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Quantifying Physiological Responses of Beef Cattle Using a Tympanic Temperature Measurement Device

Jacob John Mayer

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QUANTIFYING PHYSIOLOGICAL RESPONSES OF BEEF CATTLE USING A TYMPANIC TEMPERATURE MEASUREMENT DEVICE

By

Jacob John Mayer

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in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Biological Engineering
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QUANTIFYING PHYSIOLOGICAL RESPONSES OF BEEF CATTLE USING A TYMPANIC TEMPERATURE MEASUREMENT DEVICE

By

Jacob John Mayer

Approved:

Jeremiah D. Davis
Assistant Professor of Agricultural and
Biological Engineering
(Major Professor)

Joseph L. Purswell
Agricultural Engineer at USDA ARS
Poultry Research Unit
(Thesis Director)

Tami M. Brown-Brandl
Agricultural Engineer at USDA ARS
US Meat Animal Research Center
(Committee Member)

Jonathan W. Pote
Professor of Agricultural and
Biological Engineering
(Committee Member)

Radhakrishnan Srinivasan
Assistant Professor of Agricultural and
Biological Engineering
(Graduate Coordinator)

Lori M. Bruce
Associate Dean for Research and
Graduate Studies of the Bagley
College of Engineering

Name: Jacob John Mayer

Date of Degree: December 9, 2011

Institution: Mississippi State University

Major Field: Biological Engineering

Major Professor: Dr. Jeremiah D. Davis

Thesis Director: Dr. Joseph L. Purswell

Title of Study: QUANTIFYING PHYSIOLOGICAL RESPONSES OF BEEF CATTLE USING A TYMPANIC TEMPERATURE MEASUREMENT DEVICE

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Candidate for Degree of Master of Science

The primary goals of this research were to develop an improved design for measuring tympanic temperature in groups of beef cattle, determine the ideal operating parameters of the new device, and to verify its effectiveness in a research application. Development of the continuous tympanic temperature logger (CTTL) consisted of two steps: identifying a small temperature logger capable of adequate data storage and constructing a probe to hold the logger and fit in the ear canal of a bovine animal. The minimum sampling interval needed to measure tympanic temperature in beef cattle was calculated using Fourier analysis. In addition, the differences in core body temperature between three measurement locations (left ear, right ear, and vagina) were quantified. The CTTL was also used to record the thermoregulatory responses of feedlot heifers with access to shade provided by three different materials.

DEDICATION

I would like to dedicate this research to two incredible women: my amazing wife, Katie, for her unwavering support and understanding over the last two years and my Mom for her never-ending love, encouragement, and prayers. Thanks Mom for the countless hours you spent reading to me as a child. I am confident you are proudly looking down on us from heaven.

ACKNOWLEDGEMENTS

I would like to begin by recognizing my Lord and Savior, Jesus Christ, who died on the cross for my sins. My prayer is that this document would bring Him honor and glory.

I want to thank my Dad for teaching me life's most important lessons (always do what is right, always do your best, and always tell the truth) and when I would not have it any other way, beating them into me. You have shown me by your example that you cannot put a price tag on integrity. Thanks for instilling a passion for agriculture in me; it has made me the person I am today. I would also like to extend a special thanks to my brother, Tedd, for reminding me not to sweat the small stuff. You are always welcome to move into the basement.

I especially want to recognize my committee members: Jeremiah Davis, Jody Purswell, and Tami Brandl for going above and beyond in their efforts to get me to this point. You have been more than just advisors; you are friends and that has been a tremendous blessing in my life. I would also like to say thank you to Trey Koury for being an awesome sidekick in this adventure. To my peers and fellow graduate students: Jason Ward, Brian Luck, Drew Massey, Wes Lowe, Chris Ryals, and Daniel Chesser thanks for always being there when I needed someone to lend a hand.

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I want to extend a special note of gratitude to my grandparents, Melvin and Lois Mayer, for being such an inspiration to me and to the countless number of family members and friends that have helped me along the way especially with your prayers: Jody and Nathan Harris, Billy and Cynde Ray, Tonia Ray, Bill and Deb Mayer, Abby Priebe, Bill and Jean Mangold, Tammy Roberts, Todd and Jennifer Boyd, Dick and Pensie Herbel, Carl and Kathy Larsen, the Clark family in Montana, the Arb family in Kansas, the Freund family in Iowa, Paul Anderson, Andy Kuntz, Amanda King, Craig and Jacque Homan, Brian and Jennifer Conrad, Bradley House, Suzie Sorey, Bree Willcutt, and Regan Belton. God has truly surrounded me with an incredible group of people. I pray that grouping everyone together in no way diminishes your individual contributions and the impact they have made on me.

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CHAPTER I

INTRODUCTION TO RESEARCH

In 2010, the value of U.S. cattle and calf production was $37.0 billion (USDA-NASS, 2011). Most cattle destined for meat production in the U.S. are grown to their finished size at a feedlot. In a feedlot cattle are fed a nutrient rich diet formulated especially for specific groups of animals. Cattle feeding operations are primarily located in the Plains states due to the availability of feed grains, the locations of packing plants, and the climatic and geographic conditions that favor cattle feeding (Field, 2007).

Disease can prevent cattle from maximizing their genetic potential and production efficiency. Economic and production losses result from diseases such as Bovine Viral Diarrhea Virus (BVDV) and Bovine Respiratory Disease (BRD). Schneider et al. (2009) reported the potential decrease in performance and carcass merit were associated with a decline of $23.23, $30.15, and $54.01 in carcass value when comparing cattle never treated for BRD with cattle treated once, twice, and 3 or more times, respectively.

Feedlots train their employees to visually inspect, identify, and treat sick animals with antibiotics prescribed by a licensed veterinarian. However, human evaluation of livestock is subjective. Upon the onset of disease it is common for unhealthy cattle to mask their symptoms in the presence of humans as a result of the predator-prey response making detection of the illness even more difficult. An abnormal temperature is a primary objective indicator of a health problem (Field, 2007).

Fever is perhaps the best-known characteristic of disease (Atkins and Bodel, 1972). Cattle are considered febrile when their body temperature exceeds one degree above the upper critical temperature (Field, 2007). Early recognition of disease could prevent economic losses from mortality and morbidity (Davis, 2003). Quick detection is critical to maximizing the efficacy of the available treatment options and providing the highest level of animal health and well-being possible. Seawright (1977) recognized the potential value of an electronic method for identifying febrile animals. Creating a tool to aid in the evaluation of a bovine animal's health status could reduce the beef industry's reliance on human judgment.

The potential applications for a temperature measurement device extend far beyond disease detection. Mitchell et al. (2001) concluded that remote monitoring of physiological signals in livestock was a major advance in the assessment of stress and welfare in commercial production systems during procedures such as handling, transport, and slaughter. Much like disease, animals that are heat stressed alter their behavior, spending less time eating and lying down (Brown-Brandl, 2006). These behaviors lead to losses in production. St-Pierre et al. (2003) estimated the annual total economic loss from heat stress to be $370 million in the beef industry. In regard to heat stress, early identification could provide producers with the information needed to deploy appropriate management techniques such as shade or sprinklers to protect vulnerable animals.

Prior to the large-scale implementation of a temperature monitoring system, research must be conducted to establish a foundation of information. This research increases and improves the body of knowledge about the physiological responses of beef cattle. Chapter two provides an overview of the development and characterization of a research device that is low cost, easy to install, and can be implemented in group housed bovine animals. Chapter three demonstrates one application of the device in a research feedlot.

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CHAPTER II

DEVELOPMENT AND CHARACTERIZATION OF A CONTINUOUS TYMPANIC TEMPERATURE LOGGER (CTTL) FOR BEEF CATTLE

Abstract

Developing a research tool that is low cost, easy to install, and can be implemented in group housed animals is important to quantify parameters needed to promptly assess animal health and well-being. However, a practical and cost-effective solution for monitoring large numbers of animals in a production setting has not been developed. A two-part device, consisting of a temperature logger housed in a molded foam probe, was developed to measure tympanic temperature (T_T) in grouped beef cattle. Three experiments were performed to evaluate the properties of the device. Testing determined a minimum effective sampling interval of 2.5 minutes. A standard temperature offset between the left or right ear as the point of measurement was unable to be calculated because of the high level of variability among the cattle used in the project. Asymmetry in T_T was observed in the cattle used in this research. When compared with vaginal temperature (T_V), tympanic temperature was generally lower, but the magnitude of the offset ranged widely between animals.

Introduction

Prompt recognition of disease and distress is crucial enhancing animal well-being, and its importance is reinforced by the economic impact of disease and heat stress in the beef industry. Financial losses resulting from diseases such as Bovine Viral Diarrhea Virus (BVDV) and Bovine Respiratory Disease (BRD) are economically significant. Losses solely from decreased performance in feedyard calves to animals that were persistently infected (PI) with BVDV were estimated to be $88.26 per animal (Hessman et al., 2009). Similarly, net profit was reduced by $57.48 per animal for steers treated for BRD (Faber et al. (1999). Additionally, Busby and Loy (1996) estimated direct losses of $2.8 million and production losses of $28 million during a 1995 heat wave in which over 3,500 head of cattle perished from hyperthermia. Developing a research tool that is low cost, easy to install, and can be implemented in group housed animals is important to quantify parameters needed to promptly assess these issues.

One approach has been to monitor the core body temperature (T_{CB}) of livestock. Core body temperature is a gauge of the animal's energy balance. Measuring T_{CB} can reveal an animal's thermoregulatory reaction to a given stimulus. Core body temperature has been used by livestock researchers to study thermal stress (Hahn et al., 1992, Brown-Brandl et. al, 2001), predict estrus (Kyle et al., 1998), and as a threshold for treatment of disease (Galyean et al., 1995). A method for remote, continuous monitoring of T_{CB} would enable livestock producers to identify stressed or sick animals to aid in early diagnosis and proper treatment. However, a practical and cost-effective solution for monitoring large numbers of animals in a production setting has not been developed (Mader et al., 2006).

Three body locations have typically been used by researchers to measure T_{CB} in beef cattle without surgical intervention; the vagina, the rectum, and the ear canal adjacent to the tympanic membrane (Davis et al., 2003). Vaginal temperature (T_V) measurement is restricted to female animals and thus limits its use. Female animals account for less than 40% of the cattle on feed in U.S. feedlots with capacities over 1,000 animals (USDA-NASS, 2011). Rectal temperature (T_R), though the most common index of T_{CB} in cattle, is not feasible for animals in grouped settings or for long durations of time (Brown-Brandl et al., 2001). Guidry and McDowell (1966) concluded that because of shorter response times T_T was more suitable than T_R for determining the thermal responses of cattle to both internal and external temperature changes. Tympanic temperature has been shown to reflect thermoregulatory responses not apparent in T_R (Hahn et al., 1990). Myers and Henderson (1996) reported T_T to be a more accurate predictor of thermoregulatory status than other sites because of the anatomical proximity of the tympanic membrane and the hypothalamus.

Techniques for measuring T_T were developed by Wiersma and Stott (1983) and revised by Paul (1999) and Davis et al. (2003). The method used by Davis et al. (2003) required each animal to be restrained while a temperature probe was inserted near the tympanic membrane, the ear canal was filled with prosthetic foam, and the foam was allowed to set (Figure 2.1). Although this procedure proved to be an effective way to collect thermal data, installation and removal was time consuming and labor intensive. Hahn et al. (1990) discussed the need for development of practical tools for continuous measurements of physiological responses from unrestrained animals. The current research efforts focused on creating an improved device for measuring T_T in beef cattle.

Figure 2.1

Installation of T_T Probe by Davis et al. (2003)

Objectives

The objectives of this project were to develop a self-contained and easy to deploy probe capable of recording and storing T_T data from bovine animals in a group setting, determine minimum sampling interval needed to measure T_T in beef cattle, and quantify the differences between three different measurement locations: the ear (left and right) and vagina.

Materials and Methods

Development of a self-contained continuous tympanic temperature logger (CTTL) consisted of two steps. First, identify a small temperature logger capable of sufficient data storage. Second, a probe must be constructed to fit in the ear canal of a bovine animal.

Temperature Measurement

A miniature temperature logger (DS1922L iButton, Maxim Integrated Products, Dallas, TX) was used to measure and record T_T data. Arias, et al. (2009) used the same type of logger to investigate the effects of environmental factors on T_{CB} in feedlot cattle. Each logger has a diameter of 17.35 mm (0.68 in), a depth of 5.89 mm (0.23 in), and weighs 2.89 g (0.1 oz). The loggers are capable of internally storing 2^{12} (4096) readings at a user-defined interval over a range of temperatures from -40 °C (-40 °F) to 85 °C (185 °F). Measurements have a resolution of 0.0625 °C (0.1125 °F) and a reported accuracy of ± 0.5 °C (0.9 °F). The reported logger battery life is two to over five years depending on the sampling frequency used. Additionally, each logger has a unique 64 bit hex identification number. The loggers were launched and downloaded using micro-T software (NexSens Technology, Inc., Beavercreek, OH).

Logger calibration was performed in a heated and refrigerated water bath (Isotemp 3013D, Fisher Scientific, Pittsburgh, PA) using the comparison method (Dally et al., 1993). The loggers were evaluated from 35 to 45 °C (95 to 113 °F) in 0.25 °C increments. The temperature was changed every 20 min on a ramp and soak pattern shown in Figure 2.2. The recorded temperature for each logger was compared with water bath temperature 15 minutes after each set point change to allow the bath temperature to stabilize. Linear regression equations (Table 2.1) were generated using PROC GLM in PC-SAS (v9.2, SAS Institute, Cary, N.C.).

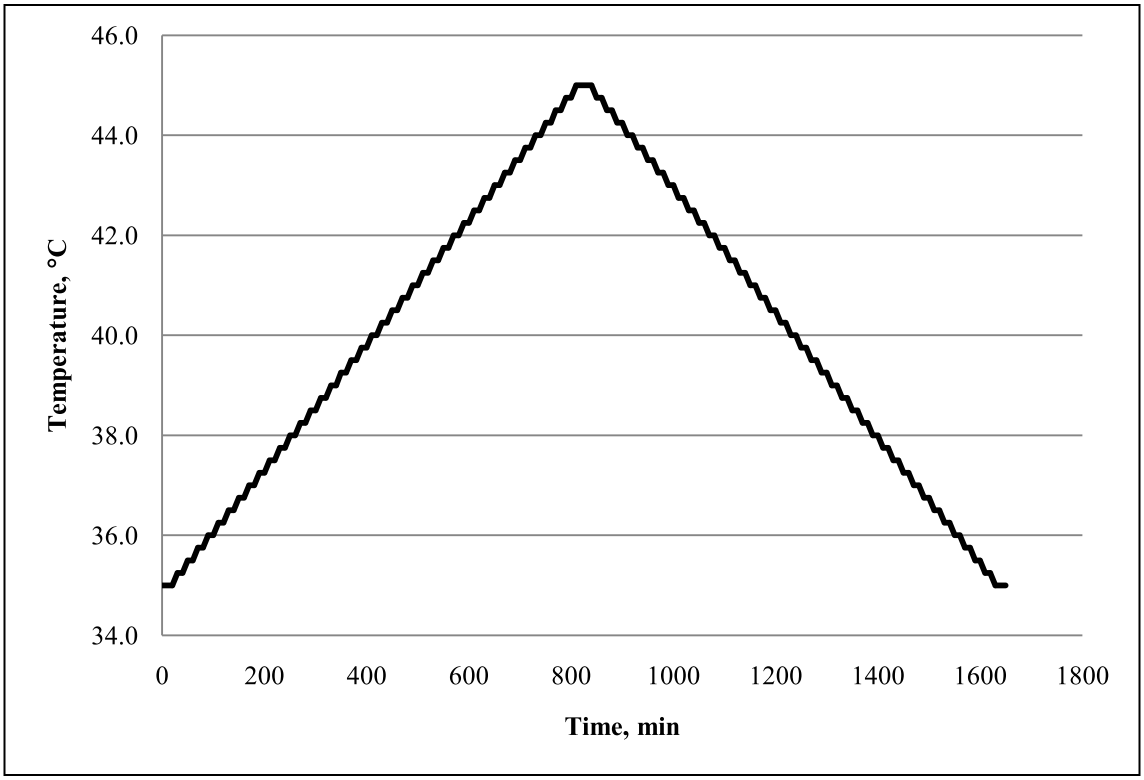


Figure 2.2

Illustration of the Ramp and Soak Set Points Measured by an iButton Logger in a Water Bath during the Calibration Protocol

Table 2.1

Linear Regression Coefficients for iButton Loggers

Trial 1			
iButton ID	**Slope**	**Intercept**	**R^2**
D5A18	1.00	0.34	0.99
D364F	1.01	0.23	0.99
D5418	1.00	0.26	0.99
D6ABB	1.00	0.36	0.99
D5FF4	1.00	0.28	0.99
D64C5	1.00	0.28	0.99

Trial 2			
iButton ID	**Slope**	**Intercept**	**R^2**
3C8F3	1.01	0.16	0.99
3C4F1	1.00	0.00	0.99
3B093	1.01	0.00	0.99
D64A7	1.01	0.32	0.99
1B157	1.01	0.32	0.99
3BCFA	1.01	0.16	0.99
3C826	1.00	0.24	0.99
3BCB2	1.01	0.24	0.99
3BC31	1.00	0.00	0.99
3C76A	1.01	0.13	0.99
3C9EF	1.00	0.27	0.99
D5B6F	1.01	0.27	0.99
1B39C	1.00	0.39	0.99
3CACF	1.01	0.17	0.99
1A71A	1.00	0.35	0.99
3C02A	1.00	0.00	0.99
3C092	1.01	0.00	0.99
3C42F	1.00	0.00	0.99
3BE4E	1.00	0.00	0.99
D67A1	1.00	0.31	0.99
3C2CA	1.00	0.30	0.99
D7441	1.01	0.29	0.99
D53B6	1.00	0.36	0.99
3BC78	1.00	0.25	0.99

Trial 3			
iButton ID	**Slope**	**Intercept**	**R^2**
B36D2	1.00	0.38	0.99
B1CAB	1.00	0.34	0.99
B3B31	1.00	0.41	0.99
B028E	1.00	0.32	0.99

Ear Probe Development

Bovine ears were obtained from a commercial beef packer to develop the probe. The source cattle were mostly Brahman (*Bos indicus*) influenced and the slaughter weight of these animals was approximately 545 ± 45 kg (1200 ± 100 lbs). The ears were removed from the head near the skull to retain the ear cavity. Twelve right ears were randomly selected to create hard plastic castings of the internal ear cavity (Figure 2.3 A). Casting resin (Smooth Cast 300, Smooth-On Inc., Eaton, PA) was mixed and poured into each ear and allowed to cure. Each casting was removed from the ear and two physical measurements were made at the base of the ear canal (Figure 2.4) using calipers (ABSOLUTE Digimatic Caliper, No. 500-196-20, Mitutoyo Corp., Kawasaki, Japan).

Using the ear canal measurements, a representative ear was selected from the group to create a silicon rubber (OOMOO® 25 Silicon Rubber, Smooth-On Inc., Eaton, PA) probe blank (Figure 2.3 B). The internal ear cavity was removed from the casting at the plane of measurement (Figure 2.4). This created a surface to install a temperature logger. A hard plastic mold was created using casting resin (Figure 2.3 C). The mold was split with a band saw and the ear canal casting was removed. Prosthetic foam (A-2370, Factor II Inc., Lakeside, AZ) was then injected into the mold to produce a replica probe of the original cast (Figure 2.3 D). The process was repeated to create the form required to make left ear probes.

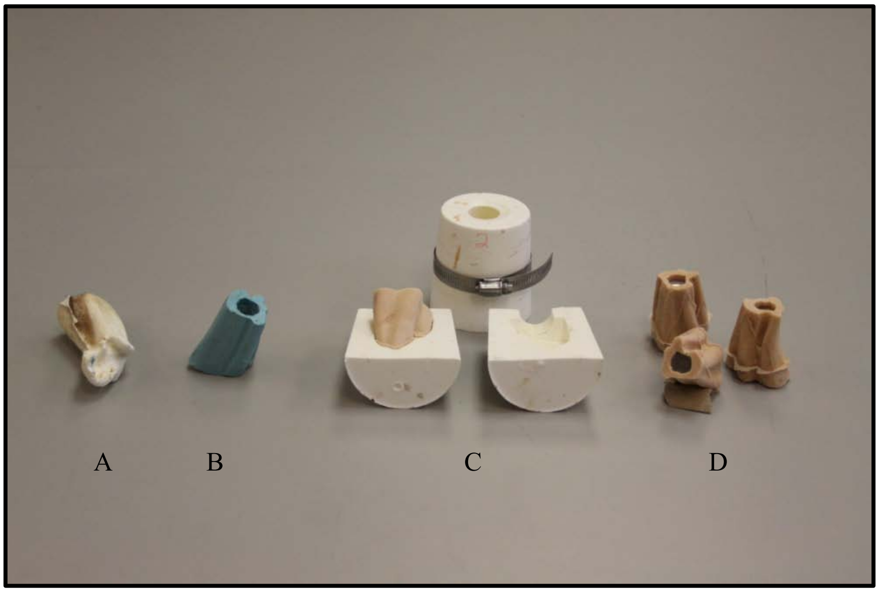


Figure 2.3

Ear Probe Development Process

*A: Casting of bovine ear canal; B: Silicon rubber probe blank; C: Hard plastic probe mold; D: Prosthetic foam probes.

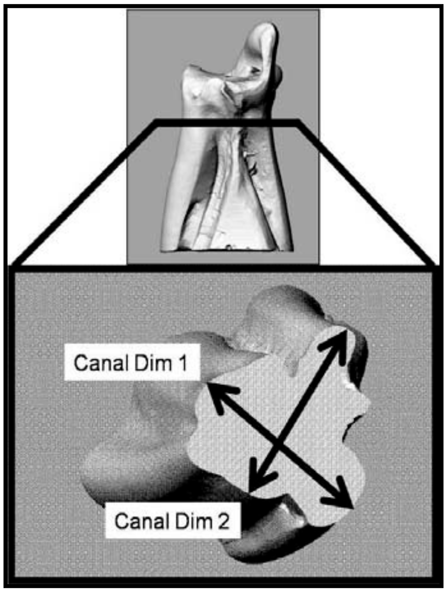


Figure 2.4

3D Scan of Ear Canal Casting and Cross Section with Measurement References

Vaginal Probe Development

Vaginal temperature was chosen as the T_{CB} measurement because it can be easily employed in female animals in a group setting. When compared to T_R, T_V has an offset of -0.17 °C (0.3 °F), (Kriss, 1921). Vaginal temperature probes were constructed with an iButton temperature logger fastened to an inert CIDR® device (Eazi-Breed, Pfizer Animal Health, Madison, NJ), (Kendall et al. 2006; Jousan et al. 2007; McGee et al. 2008). The iButton was secured with a plastic mounting bracket (DS9093 iButton Wall Mount, Maxim Integrated Products, Dallas, TX) attached to the dorsal surface with screws (Figure 2.5).

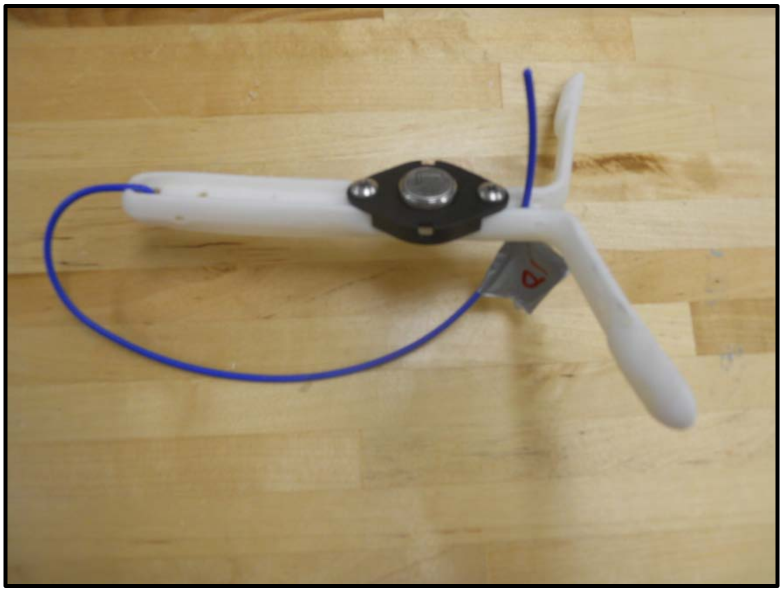


Figure 2.5

Vaginal Temperature Probe

*The iButton is attached to the blank CIDR using a plastic mounting bracket.

Minimum Sampling Interval

Experiment 1

Mean temperature comparisons cannot be used to examine the effect of temporal sampling intervals because T_{CB} has a diurnal circadian rhythm (Piccione et al., 2003). Calculation of the minimum effective sampling interval was based on the spectral analysis approach used by Korthals et al. (1995) in swine. The frequency threshold beyond which the remaining signal components are noise is the minimum sampling rate required to accurately characterize a signal. Hahn et al. (1992) and Korthals et al. (1997) suggest measurement frequencies of 5 to 12.5 minutes and 3 to 15 minutes, respectively, to capture significant thermal events in beef cattle.

Eight *Bos taurus* beef heifers weighing 304.1 ± 12.6 kg (669.0 ± 27.7 lbs) were equipped with a CTTL in the right ear (Figure 2.6). The device was inserted and Vetrap™ (3M™, St. Paul, MN) was wrapped snugly at the base of the ear to keep the CTTL in place. The wrap seam was secured with tape (3M Duct Tape, St. Paul, MN). Data was collected for 48 h at 0.0167 Hz (1/min).


(L) (R)

Figure 2.6

CTTL Installation

*(L): CTTL inserted in the right ear of a research heifer; (R): Vetrap is positioned around the ear to maintain the probe position.

A 2^n sub-set of 2048 minutes was used for analysis (Figure 2.7). Signal power was estimated using Welch's method (Welch, 1967) with a Hamming window of 64 data points (Oppenheim and Schafer, 1989) to produce a periodogram. A window size of 64 points was selected because it closely represents one hour of data and still maintains a record length of 2^n. The data was normalized by subtracting the mean value (DC component) before analysis to reduce the bias and/or variance of the signal power estimate as shown in Figure 2.8 (Marple, 1987). An example plot of frequency versus power shown in Figure 2.9 illustrates the output of the periodogram analysis.

The peak frequency reflects the underlying diurnal temperature cycle observed in bovines and other animals (Wrenn et al., 1961). The initial value of the periodogram was removed as it was not of interest because it lies beyond the peak frequency. An exponential decay relationship (Equation 2-1) was selected to describe the periodogram, as the data typically follow the form of an exponential decay towards and asymptotic minimum. The equation was fit to the periodogram using PROC NLIN in PC-SAS (Figure 2.10).

$$P = P_0 + ae^{-f/\tau} \qquad (2\text{-}1)$$

where:

P = signal power

P_0 = minimum power (noise)

P_1 = maximum power

$a = P_1 - P_0$

f = frequency

τ = decay constant

Per Korthals et al. (1995), the noise floor for the periodogram was set at 10% of the peak frequency value, and sampling frequencies below this threshold were considered random noise. Doubling the decay constant (2τ) indicates the frequency at which a 90% reduction in peak power occurs and the corresponding frequency was used to determine the minimum effective sampling interval for a given animal. Due to the non-linear nature of the function a pseudo coefficient of determination (Pseudo–R^2) was calculated (Equation 2-2), as discussed by Juneja et al. (2009).

$$\text{Pseudo-}R^2 = 1 - (SSE/SSTC) \tag{2-2}$$

where:

SSE = sum of squares error

SSTC = sum of squares corrected total

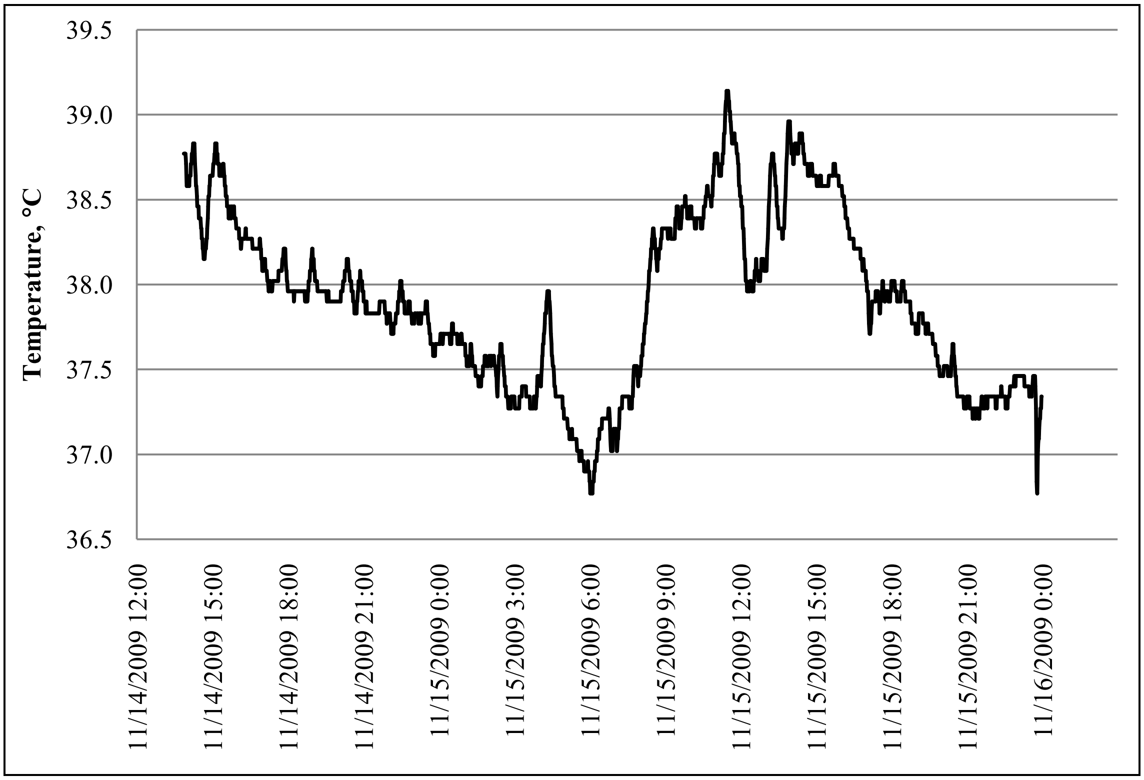


Figure 2.7

Minimum Sampling Interval Determination: Original Tympanic Temperature Profile for Heifer W032 over a 2048 min Period

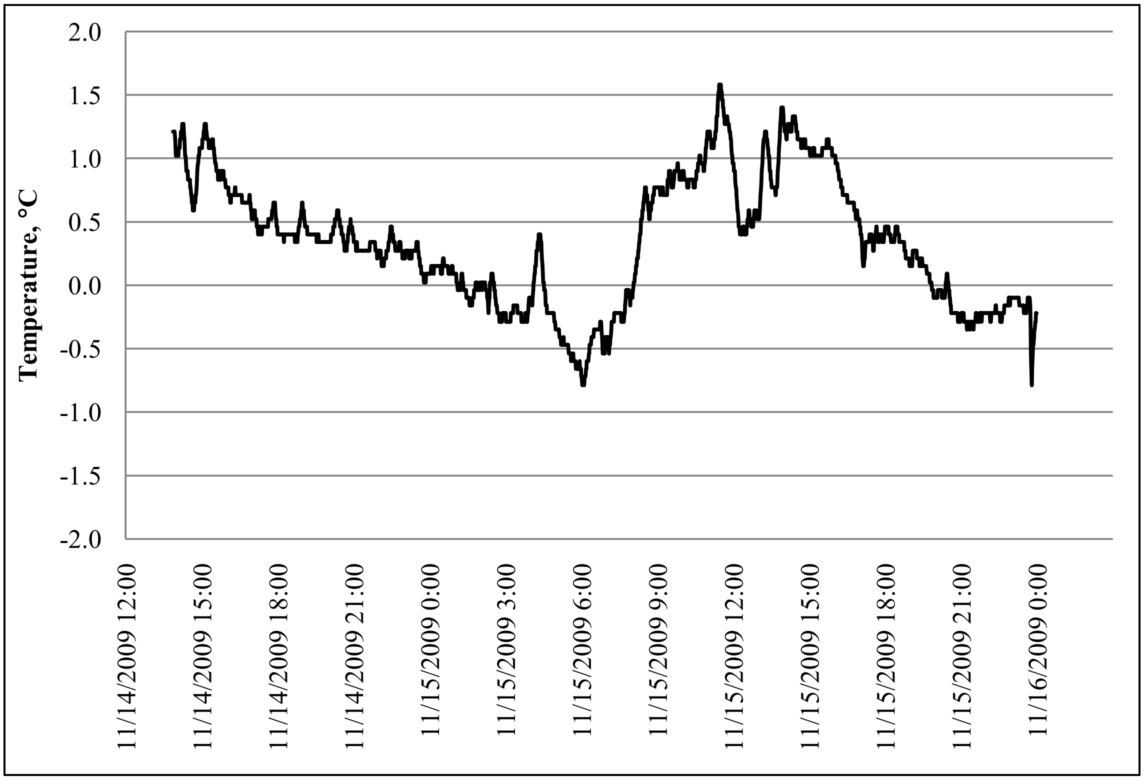


Figure 2.8

Minimum Sampling Interval Determination: Tympanic Temperature Profile after Removal of DC Component in Heifer W032

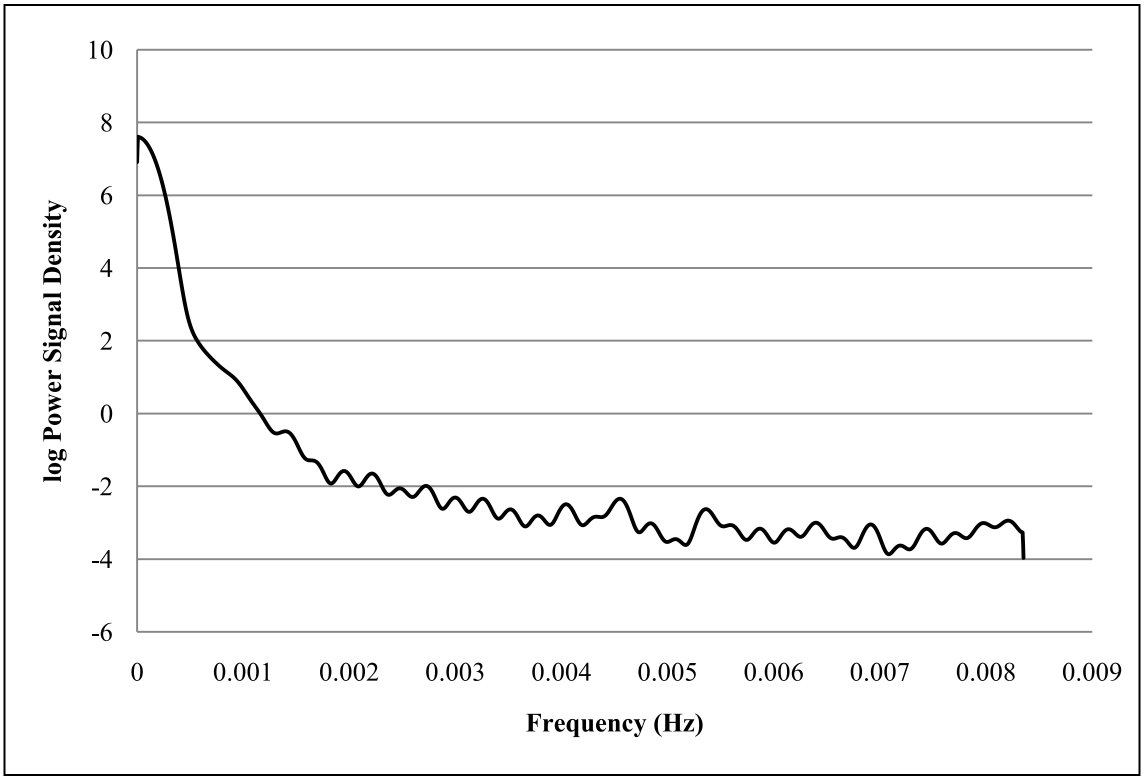


Figure 2.9

Minimum Sampling Interval Determination: Periodogram of Tympanic Temperature for Heifer W032

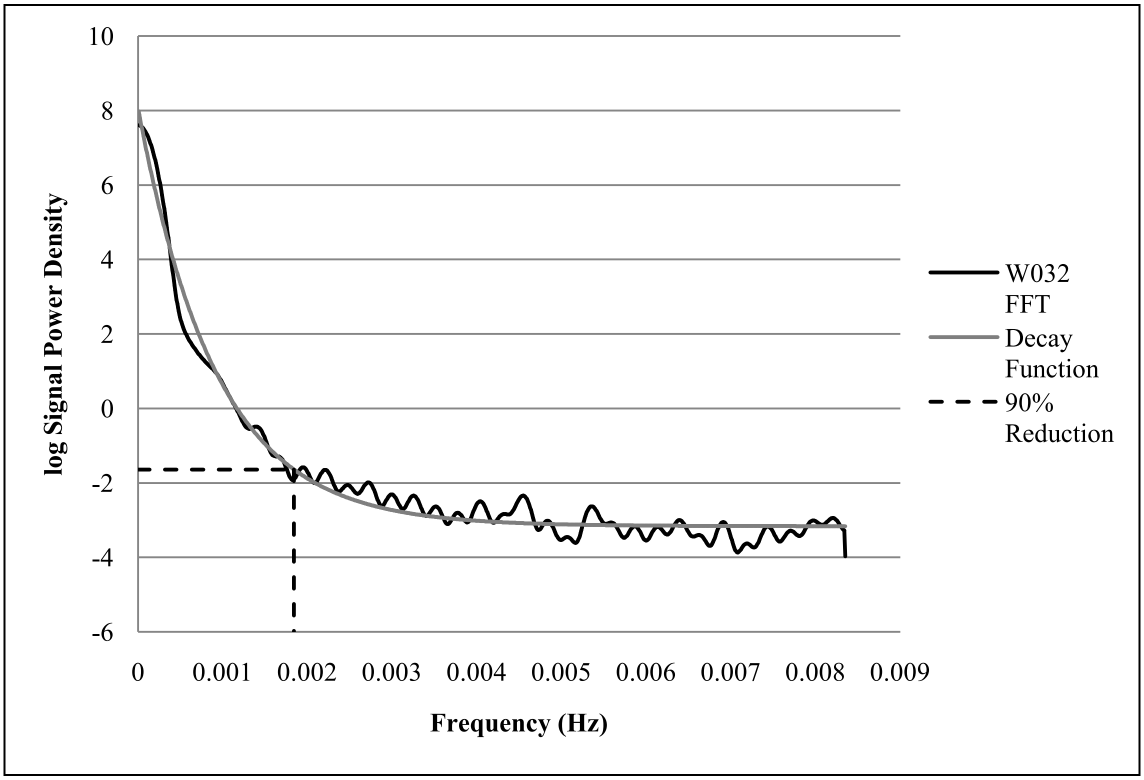


Figure 2.10

Minimum Sampling Interval Determination: Exponential Decay Function Fit to Tympanic Temperature Periodogram for Heifer W032

Experiment 2

Eight *Bos taurus* beef heifers weighing 316.4 ± 11.4 kg (696.0 ± 25.2 lbs) were each fitted with a CTTL in the right ear using the methods established in Experiment 1. The objective was to determine if the minimum sampling interval was affected by the duration of the data collection period. The CTTL was removed from each heifer every 48 h and replaced with a new CTTL for a total of 144 h to compensate for the storage limitations of the data loggers. The data was divided into subsets of three period durations (2048 min [subsets A, B, and C], 4096 min [subsets D and E], and 8192 min). The analysis followed the same procedure as Experiment 1.

Location Comparison

A third experiment was conducted to quantify differences, if any, between T_{CB} measured in the left and right ears and in the vagina. A CTTL was placed in both the left and right ears of eight *Bos taurus* beef heifers weighing 372.2 ± 19.5 kg (818.8 ± 42.9 lbs). Each animal was also equipped with a vaginal temperature probe. Temperature data was collected every minute for 48 h for each of the three locations. The data was summarized by location and differences between locations with descriptive statistics. Additional analysis calculated the period of time an animal spent over the temperature levels of 39.5 °C (103.1 °F) and 40.0 °C (104.0 °F). These thresholds were selected based on their frequent use in beef cattle management as indicators of disease or stress (Le Viness, 1999).

Results and Discussion

Ear Probe Development

Results of the ear canal measurements are reported in Table 2.2. The mean ear canal dimensions were 3.31 cm (1.30 in) and 3.78 cm (1.49 in). Given the small standard error values compared to the means (<5%) it was determined that a one-size-fits-all probe could be used because of the consistency in internal ear dimensions.

Both the silicon rubber (OOMOO® 25) and prosthetic foam (A-2370) products were evaluated for the CTTL with inconsistent results. The durable silicon based probes were much heavier and were more difficult to keep in place due to their weight. The lighter prosthetic foam probes were more likely to remain in place, but durability was a problem. The density and malleability of the prosthetic foam varied between batches even when a consistent manufacturing procedure was used in identical environmental conditions. This caused some of the initial probes to crumble in the ears. Due to their fragile nature and the inability to sterilize them after the initial use, probes made from the prosthetic foam are not reusable. Despite these limitations, the foam probes were the preferred material because of their higher recovery rate.

Table 2.2

Ear Canal Measurements

Mold Number	**Mold Measurement** Dim 1 (cm)	 Dim 2 (cm)
1	3.46	3.81
2	3.31	3.97
3	3.47	3.45
4	3.51	3.65
5	3.29	3.53
6	3.50	4.14
7	3.16	4.15
8	3.48	3.82
9	3.13	3.51
10	3.15	3.82
11	3.56	4.01
12	2.64	3.45
Mean	**3.31**	**3.78**
SE	0.08	0.07

Installation and removal times were reduced from over 20 minutes per animal for the technique described by Davis et al. (2003) to under 5 minutes for the CTTL system (Table 2.3). The cost for the materials required for one CTTL was approximately $50.00, which was less than one of the units used by Davis et al. (2003). The financial and time savings gained from the CTTL were a considerable improvement on previous T_T measurement methods.

Aside from keeping the temperature logger in place, the probe also served another purpose. It also acted as an insulator for the sensor from the ambient air conditions. Commercially available T_T measurement products do not provide an accurate measurement of T_T because they do not adjust for the influence of external conditions and are partially exposed to external weather conditions.

Table 2.3

Cost Comparison of Two Tympanic Temperature Measurement Methods

Davis et al. (2003)		**CTTL**	
Component	**Cost**	**Component**	**Cost**
Prosthetic Foam (30cc)	$5.00	Prosthetic Foam (30cc)	$5.00
Halter	$15.00		
Plastic Enclosure	$10.00		
Nylon Case	$10.00		
Custom Datalogger	$110.00	iButton Logger	$45.00
Thermistor Probe	$25.00		
Total	**$175.00**	Total	**$50.00**
Installation/Removal	**20 - 30 min**	Installation/Removal	**2 - 5 min**

The CTTL worked best in dry weather conditions; when the ear wrap becomes wet it becomes less effective at keeping the probe in place. It is important to make sure the Vetrap™ is pulled snugly around the ear, but not so tight as to restrict blood flow in the ear. Caution should be taken with metal bangs tags (for Brucellosis), common bovine ear tags, and electronic identification tags as the wrap can cause irritation and lesions around these items. Recovery rate is greatly affected by cattle behavior, weather, duration of collection, and installer, but a rate at or above 75% should be considered successful and less than 50% unsatisfactory. When planning future research trials, increasing the number of animals used accordingly would compensate for dislodged temperature loggers.

Minimum Sampling Interval

Experiment 1

Six of the eight CTTL installed were recovered at the end of Experiment 1. Periodogram analysis was performed on 2048 T_T data points for each of the six heifers. Table 2.4 summarizes the required sampling interval needed to characterize T_T. The mean required sampling interval was 9.0 ± 0.28 min. However, the Nyquist sampling theory requires a sampling frequency two times faster than maximum frequency to avoid aliasing (Dally et al., 1993). Therefore, the minimum effective sampling interval needed for the animals used in this trial would be one temperature reading every 4.5 minutes. This would extend the maximum study period from 68.3 h (1-min sample) to 307.2 h without the need to download data.

Table 2.4

Required Sampling Interval for Each Animal in Trial 1

Animal ID	**Data Length (min)**	**Required Sampling Interval (min)**	**Pseudo R^2**
W005	2048	9.8	0.987
W032	2048	9.0	0.980
W044	2048	9.7	0.968
W058	2048	9.1	0.968
W059	2048	7.9	0.990
W060	2048	8.5	0.992
	Mean	**9.0**	
	SE	0.28	

Experiment 2

Only four of the eight CTTL were reclaimed at the conclusion of Experiment 2. Although a different group of cattle were used from Experiment 1, similar results were expected. Two subsets, A (n = 2048) and D (n = 4096) produced an outcome inconsistent with the other subsets in the initial analysis. Upon closer examination of T_T and weather data, a significant rainfall event occurred during the first day of this experiment. This caused a substantial drop in T_T for all four heifers. Subsets A and D were removed from the final analysis because the inconsistency in environmental conditions distorted the comparison between subsets. However, since all the animals were exposed to the same weather pattern over the entire data collection period, day one was included in the largest subset (n = 8192).

The sampling interval for the shortest subsets (B and C) was 10.6 ± 0.28 min with a Psuedo $R^2 = 0.975$ (Table 2.5). This translated to an effective sampling interval of one reading every 5.3 minutes, similar to Experiment 1. Subset E (n = 4096) was also comparable with a minimum effective sampling interval of 5.2 ± 0.26 minutes (Table 2.6). Contrary to the smaller data sets, the findings from the analysis of the full data set (n = 8192) demonstrated a required sampling rate of 5.4 minutes (Table 2.7). The effective sampling rate was 2.7 ± 0.31 min, approximately half that from the short term results. These results are likely in part due to the rainfall event during the first day. As the length of the measurement period increases, the probability of some sudden change in thermal state occurring also increases, and a faster sampling interval is required to accurately capture the animal’s response. This sampling frequency is also slightly lower than those previously reported in the literature (5 to 12.5 min, Hahn et al., 1992; and 3 to

15 min, Korthals et al., 1997). However, previous studies were conducted in environmentally controlled chambers where weather was not an influence. Future research using the CTTL should apply a minimum sampling interval of one temperature measurement every 2.5 min.

Table 2.5

Required Sampling Interval for Each Animal in Trial 2 (Subsets B and C)

Animal ID	**Sub-Set**	**Data Length (min)**	**Required Sampling Interval (min)**	**Pseudo R^2**
X056	B	2048	11.6	0.970
X068	B	2048	12.0	0.965
X097	B	2048	10.3	0.966
X116	B	2048	11.0	0.970
X056	C	2048	9.8	0.979
X068	C	2048	10.6	0.982
X097	C	2048	9.8	0.988
X116	C	2048	10.2	0.980
		Mean	**10.6**	
		SE	0.28	

Table 2.6

Required Sampling Interval for Each Animal in Trial 2 (Subset E)

Animal ID	**Sub-Set**	**Data Length (min)**	**Required Sampling Interval (min)**	**Pseudo R^2**
X056	E	4096	10.2	0.979
X068	E	4096	11.0	0.977
X097	E	4096	9.8	0.981
X116	E	4096	10.3	0.979
		Mean	**10.3**	
		SE	0.26	

Table 2.7

Required Sampling Interval for Each Animal in Trial 2 (Entire Data Set)

Animal ID	**Data Length (min)**	**Required Sampling Interval (min)**	**Pseudo R^2**
X056	8192	5.1	0.988
X068	8192	6.0	0.980
X097	8192	5.7	0.985
X116	8192	4.7	0.987
	Mean	**5.4**	
	SE	0.31	

Location Comparison

All of the temperature loggers that were used in Experiment 3 were recovered. Each location (left ear, right ear, and vagina) proved to be suitable to collect temperature data (Figure 2.11). Results from the third trial are displayed in Table 2.8. Vaginal temperature was less variable than T_T. Differences were calculated between each of the three location combinations for each animal (Table 2.9). The mean difference between the left and right ear was only 0.1 °C, but ranged greatly from +0.58 to -1.06 for the group of eight heifers.

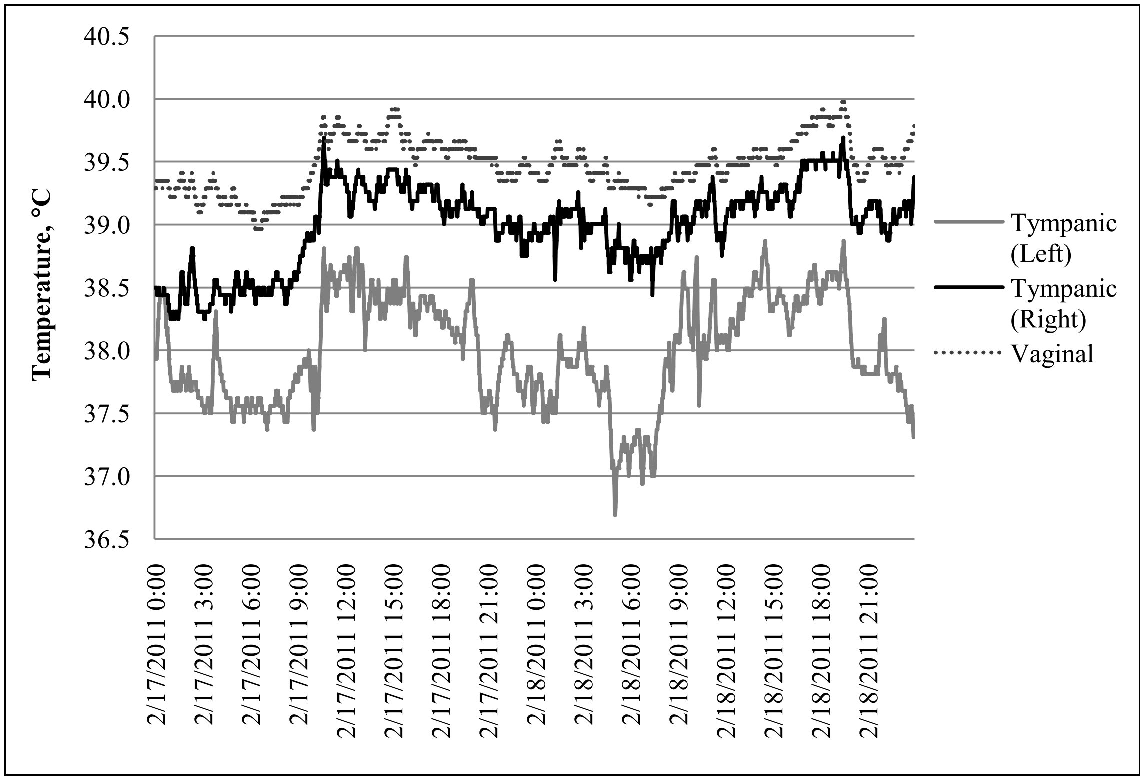


Figure 2.11

Temperature Signal for Heifer X039 at Three Locations (Left Ear, Right Ear, and Vagina)

Table 2.8

Mean Temperature for Each Location for Eight Heifers

Location	**Heifer Means**								**Group Means**
	X004	X012	X013	X019	X021	X036	X037	X039	
Left Ear	38.46	37.74	37.71	39.01	38.43	37.99	39.07	38.59	38.38
Right Ear	38.07	38.13	38.77	38.61	38.39	38.99	38.49	38.34	38.47
Vagina	38.85	39.12	39.43	39.72	39.29	39.47	39.18	39.32	39.30
Location	**Heifer Standard Deviation**								**Group Means**
Left Ear	0.75	0.82	0.69	0.54	0.72	0.42	0.41	0.39	0.59
Right Ear	0.77	0.47	0.61	0.52	0.62	0.32	0.58	0.31	0.53
Vagina	0.20	0.19	0.34	0.26	0.40	0.21	0.28	0.14	0.25
Location	**Heifer Spans**								**Group Means**
Left Ear	3.46	4.03	3.43	2.26	3.06	2.18	2.32	1.88	2.83
Right Ear	3.74	2.37	2.83	2.12	2.86	1.44	3.18	1.44	2.50
Vagina	0.87	0.87	1.76	1.26	1.75	1.01	1.25	0.63	1.17

*Span = (Max Temp – Min Temp)

Table 2.9

Locational Differences in Mean Temperature for Eight Heifers

Difference	Heifer Means								Group Means
	X004	X012	X013	X019	X021	X036	X037	X039	
Left Ear - Right Ear	0.39	-0.38	-1.06	0.40	0.05	-1.00	0.58	0.25	-0.10
Vagina - Left Ear	0.39	1.37	1.73	0.71	0.86	1.48	0.11	0.73	0.92
Vagina - Right Ear	0.77	0.99	0.67	1.12	0.90	0.48	0.69	0.99	0.83
Difference	**Heifer Standard Deviations**								**Group Means**
Left Ear - Right Ear	0.25	0.42	0.29	0.08	0.19	0.31	0.23	0.19	0.25
Vagina - Left Ear	0.63	0.71	0.48	0.49	0.51	0.31	0.21	0.31	0.46
Vagina - Right Ear	0.63	0.35	0.33	0.48	0.46	0.17	0.40	0.22	0.38
Difference	**Heifer Spans**								**Group Means**
Left Ear - Right Ear	1.80	2.32	2.51	0.69	1.25	2.23	1.43	1.26	1.69
Vagina - Left Ear	3.15	3.66	3.06	2.08	2.18	1.93	1.14	1.63	2.35
Vagina - Right Ear	3.43	1.94	1.71	1.87	2.31	0.89	2.05	1.26	1.93

*Span = (Max Diff – Min Diff)

Asymmetry in T_T in bovine animals is consistent with the recorded differences between the left and right ears of other mammals. Significant asymmetry was detected in T_T in both Rhesus monkeys and human children, with left-sided temperatures measuring significantly higher than those from the right tympanic membrane (Boyce et al., 1996). A significant difference was found between left and right T_T in chimpanzees when they were exposed to negative stimuli (Parr and Hopkins, 2000). In marmosets, T_T measured in the right ear was significantly higher than the left (Boere et al., 2003). This difference was also attributed to increased and non-symmetrical brain activity under stress.

The mean offset between T_V and the left and right ears was 0.92 and 0.83 °C respectively, however these offsets also ranged widely between animals. Bergen and

Kennedy (2000) also reported that the relationship between T_V and T_T varied considerably. Therefore, a standardized offset is not suitable to describe the differences between locations because of the high level of variability in the temperature signals among animals.

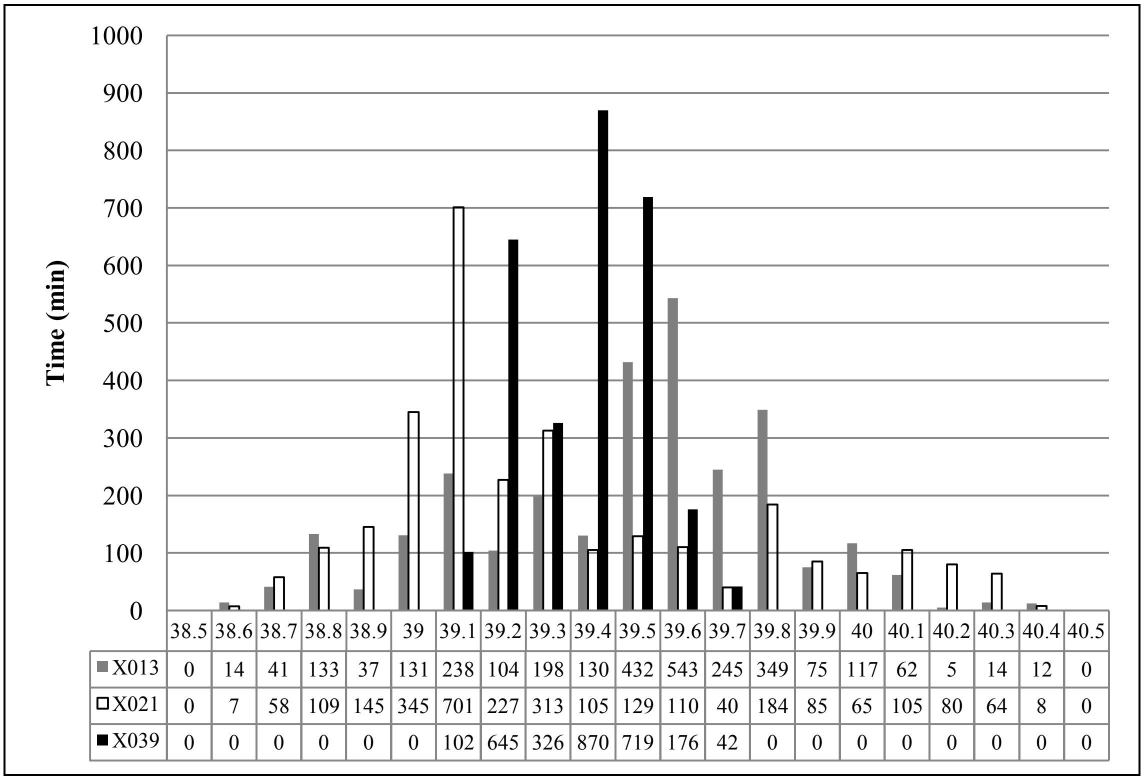
Three animals (X013, X021 and X039) with similar mean and maximum T_V were selected for further analysis (Table 2.10) in using mean temperature to characterize each animal's thermal state, common in both research and animal husbandry. The time that each animal's T_V exceeded temperature thresholds of 39.5 °C and 40.0 °C ranged from 218 to 1,422 min and 0 to 257 min, respectively. Examination of this information suggests that the thermal states of the three heifers are different. A histogram analysis was performed on the T_V for each heifer over the period (Figure 2.12). Visual inspection shows differences in temperature profiles not illustrated in each animal's mean temperature. Daily mean temperatures may not be useful in characterizing the thermal status of an animal for short periods (< 24 h). Additionally, care must be taken when using spot measurements of an animal's temperature as an indicator of average or representative temperature (Kortals et al., 1995). Additionally, given concerns with antibiotic resistance, medicating beef cattle based solely on one temperature measurement would be ill advised.

Table 2.10

Comparison of T_V Signal Summary and Time Spent Above Two Temperature Thresholds for Three Heifers with Similar Mean Vaginal Temperatures

Vaginal Temperature, °C	Heifer X013	 X021	 X039
Maximum	40.35	40.35	39.68
Mean	**39.43**	**39.29**	**39.32**
Minimum	38.59	38.60	39.05
Time above 39.5°C, min	1422	741	218
Time above 40.0°C, min	93	257	0

*Mean Dry Bulb Temperature = 17.1 °C (62.8 °F) and Mean Dew Point Temperature = 11.9 °C (53.5 °F) during Trial 3



	38.5	38.6	38.7	38.8	38.9	39	39.1	39.2	39.3	39.4	39.5	39.6	39.7	39.8	39.9	40	40.1	40.2	40.3	40.4	40.5
▨X013	0	14	41	133	37	131	238	104	198	130	432	543	245	349	75	117	62	5	14	12	0
□X021	0	7	58	109	145	345	701	227	313	105	129	110	40	184	85	65	105	80	64	8	0
■X039	0	0	0	0	0	0	102	645	326	870	719	176	42	0	0	0	0	0	0	0	0

Figure 2.12

Vaginal Temperature Histogram for Three Animals of Interest from Trial 3

The high level of variability in the temperature signals both within and between animals presents difficulty characterizing, modeling, and with subsequent prediction of thermal status. Future research should be directed towards characterizing T_T profiles of beef cattle using signal analysis for different phenotypes and growth stages.

One of the primary limitations with the CTTL is the storage limitation of the logger. Although other temperature sensor and storage options are available, these alternatives can quickly become increasingly expensive and complex. While it is important to sample at a frequency fast enough to capture any sudden changes in an animal's thermal state, it may be unnecessary to have a high sampling interval during periods of rest or sleep. Developing sampling methods and equipment to implement variable frequency sampling schemes would better utilize storage capacity and battery life to extend the length of data records.

Conclusion

The ear canal dimensions of mature beef cattle were found to exhibit little variation, and were used as a basis for the development of a device to measure T_T in beef cattle. The CTTL can be effectively used to measure T_T in group housed animals in both the left and right ears. However, CTTL probes made from prosthetic foam probe have limited durability. The CTTL is cheaper, faster, and easier to install or remove when compared to past methods. Periodogram analysis determined a sampling rate of one measurement per every 2.5 minutes is sufficient to characterize dynamic response of T_T. The necessary sampling rate is affected by any event that causes a sudden change in the thermal state of an animal. For longer study durations, a shorter sampling interval may be required when there is an increased potential for the occurrence of such events.

Differences in T_T between left and right ears exhibited a high level of variability among the animals used in this study. Vaginal temperature was consistently higher and less variable than T_T. A standardized difference between T_T and T_V was not calculated due to the high level of variability in T_T data. Additional research should be conducted to better understand the thermal signals of beef cattle and their role in assessing animal health.

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CHAPTER III

PHYSIOLOGICAL RESPONSES OF FEEDLOT HEIFERS TO THREE SHADE MATERIALS

Abstract

Heat stress in cattle can cause decreased feed intake and growth, and in extreme cases death. Shade has been used to reduce heat stress in beef cattle. However, the cost and maintenance of shades has deterred many producers from using them. The objective of this experiment was to determine the thermoregulatory response of feedlot heifers with access to three common shade materials. Thirty-two Black Angus heifers were randomly assigned to one of four treatments (no-shade access, 25, 60, 100% shade effectiveness). Responses monitored included vaginal temperature (T_V) and tympanic temperature (T_T). Body temperature was recorded every minute using a vaginal temperature probe and every five minutes using a Continuous Tympanic Temperature Logger (CTTL). On days that had a maximum THI greater than 84 (Emergency category) mean T_T and T_V were lowest in the 100% shade treatment pen. From 12:00 to 18:00 on Emergency days, all three shade materials were effective at decreasing heat stress in feedlot heifers when compared to no-shade access.

Introduction

Heat stress in cattle can cause decreased feed intake and growth, and in extreme cases can cause death (Brown-Brandl et al., 2005). Heat stress occurs when the weather patterns change suddenly and the temperature increases rapidly, or temperatures remain hot for several consecutive days with little or no relief at night (Brown-Brandl et al., 2010). During these periods, incident solar radiation may exceed metabolic heat production by several times (Blackshaw and Blackshaw, 1994). A simple shade can reduce the animal's radiant heat load by 30% or more (Bond et al., 1967). Mader et al. (1999) recommended the use of shades to reduce the effects of heat on feedlot cattle. However, the cost and maintenance of shades has restricted adoption among producers.

In June of 2009, a heat wave killed 4,000 head of cattle in high plains feedlots. Similar disasters occurred in Kansas in July 2010 and Iowa during August 2011 when 2,000 and over 3,500 head perished respectively. St-Pierre et al. (2003) estimated the annual total economic loss from heat stress to be $370 million in the beef industry. Although shade has been shown to be an effective tool for dealing with heat stress (Mitlöehner et al., 2002, Brown-Brandl et al., 2005), it has seen limited acceptance. One suggestion to increase the use of shade structures is development of a more cost-effective system that requires less maintenance. Using materials familiar to the agriculture sector would help address these concerns.

Kelly and Bond (1958) evaluated a series of 36 artificial shade materials for effectiveness. While this was a very comprehensive study, the types of shade cloths available today are very different from those tested in that study. Eigenberg et al. (2009) measured weather conditions under three different types of shade cloth and then using a previously developed equation, predicted lower animal respiration rates under the different treatments compared to conditions observed without shade. The study predicted that as the percentage of solar radiation blocked increased the stress level would decrease. However, that research has not been validated by measuring animal thermoregulatory responses under the tested shades. The current experiment was designed to assess the effectiveness of these three types of shade cloths, used by Eigenberg et al. (2009), by monitoring animals' physiological responses.

Objective

The objective of this project was to determine the thermoregulatory response of feedlot heifers with access to three different shade materials by measuring tympanic temperature and vaginal temperature.

Materials and Methods

Data were collected during four two-week periods from thirty-two heifers during the summer of 2010 at the U.S. Meat Animal Research Center (MARC) feedlot near Clay Center, Nebraska. The experiment utilized a 4 × 4 Latin Square design with time period and pen as the control factors. Each animal was assigned to one of four pens based on their weight for a total of eight animals in each pen. A different shade treatment was applied to each of the four research pens. The heifers were rotated to a new pen at the end of every period in such a way that all of the animals were exposed to each treatment during the course of the experiment (Table 3.1). The physiological parameters measured during the experiment were vaginal temperature (T_V) and tympanic temperature (T_T).

Table 3.1

Feedlot Heifer Movement between Shade Treatments During the Experiment

Period	**Week**	**Date**	**Shade Treatment**			
			0%	25%	60%	100%
1	1	June 23 - June 30	Group #1	Group #2	Group #3	Group #4
	2	June 30 - July 7				
2	3	July 7 - July 14	Group #2	Group #3	Group #4	Group #1
	4	July 14 - July 21				
3	5	July 21 - July 28	Group #3	Group #4	Group #1	Group #2
	6	July 28 - Aug. 4				
4	7	Aug. 4 - Aug. 11	Group #4	Group #1	Group #2	Group #3
	8	Aug. 11 - Aug. 18				

Animal and Facility Description

Brown-Brandl et al. (2006) reported that dark colored animals are more susceptible to heat stress than other colors, thus Black Angus heifers were selected for this experiment. The cattle initially weighed 478.0 ± 25.1 kg (1053.9 ± 55.4 lbs). Prior to the start of the experiment, the animals were evaluated for temperament. Each animal was assigned a score from 1 – 5 based on their behavior when restrained in a hydraulic squeeze chute (Voisinet et al., 1997). A score of 1 was defined as calm, no movement and increased incrementally to 5, which was scored when the animal was rearing, twisting, or violently struggling. The mean score for all animals was 2.3 ± 0.9.

All heifers were implanted with a growth promotant, Finaplix-H (Merck Animal Health, Summit, NJ), before the experiment began. Cattle were fed twice daily, once in the morning and again in the afternoon, in such a manner that feed was not limiting. The ration consisted of approximately 78.0% corn or high moisture corn, 17.5% corn silage, and 4.5% liquid supplement on a dry matter basis. The heifers also received melengestrol acetate (MGA) in the feed to suppress the estrous cycle and encourage weight gain

(O'Brien et al., 1968). Water was provided on an ad libitum basis using an automatic fountain (Ritchie Industries, Inc., Conrad, IA) located in the west fence line of each pen and under the shade structure. Feed bunks were not covered by the shades. Heifers in the shade treatment pens were allowed free access to the shaded space.

The feedlot pens used for this research were 7.3 by 20.7 m (24 x 68 ft). Each pen was assigned a shade treatment; animals in three of the pens had access to shade produced by one of three different shade cloths and the fourth pen was used as a non-shaded control. The shade cloths provided a reduction in solar radiation of approximately 25, 60, and 100 percent. Figure 3.1 shows a visual diagram of the experiment's layout.

The 25% reduction treatment was created using orange construction fence material (14 lb Oval, Fastenal, Winona, MN). Aluminet reflective shade cloth (Farmtek, Dyersville, IA) was used for the shade material in the 60% treatment. The third treatment, 100% reduction in solar radiation, used PolyMax all-purpose fabric (7.5 oz. Silver/White, Farmtek, Dyersville, IA).

The free-standing shade structures were 7.2 m long by 8.3 m wide (23.5 x 27.3 ft) and measured 2.1 m (7 ft) high at the eave and 4.3 m (14 ft) at the peak. These shade structures were designed such that heifers had access to shade from mid-morning (approximately 10:00 h Central Daylight Time [CDT]) to early evening (19:00 h CDT). The shade structures covered approximately 40% of the pen area. An empty pen of equal size was left open between each of the research pens to prevent animals in a given treatment from accessing shade created by another treatment.

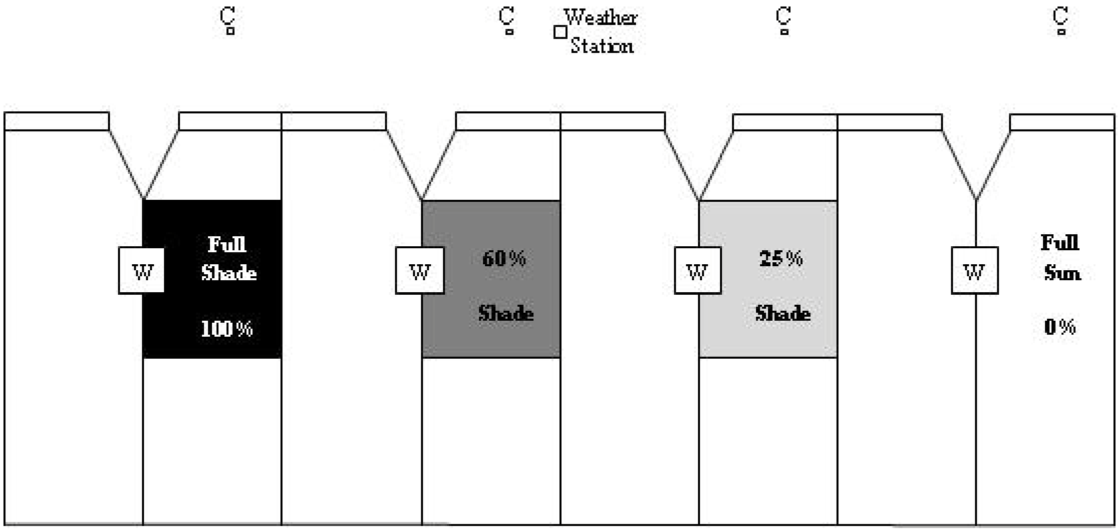

Figure 3.1

Basic Diagram of Facilities Used at MARC Feedlot in the Experiment

*The research pens are 7.3 by 20.7 m (24 x 68 ft) and the shade structures are 7.2 m by 8.3 m (23.5 x 27.3 ft). The feed bunks are oriented in an East-West direction.

*(W = Water Fountain, C = Camera)

Data Collection

Vaginal temperatures were recorded every minute using an HOBO Pro v2 Water Temperature Logger (U22, Onset Computer Corporation, Bourne, MA) according to the procedures detailed by Hillman et al. (2009). A flexible plastic anchor was used to keep the cylindrical sensor capsule in place. Tympanic temperatures were collected using the Continuous Tympanic Temperature Logger (CTTL). The CTTL is a tympanic temperature measurement device developed by Mayer et al., 2011. It consists of a temperature logger (DS1922L iButton, Maxim Integrated Products, Dallas, TX) house in a molded prosthetic foam probe. Tympanic temperatures were recorded once every five minutes.

For instrumentation purposes, each group of heifers was divided into two sub-groups: A and B. All of the A subsets were equipped with the T_V loggers during weeks one through three and five through seven and the CTTLs on weeks one, three, five, and seven. Similarly, B subsets were fitted with the T_V collection devices on weeks two through four and six through eight and the T_T loggers for weeks two, four, six, and eight. Thus, T_V and T_T records were three and one week in length respectively. The temperature instruments were installed in this way to insure that the data would be collected for each period and from animals in each treatment and to limit exposure as precautionary measure against infection in the reproductive tract or ear canal of the cattle used in this study.

Digital photographs were taken to record animal behavior and shade usage (Figure 3.2). Images were recorded once every five minutes using a stationary outdoor camera (BirdCam 2.0, Wingscapes, Inc., Alabaster, AL). A time stamp was added to each image; the pictures were then saved on a secure digital (SD) card. The SD cards were changed five times per week to ensure their storage capacity was not exceeded.

Weather data were collected at an automated weather data center located approximately 3.4 km (2.1 mi) northeast of the research pens at a South Central Station of the Automated Weather Data Network (AWDN), operated by the High Plains Regional Climate Center. The environmental conditions monitored at the station included dry bulb temperature (T_{db}), relative humidity (RH), wind speed (WS), and solar radiation (R_S). The measured parameters were also used to calculate dew point temperature (T_{dp}). Weather conditions at the AWDN were recorded on an hourly basis. On-site weather data were recorded for the last three of the four data collection periods and data were collected every 15 min by a Davis Instruments weather station (Model Vantage PRO, Hayward, CA). On-site data were used for analyses when available.

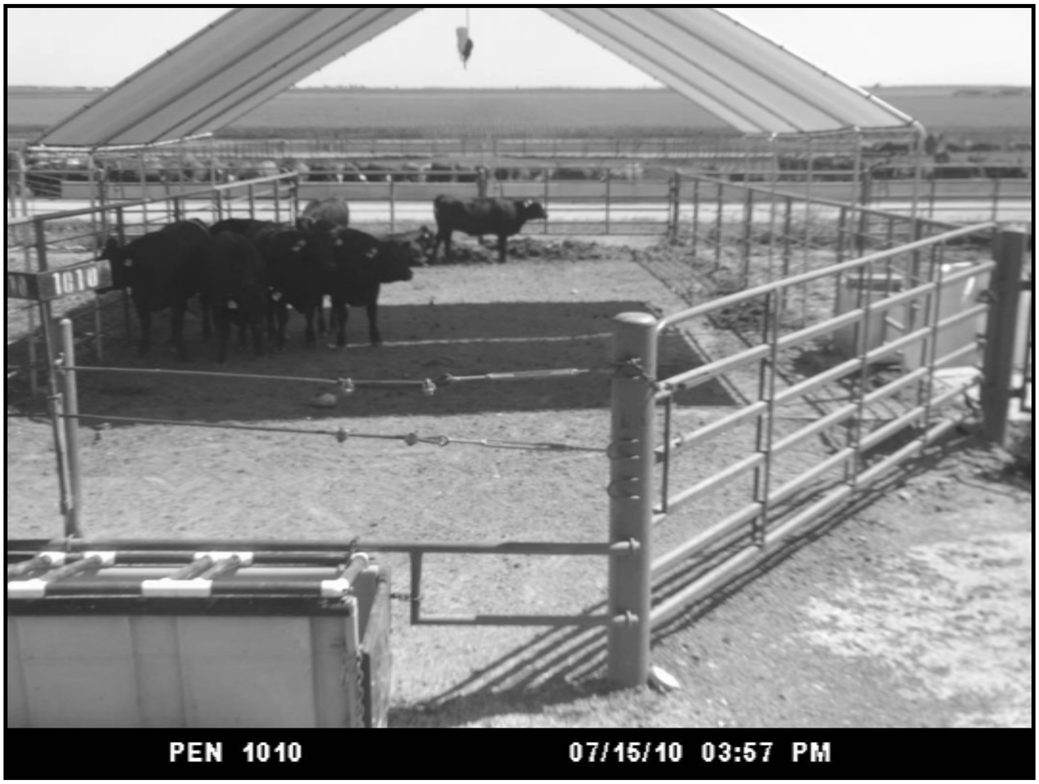

Figure 3.2

Representative Digital Image

*This picture was taken by outdoor camera of the eight Black Angus heifers in the 100% shade treatment pen at the U.S. MARC Research Feedlot. Photos were taken of each of the four pens once every five minutes for the duration of the experiment.

Data Analysis

For the analyses, temperature humidity index (THI) values were determined for every time interval (Thom, 1959).

$$THI = T_{db} + 0.36 \times T_{dp} + 41.2 \quad (3\text{-}1)$$

The data was categorized into four groups (Normal, Alert, Danger, and Emergency) using the daily maximum THI according to the Livestock Weather Safety Index (LWSI; LCI, 1970). The Normal category was defined as a maximum daily THI below 74. The Alert category had a maximum daily THI greater than or equal to 74, and less than 78. The Danger category had a maximum daily THI greater than or equal to 78, and less than 84. The Emergency category had a maximum daily THI equal to or above 84. Eight days were selected for analysis based on their maximum daily THI classification. Two days were chosen from each of the two-week data collection periods with one being in the Alert category and the other being in the Emergency category (Table 3.2).

Hourly averages were calculated from the T_V and T_T data. The physiological data was analyzed using PROC MIXED in PC-SAS (v9.2, SAS Institute, Cary, N.C.) for effects of THI category, treatment, hour of the day, and the interactions of THI category with hour of the day, treatment with hour of the day, THI category with treatment, as well as the three way interaction of THI category, treatment, and hour. The number of animals under the three shade structures between the hours of 10:00 and 19:00 h was converted to an hourly mean. These averages were analyzed using PROC MIXED in PC-SAS for the effects of THI category, treatment, and hour of the day. Least-squares means were used to discern differences and were considered significant at the $P \leq 0.05$ level.

Table 3.2

Days during the Experiment Selected for Analysis in Two THI Categories

Period	Date	Max THI
1	July 5	76.4
2	July 15	76.7
3	July 24	76.0
4	August 16	76.6
	MEAN	***76.4***
Period	**Date**	**Max THI**
1	June 25	83.7
2	July 17	86.2
3	August 2	85.8
4	August 8	85.3
	MEAN	***85.3***

*Selection was based on maximum daily value.

Results and Discussion

Only data from the second and third periods of the experiment were included in this analysis because of low CTTL recovery rates during period one and four. Tympanic temperature was significantly affected by THI category ($P < 0.0001$), treatment ($P < 0.0001$), hour of the day ($P < 0.0001$), THI category by hour ($P < 0.0001$), treatment by hour ($P < 0.0001$), THI category by treatment ($P < 0.0001$), and the three way interaction of treatment, THI category, and hour of the day ($P < 0.0001$). Similarly, T_V was also significantly affected by all of the analyzed effects. THI category, which was calculated using the LWSI, was used to summarize the weather conditions in the statistical model. A synopsis of common weather parameters for the four days with corresponding physiological temperature data is shown in Table 3.3.

Table 3.3

Weather Parameter Means for Days Used in Physiological Data Analysis

	Alert	**Emergency**
Number of Days	2	2
Dry-Bulb Temperature (°C)	24.3 ± 2.8	28.3 ± 4.3
Dew Point (°C)	17.7 ± 1.9	22.3 ± 2.3
Wind Speed (m/s)	1.5 ± 1.0	2.5 ± 1.8
Solar Radiation (W/m^2)	276.9 ± 316.3	263.4 ± 308.4
THI	72.2 ± 2.8	78.5 ± 4.9
Maximum THI	76.4 ± 0.5	86.0 ± 0.3

For days in the Alert category (Figure 3.3), T_{db} peaked at 28.00 °C at 17:00 and for those in the Emergency category (Figure 3.4), the maximum T_{db} was 35.31 °C and occurred at 16:00. Both T_T and T_V followed a diurnal pattern, which has been well documented (Wrenn, 1961). Tympanic temperature and T_V lagged T_{db} by approximately 2 h on Alert days and 3 h on Emergency days. These lags in T_{CB} are consistent with the findings of Hahn (1989).

Weather influenced the temperatures observed in this experiment (Figure 3.5). Tympanic temperature was significantly higher for all hours on the days in the Emergency THI classification than the corresponding hours on Alert category days. Vaginal temperature was significantly higher on Emergency than Alert days from 9:00 to 23:59. The mean T_T was 39.0 ± 0.01 °C on Alert days and increased to 39.46 ± 0.00 °C on Emergency days. Likewise, mean T_V rose from 38.96 ± 0.01 °C to 39.13 ± 0.00 °C on Alert and Emergency days, respectively. Maximum temperatures, both tympanic and vaginal, were also higher on days in the Emergency category.

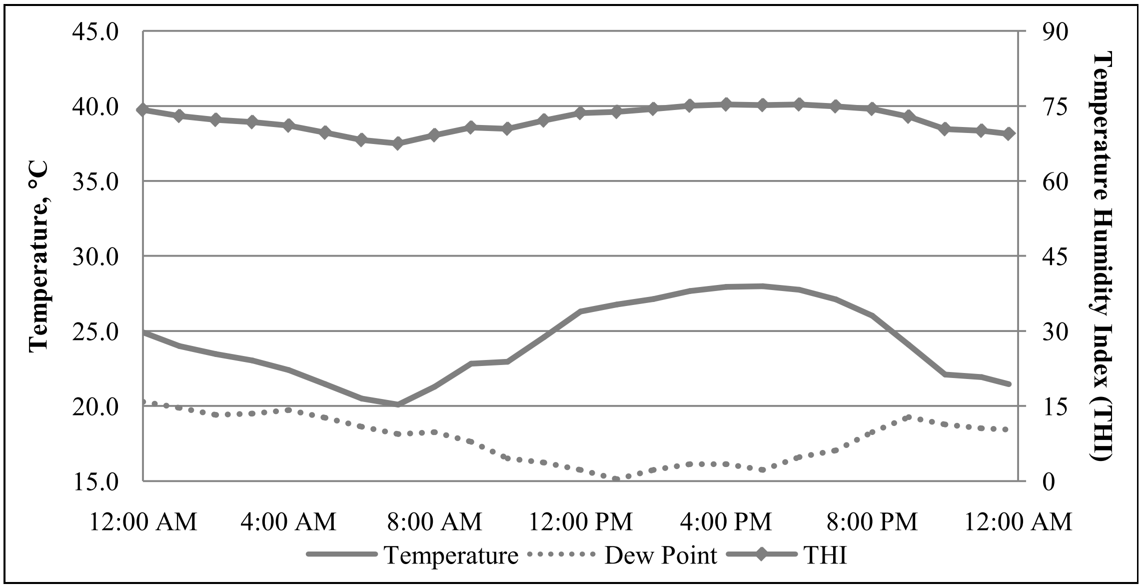

Figure 3.3

Weather Data Summary of Hourly Means: Alert THI Category Days (July 15 and 24)

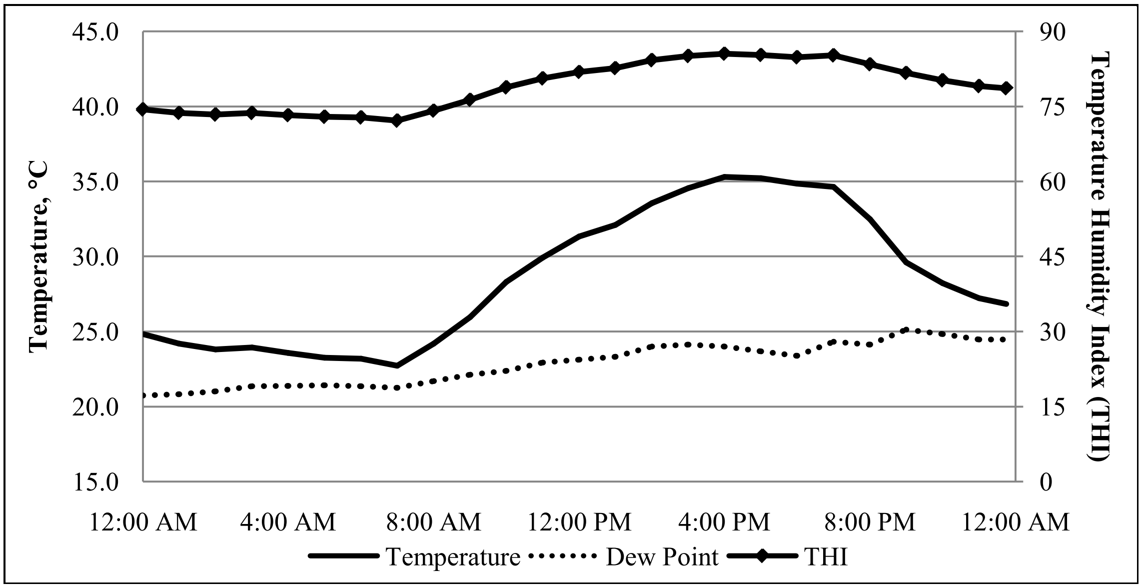

Figure 3.4

Weather Data Summary of Hourly Means: Emergency THI Category Days
(July 17 and August 2)

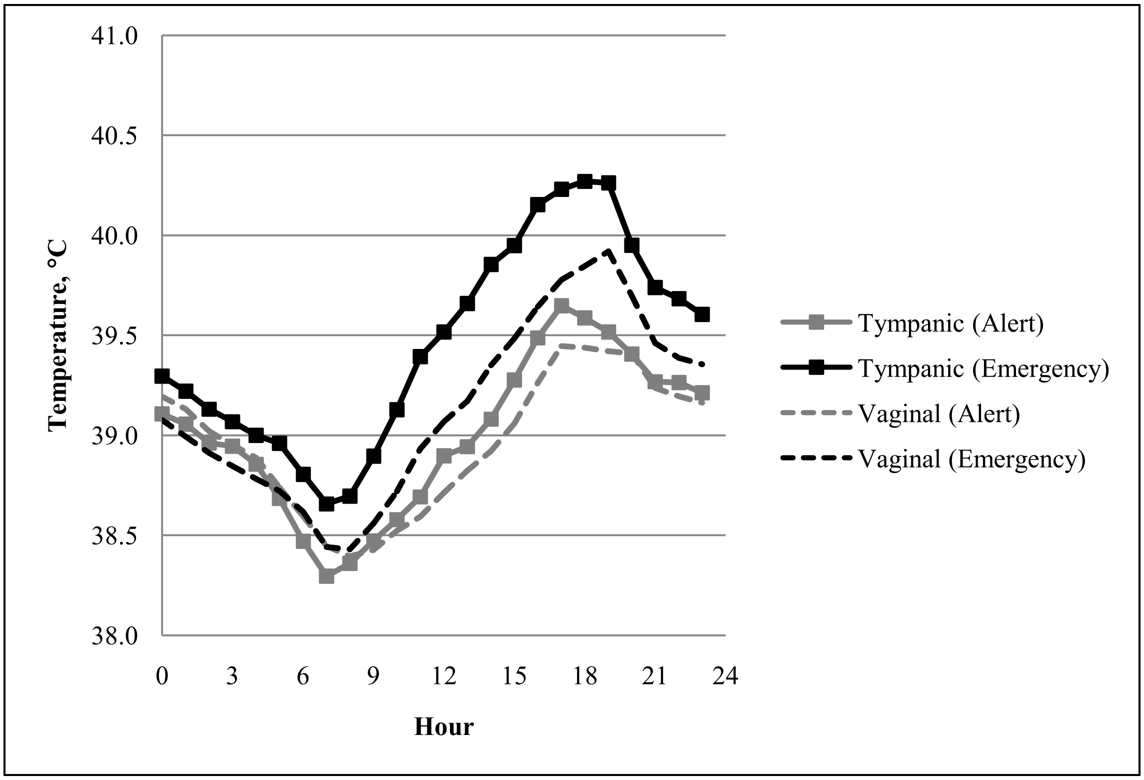

Figure 3.5

Core Body Temperature Measured at Two Locations on Days in the Alert
and Emergency THI Categories in Feedlot Heifers
(n = 14 and n = 15, Respectively)

Treatment × THI Effects

Mean T_T was higher ($P < 0.0001$) for days in the Emergency THI category when compared to days in the Alert THI category for all four shade treatments (Table 3.4). In the control pen the mean T_T increased 0.63 °C from Alert days to Emergency days. For the heifers in the 25% shade treatment, mean T_T was 0.51 °C lower on Alert days than on Emergency days. On days in the Emergency category, mean T_T for the 60% treatment was 0.67 °C than days in the Alert category. In the full shade (100%) treatment, mean T_T only increased 0.04 °C from Alert to Emergency days. Tympanic temperature was 0.46

°C lower in the 100% shade treatment pen than the no-shade treatment on Emergency days.

Table 3.4

Mean Tympanic Temperatures of Feedlot Heifers from All Four Shade Treatments in Two THI Categories

Treatment	**THI Category**	
	Alert	Emergency
No Shade (0%)	38.90 ± 0.01[a]	39.53 ± 0.01[b]
25% Shade	39.15 ± 0.01[a]	39.66 ± 0.01[b]
60% Shade	38.92 ± 0.01[a]	39.59 ± 0.01[b]
Full Shade (100%)	39.03 ± 0.01[a]	39.07 ± 0.01[b]

*Means in the same row with different superscripts are significantly different at the $P \leq 0.05$ level.

Mean T_V actually decreased 0.11 °C from Alert to Emergency days in the 100% shade treatment. This may be a result of a carryover effect of elevated T_V in the animals prior to the Alert category days. Another possible explanation is decreased feed intake on the days preceding those in the Emergency category leading to less heat production on Emergency days. All other treatments had a significantly lower mean T_V on days in the Alert category when compared to those in the Emergency category (Table 3.5). Vaginal temperature in the 25% and 60% shade treatment increased 0.21 and 0.36 °C respectively from Alert to Emergency days. Mean T_V in the 100% shade treatment was 0.30 °C lower than the 0% shade treatment on Emergency days.

Table 3.5

Mean Vaginal Temperatures of Feedlot Heifers from All Four Shade Treatments in Two THI Categories

Treatment	**THI Category**	
	Alert	Emergency
No Shade (0%)	38.91 ± 0.01^a	39.15 ± 0.01^b
25% Shade	39.03 ± 0.01^a	39.24 ± 0.01^b
60% Shade	38.93 ± 0.01^a	39.29 ± 0.01^b
Full Shade (100%)	38.96 ± 0.01^a	38.85 ± 0.01^b

*Means in the same row with different superscripts are significantly different at the $P \leq 0.05$ level.

Diurnal Effects

The maximum recorded T_T was significantly lower for all three shade materials when compared to non-shaded heifers on Emergency days. For days in the Emergency THI category, the maximum hourly T_T was 40.69 ± 0.04 °C in the no-shade pen (Figure 3.6), 40.54 ± 0.04 °C in the 25% treatment (Figure 3.7), 40.35 ± 0.04 °C in the 60% treatment (Figure 3.8), and 39.72 ± 0.05 °C in the full shade (100%) (Figure 3.9). These are reductions of 0.15, 0.34, and 0.97 °C respectively. During the afternoon hours of 12:00 to 18:00 on Emergency THI category days, T_T in the 0% shade treatment was significantly higher than T_T in any of other treatments. Vaginal temperature in the no-shade treatment was also significantly higher than any of the other treatments from 12:00 to 19:00 on Emergency days, suggesting that during emergency situations all of the shade materials tested reduce T_{CB} and could be used to lessen the impact of heat stress on feedlot heifers.

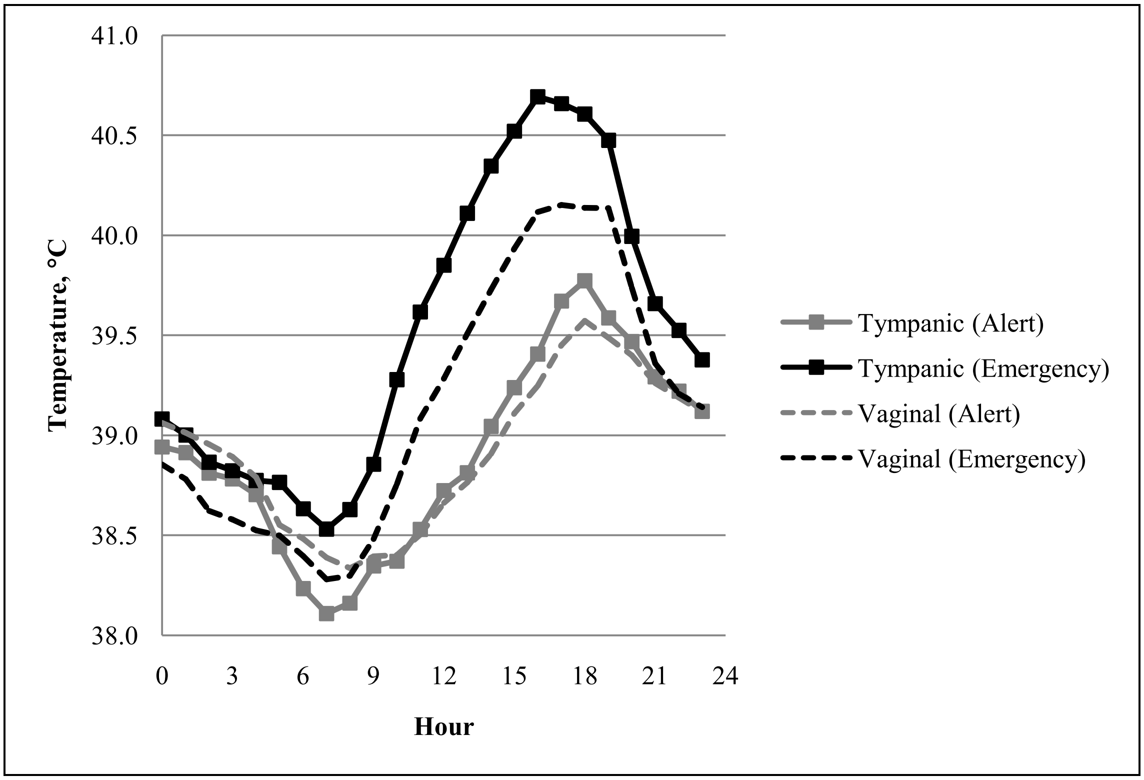

Figure 3.6

Core Body Temperature Measured at Two Locations during Days in the Alert and Emergency THI Categories: 0% Shade Treatment (n = 4 and n = 6, Respectively)

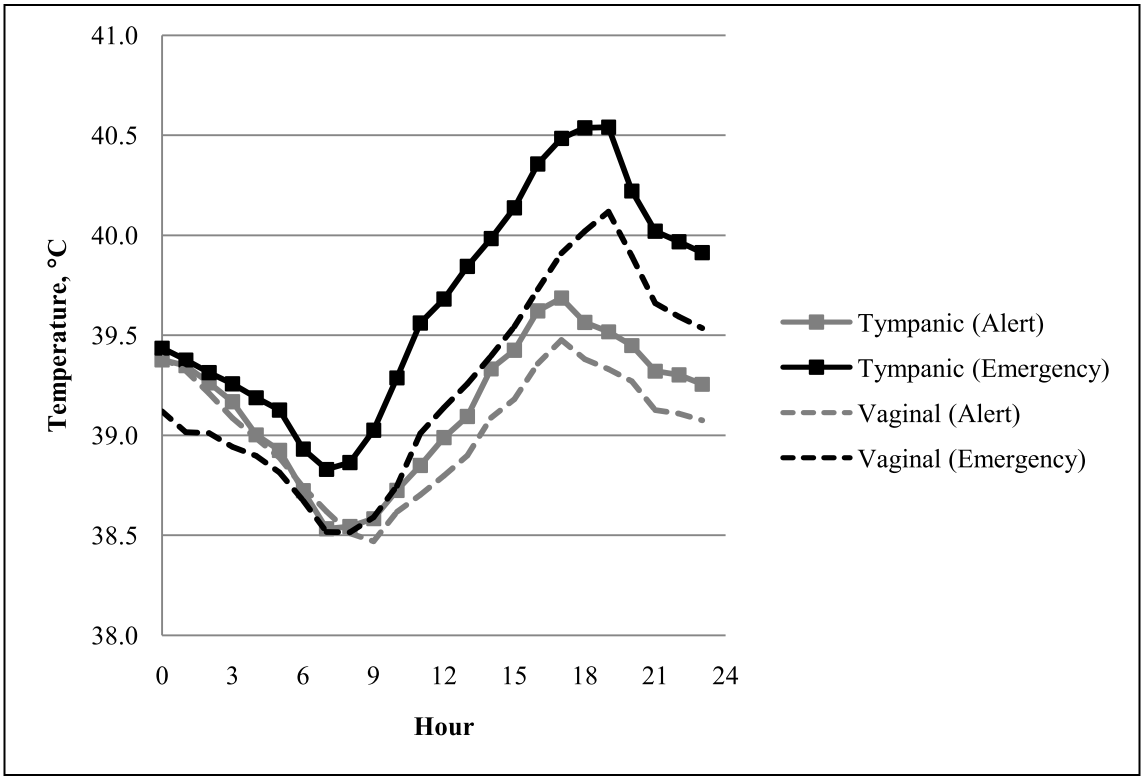

Figure 3.7

Core Body Temperature Measured at Two Locations during Days in the Alert and Emergency THI Categories: 25% Shade Treatment (n = 3 and n = 2, Respectively)

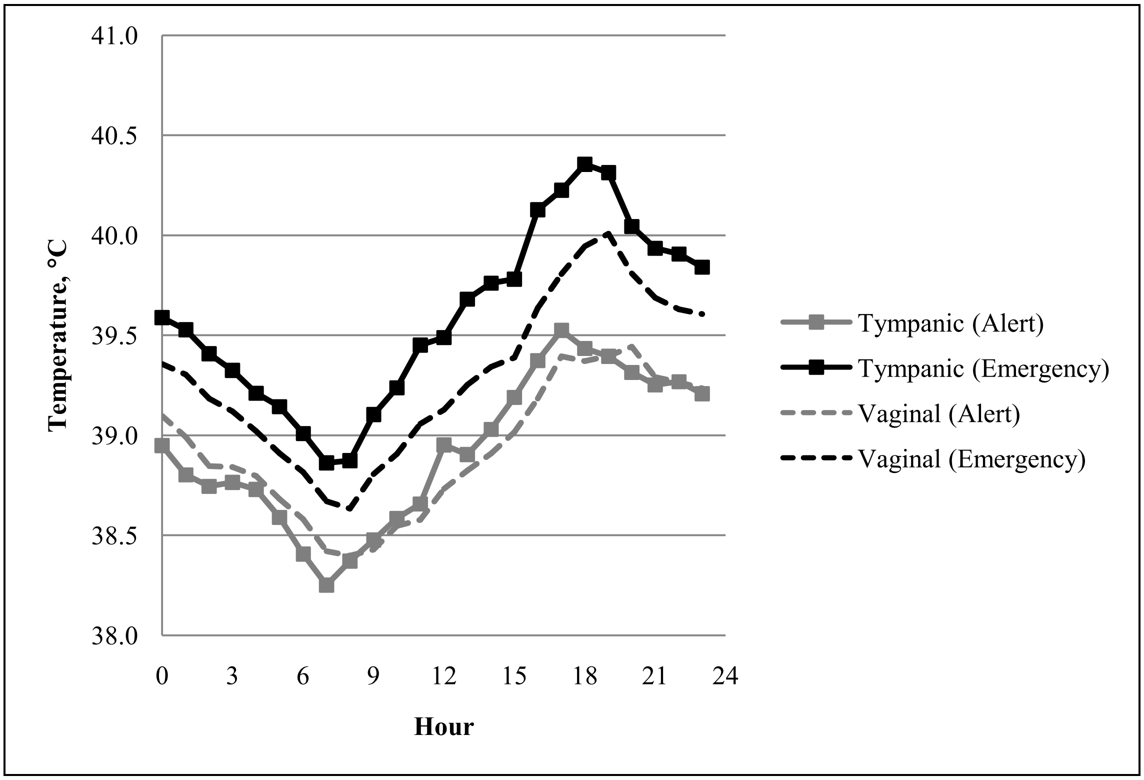

Figure 3.8

Core Body Temperature Measured at Two Locations during Days in the Alert and Emergency THI Categories: 60% Shade Treatment (n = 4 and n = 4, Respectively)

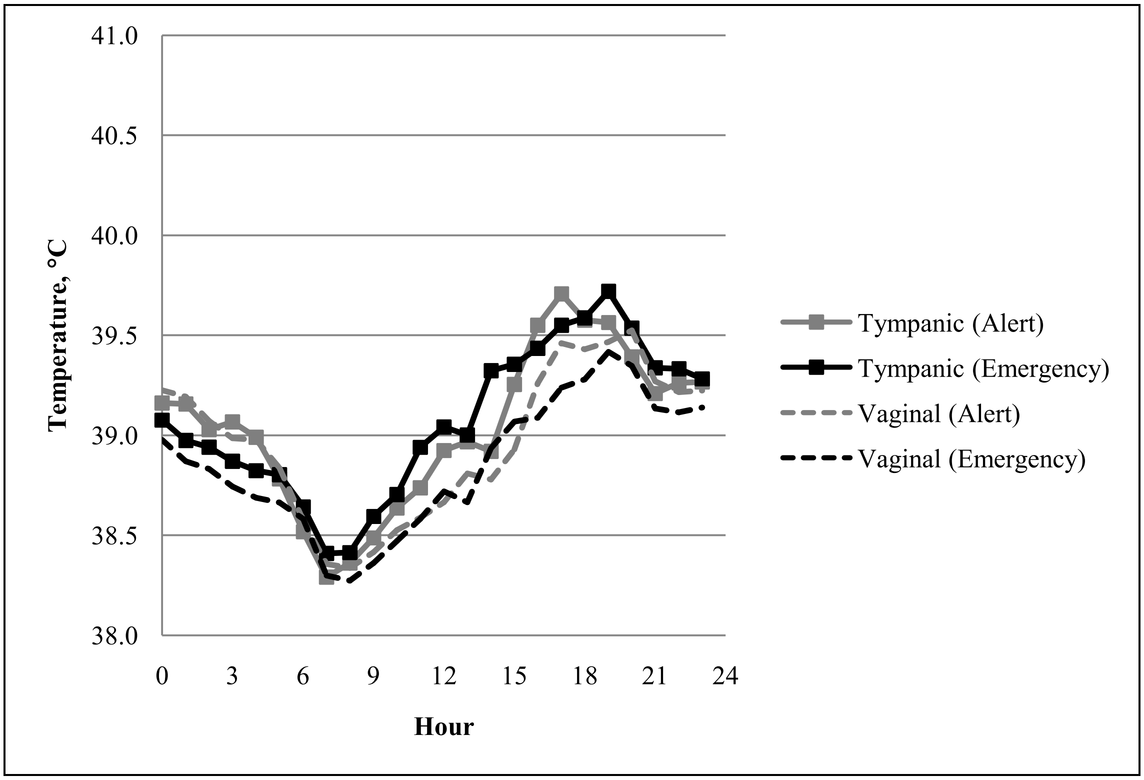

Figure 3.9

Core Body Temperature Measured at Two Locations during Days in the Alert and Emergency THI Categories: 100% Shade Treatment (n = 3 and n = 3, Respectively)

The maximum hourly mean T_T for all days was 40.19 ± 0.03 °C and was recorded in the control pen during the 18:00 to 18:59 hour. The non-shaded cattle also produced the lowest hourly mean T_T (38.32 ± 0.03 °C), which occurred from 7:00 to 7:59. The lowest hourly mean vaginal temperatures were logged from 7:00 to 8:59 in the 0% and 100% shade treatments. The highest hourly mean T_V of 39.85 ± 0.03 °C occurred in the non-shaded pen during the 18:00 to 18:59 hour. It is worth noting that both the max and min hourly means for both T_T and T_V were observed in the no shade treatment, agreeing with the findings of Blackshaw and Blackshaw (1994) and Brown-Brandl et al. (2005).

Brown-Brandl et al. (2005) suggested that this may result from radiative heat losses from the warm animal to the cooler night sky. The non-shaded animals may also reduce feed intake, which can decrease heat production.

Behavior Data

Due to complications with the cameras during the first two-week period of the study, only images from the other three periods were analyzed. Pictures taken from 10:00 to 17:59 (the time period when shade was available) were included in the analysis. Shade usage for all treatments on all days peaked at 6.49 animals during the 14:00 to 15:00 hour. This peak occurred during the period of the day (13:00 to 14:59) with the largest amounts of solar radiation.

Shade usage was significantly higher from 10:00 to 17:59 during days in the Emergency THI category than those in the Alert group (Figure 3.10). On Emergency days, the full shade (100%) pen had a significantly lower mean T_T and T_V than all of the other treatments. However, on the days in the Alert THI category the non-shaded animals and the animals in the 60% treatment were significantly lower. These findings suggest that perhaps on Alert category days the 60% shade material is the most effective at reducing T_T and T_V. However, Figure 3.11 shows the mean number of animals in the shade for each of the three shade treatments on Alert category days. The number of animals in the shade under the 60% shade cloth was significantly higher than the 25% and 100% treatments from 15:00 to 17:59. Animal behavior during the late afternoon in the shaded pens explains the results of the T_{CB} data on the Alert THI days.

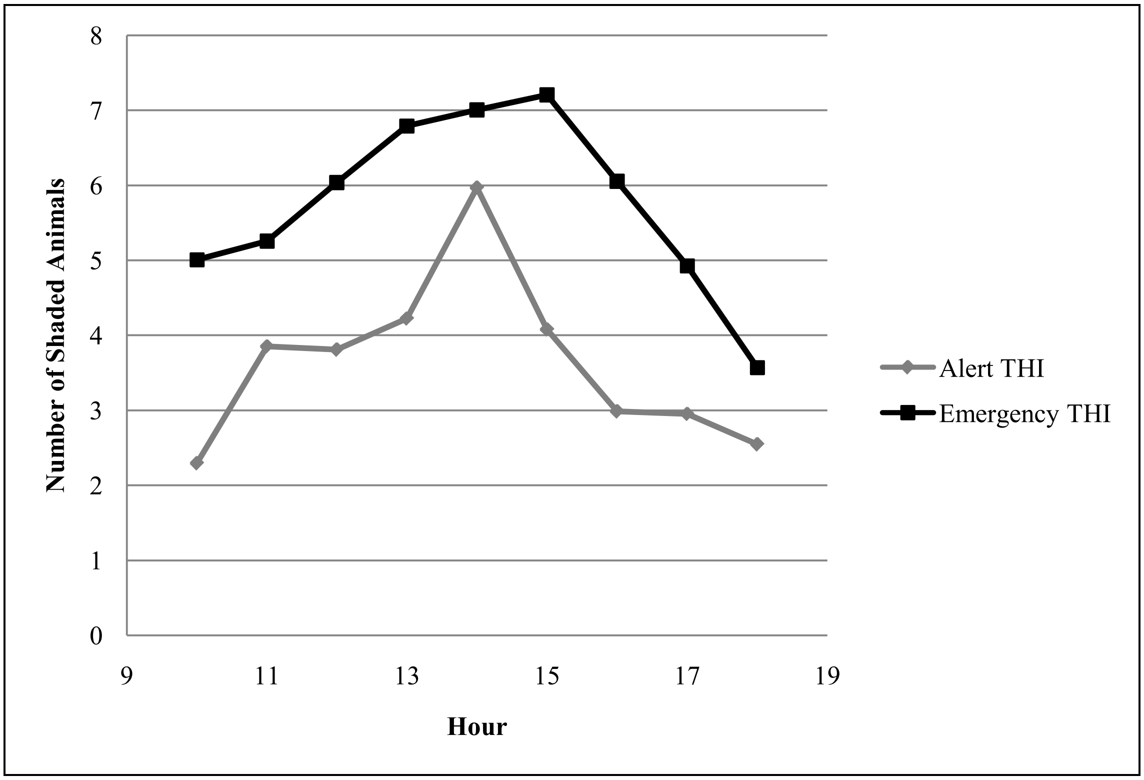

Figure 3.10

Hourly Mean Number of Shaded Feedlot Heifers in All Shade Treatments
for Two THI Categories

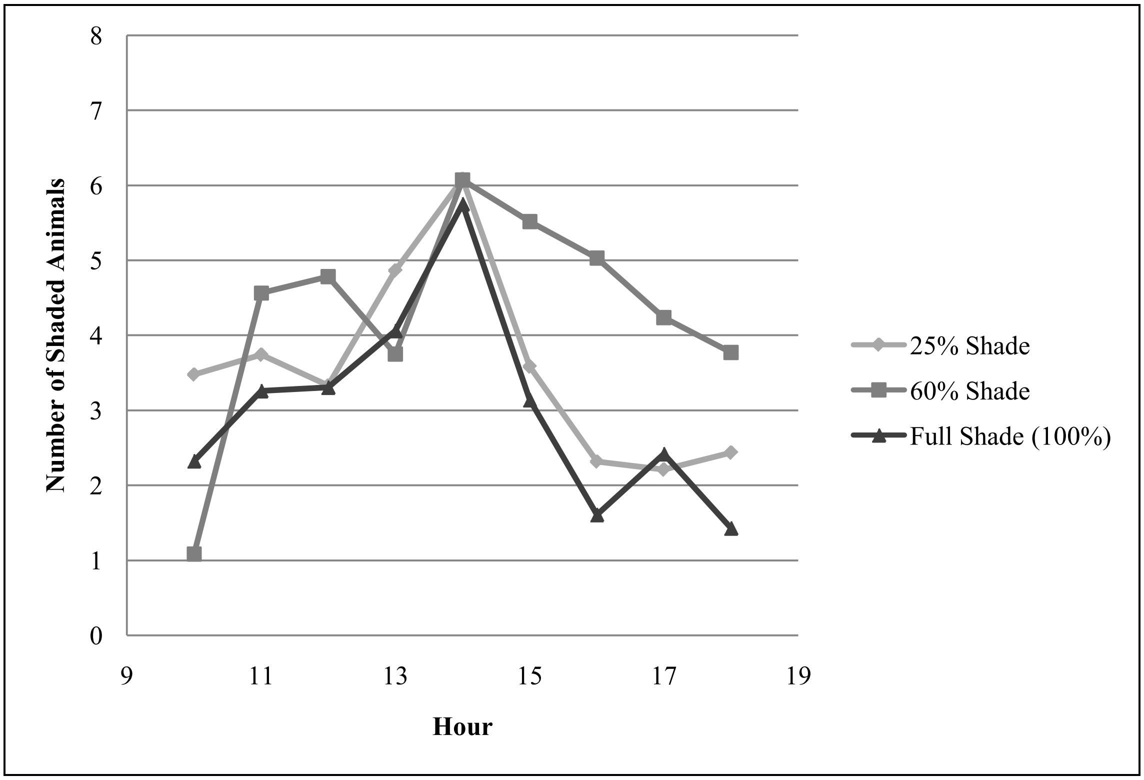

Figure 3.11

Hourly Mean Number of Shaded Animals in Three Shade Treatments on Days with Maximum THI Values in the Alert Category

Implications

Overall, the results indicate that the 100% shade material is most effective at reducing tympanic and vaginal temperature in feedlot heifers. The major concerns regarding shades from livestock producers include cost and the time required for maintenance. The 60% Aluminet shade material costs approximately 20% more than the 100% PolyMax shade material. The construction fence is the least costly option at roughly half the price of the full shade (100%) material. The primary disadvantage of the 100% shade cloth is material properties which affect its ability to handle wind or snow loads. The PolyMax fabric is less porous than the alternatives, which enables it to reduce nearly all of the solar radiation. However, this also increases wind loading. During the first period of the experiment the 100% shade cloth was severely damaged in a thunderstorm and required replacement. The two other shades received minimal damage. Despite this drawback, the 100% shade lowers T_{CB} more than tested alternatives in emergency conditions. One potential option for dealing with the durability of this material in inclement weather is to restrict use of these shades to extreme heat events.

There is a clear physiological response in feedlot heifers to shade. It seems likely that animals with lower body temperatures would be more comfortable and thus perform better in terms of feed efficiency and average daily gain (ADG). A methodology for economic optimization of broiler production was developed by Timmons and Gates (1986). However, a correlation between T_T or T_V and common industry production measures has not been established for cattle. In order to determine the cost-effectiveness of these shade materials, further research should investigate this relationship.

Premiums for black hided feeder cattle have become common in recent years, increasing the demand for Angus genetics in the United States (Barham and Troxel, 2007, Leupp et al., 2008). From 1995 to 2010 the number of black-hided cattle as a percentage of the total U.S. cattle population nearly doubled from 33.0% to 63.2% (Dr. Larry Corah, Certified Angus Beef, personal communication, 5 October 2011). Cattle with black hair coats are more susceptible to heat stress (Brown-Brandl et al., 2006). Neglecting heat tolerance when making breeding decisions can be a costly choice for producers in the long run. Given the current trends in the U.S. beef industry, a greater emphasis should be placed on research to improve the tools and techniques livestock caretakers have available to combat heat stress.

Conclusion

The Black Angus heifers used in this study had lower tympanic and vaginal temperatures on days that had a maximum THI between 74 and 78 (Alert category) than those that had a maximum THI greater than 84 (Emergency category). Providing shade for the animals used in this experiment reduced T_{CB} during Emergency days. Mean tympanic and vaginal temperatures were lowest in the 100% shade treatment pen, on days in the Emergency THI category. All three shade materials were effective at decreasing heat stress in feedlot heifers as measured by the physiological response, from 12:00 to 18:00 on Emergency days. However on Alert THI category days, none of the animals in the shade treatments had a lower mean vaginal or tympanic temperature when compared to the control (0% shade) treatment.

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CHAPTER IV

RESEARCH SUMMARY AND CONCLUSIONS

The Continuous Tympanic Temperature Logger (CTTL) can be effectively used to measure tympanic temperature (T_T) in group housed animals in both the left and right ears. The CTTL is inexpensive to construct and easier to install or remove when compared to previous methods. The high level of variability in the temperature signals both within and between animals used for this research prevented the calculation of a standardized offset between temperature measurement locations (right ear, left ear, and vagina) to be calculated. Additional research focused on characterizing T_T profiles of beef cattle using signal analysis to gain a better understanding of the thermal processes and reactions related to homeostasis is needed.

Caution should be taken when using daily mean temperatures to characterize the thermal status of an animal for short periods of time as they have been shown to be inaccurate indicators. Likewise, the use of spot temperature measurements may be misleading. Clinicians and researchers should be cautious about placing much weight on a single measure of body temperature (Vickers et al., 2010). For application of temperature-based use of pharmaceuticals, consideration needs to be given to cattle handling practices and ambient temperature when selecting the temperature threshold at which the product will be administered (Galyean et al., 1995).

Respiration rate is the best physiological indicator of stress in a production setting (Brown-Brandl et al, 2005) and remains the most effective measurement for determining the impact of heat stress on beef cattle. The primary advantage respiration rate has over core body temperature measurement is simplicity as it requires minimal training and only a stop watch to compute the results.

Providing shade for feedlot heifers lowered T_T and vaginal temperature (T_V) during heat stress conditions. Concerns with the cost and maintenance of shade structures will likely continue to inhibit widespread adoption especially given alternatives for heat stress alleviation such as sprinklers, which may also be used for dust control in feedlots. Shade designs with multiple uses such as a wind barrier during winter months and protection from solar radiation during summer months may have increased merit. However, optimizing performance by mitigating negative impacts from environmental factors may not optimize profitability of a livestock operation (Nienaber and Hahn, 1991).

Given the localized nature of extreme heat stress events such as those that cause catastrophic losses from hyperthermia, site location is particularly important. Figure 4.1 shows the area of the contiguous United States where shade has the greatest potential impact on beef cattle production (Adapted from William N. Garrett, unpublished manuscript prepared for presentation at the American Society of Animal Science 55th Annual Meeting in Corvallis, OR in 1963). A large proportion of feedlots, especially those in Nebraska, Western Kansas, and the Texas Panhandle region fall into the intermediate category. These facilities may find temporary shade structures useful or may chose to construct a small number of permanent shade structures to protect the most susceptible animals during periods of severe heat.

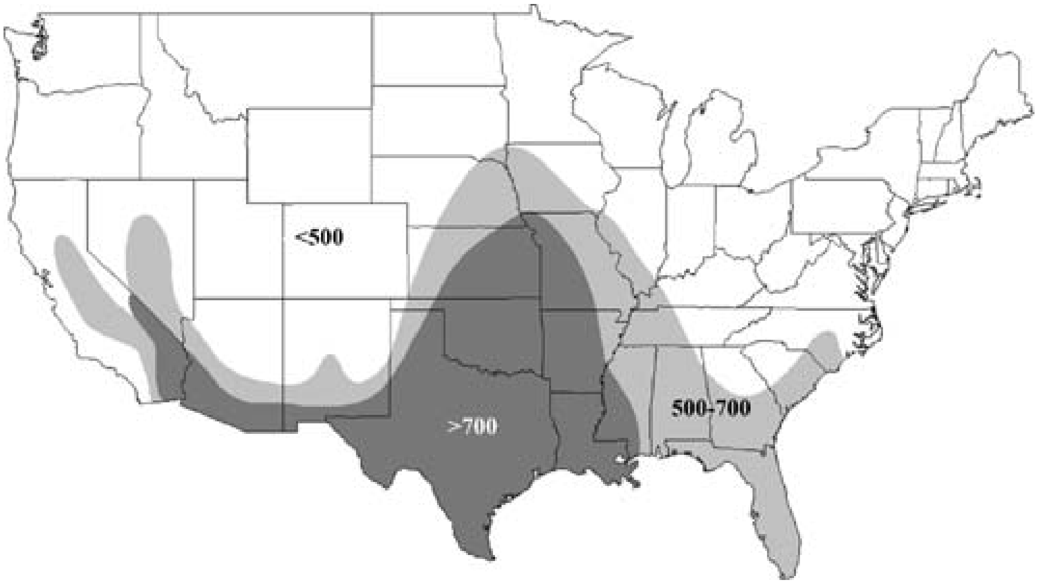

Figure 4.1

Areas of the U.S. with Selected Categories of Time in Hours Spent Above 29.4 °C

*<500 hours = no benefit from shade, 500-700 hours = some benefit from shade, >700 hours = large benefit from shade.

Facing high feed and energy costs, livestock managers of the future will utilize advanced monitoring systems to make improved production decisions and efficiently allocate resources on their operation. The findings of this work should prove useful in forthcoming designs of temperature measurement methods for production uses in beef cattle operations in the U.S.

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