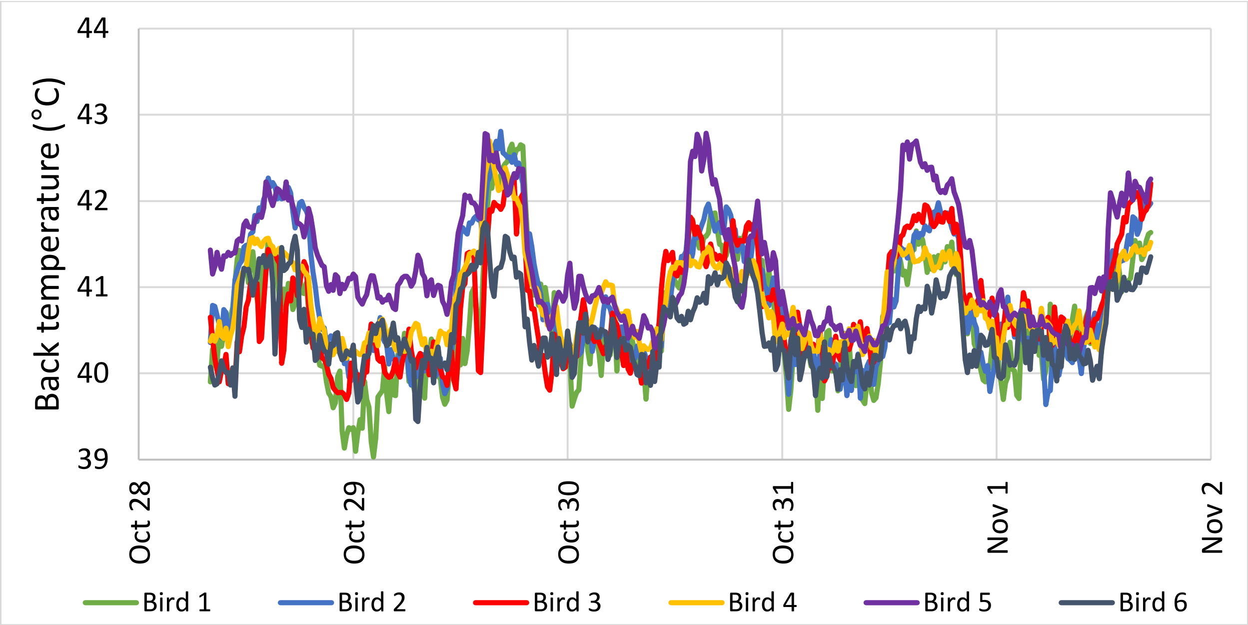

Figure 40: The individual bird back temperatures for Trial 3.

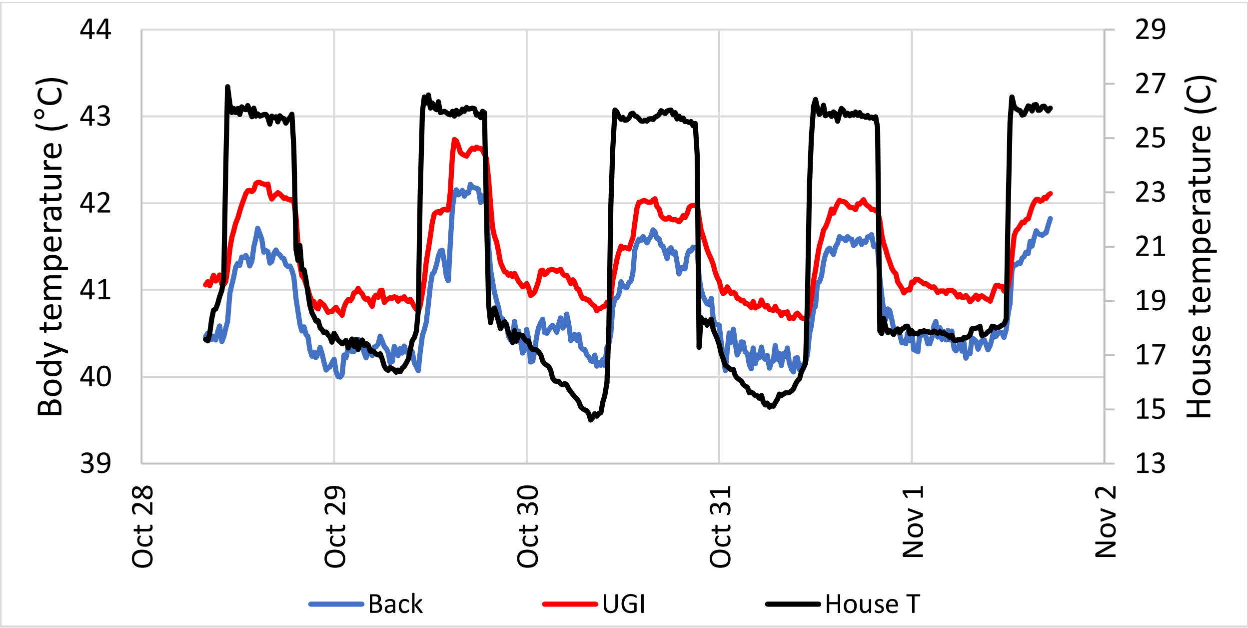

Figure 41: The average UGI and back temperatures for Trial 3.

The UGI vs. back had a correlation coefficient of 0.90 with all of the bird's temperatures combined. The individual correlations for the UGI vs. back ranged from 0.83-0.98 (Table 10). The correlation coefficients were statistically significant. The R^2 value for the UGI vs. back was 0.82 with all of the bird's temperatures combined (Figure 42).

Table 10: Trial 3 correlation coefficients of the UGI vs. back.

Bird	UGI vs. back
1	0.94**
2	0.96**
3	0.93**
4	0.98**
5	0.98**
6	0.83**
Combined	0.90**

**$P \leq 0.01$

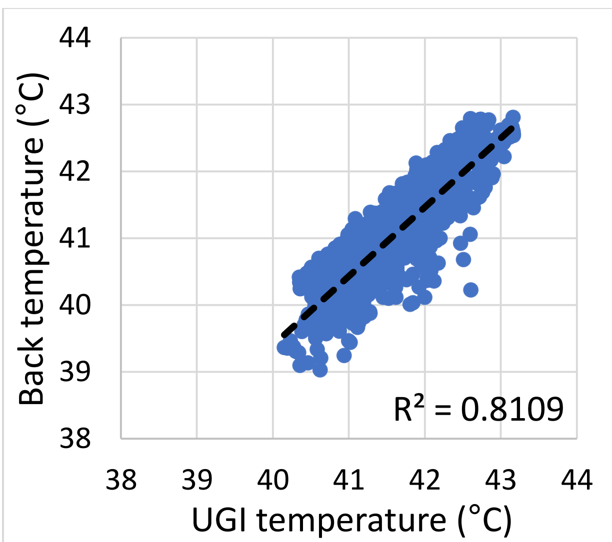

Figure 42: The relationship of the UGI vs. back for Trial 3.

CHAPTER 5

CONCLUSION

The main objective of this study was to compare subcutaneous temperatures from various sites with DBT in field and lab settings. The conclusions drawn from this study were:

1. Subcutaneous temperatures (neck and back) can be used as an indicator of DBT.
2. The UGI location should be used when using temperature data loggers to monitor DBT.

Applications

The research conducted in this study opens the doors to new opportunities with subcutaneous temperature monitoring which can be used in both future research and the poultry industry. In future research, the monitoring method should be refined by focusing on the potential causes of variation between subcutaneous temperatures and DBT, and how much variation occurs. This can be done in an environmentally controlled lab setting where each variable can be studied separately. The downside to doing lab trails is that replicating the variables that occur in the field is difficult, so lab trials are used as a baseline for field trials. Due to time constraints, the field trials were conducted before the lab trials in this study, but the research still answered the original hypothesis of subcutaneous temperatures being used as an indicator of DBT.

Animal welfare is becoming an important topic within the poultry industry and this research could be useful when monitoring poultry wellbeing. By monitoring bird body temperature, poultry integrators would have a direct measurement of how the birds are reacting to the environment within a poultry house. The integrators could then change the environment to fit the bird’s thermal comfort needs which would help increase performance and profit. The integrators would also have a tool to document the animal welfare criteria are being met. Using subcutaneous sites as a less invasive measurement of bird body temperature is viable based on this research.

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