Implications of Changes in Core Body Temperature

Michael M. Schutz[1] and Jeffrey M. Bewley
[1]Department of Animal Sciences, Purdue University
[2]Department of Animal and Food Sciences, University of Kentucky

Abstract

Dairy farmers and veterinarians have used body temperatures, most commonly rectal temperatures, to detect and manage febrile disease and changes in the state of cows (estrus and onset of calving) for many years. Mastitis, pneumonia, metritis, lameness, estrus, onset of parturition, heat stress, and subacute ruminal acidosis **(SARA)** are among the physiological conditions potentially correlated with body temperature that deviates from normal. Many new technologies have been introduced to measure body temperature of cattle at various locations, including rectum, ear (tympanic), vagina, reticulum-rumen, skin, and milk. While each location has its own advantages and disadvantages, temperature measurements at some of these locations can be automated for routine, frequent, and non-disruptive temperature recording. Systems for measurement of reticular temperature are available commercially. However, many factors other than the physiological conditions of interest affect reticular temperature. Among these are ambient temperature, food and water consumption, stage of lactation cycle, age, recumbency, activity level, stage of gestation, and of course, general health. The relationship between reticular and rectal temperatures appears to be relatively consistent, though the correlation is affected by time of season, housing system, and time of day. Reticular temperatures are affected by water intake, and substantially so for large volumes and extremely cold water; and dips in reticular temperature following water consumption must be considered when interpreting observations. Research is continuing to assess the ability of reticular temperature monitoring, perhaps in conjunction with other precision dairy farming tools, to allow earlier intervention with appropriate management. Success of early intervention will be the key to the ultimate success of any temperature monitoring technology.

Introduction

Dairy farmers and veterinarians have used body temperatures, most commonly rectal temperatures, in detection and management of febrile disease and changes in the state of cows (estrus, heat stress, and onset of calving) for many years. Nakamura et al. (1983) defined body temperature as the "single most useful measurable parameter and a sensitive indicator of the reactions of the animal to physico-environmental factors, disease processes, and physiologic functions such as nutrition, lactation, and reproduction." Because restraining animals to collect rectal temperatures manually may cause stress that alters temperature, a reliable method with no human intervention is likely to provide a more accurate measure (Prendville et al., 2002).

While the number of proposed experimental techniques for non-disruptive temperature monitoring is large, the number of companies actually marketing telemetric equipment to the livestock industry is limited (Brown-Brandl et al., 2003). The CowTemp™ telemetric system (Innotek, Inc.,

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[1]Contact at: 125 South Russell Street #105, West Lafayette, IN 47906, (765) 494-9478, FAX: (765) 494-9347, Email: mschutz@purdue.edu

[2]Contact at: 407 W.P. Garrigus Building, Lexington, KY 40546-0215, (859) 257-7543, FAX: (859) 257-7543, Email: jbewley@uky.edu

Garrett, IN) was designed to transmit body temperature at a pre-determined regular interval using a reticular bolus, a receiver, and a computer program to summarize the data. Limited research has been conducted with this product at Purdue University (McAfee et al., 1998; Nielsen et al., 2001). However, at the time of this publication, the CowTemp™ product was not being marketed commercially. The CorTemp™ (HQ Inc., Palmetto, FL) temperature/heart rate monitoring system, originally developed for work with humans, consists of ingestible body temperature sensor pills, optional heart monitors, radio frequency **(RF)** remote units, a long range central station, a series of shorter range substations, and a central information collection station (Hicks et al., 2001; Green et al., 2005). Thus far, high investment costs and limited battery life have prevented this product from being commercialized. The ETD Bolus™ system (CowTek Inc., Brule, NE) consists of a rumen bolus, a desktop or long range exciter, receivers (each monitor up to 300 feet away), and a PDA or PC for data collection and analysis and provides temperature readings as frequently as every 30 minutes. Dr. Roger Meads (Trace Technology, Inc. and Dairy Business Resource, Inc., Hortonville, WI) has also developed an automatic temperature recording system. Digital Angel Corp. (South St. Paul, MN) developed the Bio-Thermo™ technology for tracking temperature. However, due to slaughter recovery issues, Bio-Thermo is not currently being marketed for the cattle industry. The Bella Health System (**BHS**; Bella Health Systems, Greeley, CO), formerly marketed in an earlier version as MaGiiX™ Cattle Temperature Monitoring System (**CTMS**; MaGiiX Inc., Post Falls, ID) utilizes RF identification **(RFID)** technology within a rumen bolus, a panel reader placed at a parlor entrance or exit, and a software package to collect, analyze, and view data. The BHS is currently being used at several universities and on a few large dairy farms in the western United States. Rumen temperature monitors are also commercially available as Smartbolus (TenXsys Inc., Eagle, ID) and Kahne Rumen Sensor (Kahne Ltd., Auckland, New Zealand), which also combines rumen pressure sensing.

Measuring Temperature in Dairy Cows

Although valuable for monitoring animals, core body temperatures are inherently difficult to obtain. Normal temperature varies considerably among cows (Lefcourt et al., 1999). Daily temperature variation is somewhat random with a standard deviation around 0.6 (Fallon, 1959). Debate exists on how frequently temperature should be measured to detect differences in physiological responses (Lefcourt et al., 1999). Measuring temperatures continuously would be advantageous by demonstrating the dynamic changes in temperature throughout the day (Mitchell et al., 2001; Brown-Brandl et al., 2003; Green et al., 2005). Most research indicates that body temperatures of cattle follow a distinct circadian rhythm with a range of 0.2 to 0.9°C (Nakamura et al., 1983; Lefcourt et al., 1999; Al-Haidary et al., 2001; Piccione et al., 2003; Piccione and Refinetti, 2003).

Many factors influence body temperature, including overall health, environment, ambient temperature, activity level, estrus, pregnancy status, eating and drinking behavior, and excitement (Lefcourt et al., 1999). Temperatures are higher in lactating cows than in dry cows (Nakamura et al., 1983; Bennett and Holmes, 1987). Average body temperature varies by season, reflective of ambient temperatures, a phenomena termed "seasonal drift" by Fordham et al. (1988). Feeding may increase body temperatures (Bitman et al., 1984). Araki et al. (1984) found sharp decreases in temperature after cows went through the parlor. Metz et al. (1987) found that body temperature increased about 0.2°C while lactating cows were lying (and decreased after standing up) indoors; however, the same pattern was not observed for dry cows on pasture. This result may, at least in part, explain the findings that cow rumen temperatures are higher at night than during the day (Ipema et al., 2008).

Attempts to measure body temperature of cattle have been made at various locations, including rectum, ear (tympanic), vagina, reticulum-rumen, and milk. Firk et al. (2002) suggests that the value of a temperature monitor is highly dependent on its location. Tympanic temperature has been suggested to be a superior measure of deep-body temperature because of proximity to the hypothalamic thermosensitive site and reduced lag time (Seawright et al., 1983; Bergen and Kennedy, 2000). However, continuously monitoring tympanic temperature can prove challenging because temperature transmitters may create ear infections, leading to increased temperatures (Bergen and Kennedy, 2000). In a study by Bergen and Kennedy (2000), the correlation between tympanic and vaginal temperatures was 0.77, with vaginal temperatures averaging 0.35°C higher than tympanic temperatures. Rajamahendran et al. (1989) found rectal and vaginal temperatures to be highly correlated (r = 0.95).

Hahn et al. (1990) simultaneously measured temperature at four locations (tympanic, rectal, sub-dermal upper shoulder, and sub-dermal upper flank). Tympanic temperatures detected thermoregulatory responses that the rectal temperatures could not. The dermal upper shoulder and sub-dermal upper flank measurements were heavily influenced by environmental stimuli, such as changing air speeds or wetting of skin. Ultimately, the authors concluded that internal sites of temperature measurement are more useful indicators of core body temperature during changing conditions than external sites of temperature measurement (Hahn et al., 1990). The accuracy of rectal thermometers is limited to the competency of the operator using them (Aalseth, 2005).

Milk temperatures are highly correlated, but significantly lower, than body temperatures (Schlunsen et al., 1987; Fordham et al., 1988). Bitman et al. (1984) used thermistors to compare udder temperatures to core body temperatures (as measured in the peritoneal cavity) every 1.4 minutes. Udder temperatures ran about 1°C lower than peritoneal cavity temperatures, but they were highly correlated (r = 0.98 to 0.99). These researchers concluded that mammary gland temperature was not controlled by a different mechanism than core body temperature.

Rumen temperatures have been demonstrated to be effective measures of core body temperature (Hicks et al., 2001; Prendiville et al., 2002; Small et al., 2008). Because of the activity of heat-producing rumen microorganisms, ruminal temperatures are generally about 1°C higher than core body temperatures (Bitman et al., 1984). Ruminal or reticular temperatures typically run higher than rectal temperatures (Simmons et al., 1965). Prendiville et al. (2002) compared temperature readings from CowTemp™ rumen boluses, tympanic telemetry transmitters, and rectal temperatures taken hourly. The averages for the 5-day period studied were 39.0, 38.4, and 38.2°C for rumen, tympanic, and rectal temperatures, respectively. While there was no significant difference between tympanic and rectal temperatures ($P > 0.05$), rumen temperature was higher than rectal or tympanic temperature on 3 of the 5 days. Using the CorTemp sensor pill, Hicks et al. (2001) found sensor temperatures, as measured in the rumen, to be statistically the same as rectal temperatures. Dramatic decreases in ruminal temperature occur after the cow drinks water (Dracy et al., 1963; Simmons et al., 1965); and this has been further demonstrated in comparison of temperatures recorded at a stationary panel for heifers motivated by water versus activity (Small et al., 2008). It takes 60 to 90 minutes for temperatures to return back to their pre-drinking levels (Dracy et al., 1963; Cunningham et al., 1964). The level of temperature depression is related to the amount and temperature of water consumed (Cunningham et al., 1964).

Temperature and Health

Perhaps the largest potential benefit of employing an automatic temperature monitoring system on a dairy would be in early detection of cases of disease, illnesses, or disorders that plague the dairy industry (Maatje et al., 1987). For many diseases, an increase in temperature is an early physiological response. In recent years, intensive fresh cow management programs have been established based upon using electronic thermometers to detect fever (Aalseth, 2005). Many of these fresh cow management programs are based on identifying animals with temperatures outside of a pre-established range and treating outliers. Aalseth (2005) lists the primary benefits of an intensive fresh cow management program as: 1) reduced involuntary cow losses in the first 30 and 60 days post freshening, 2) decreased postpartum disease, 3) improved reproduction, and 4) increased milk production.

Attempts have been made to use milk temperature as a predictor of mastitis. Models that combine udder temperature obtained via infrared thermography with environmental temperature may be useful in future applications in predicting mastitis (Schutz et al., 2001; Berry et al., 2003; Hovinen et al., 2008). Udder temperatures are generally 3 to 5°C cooler than rectal temperatures (Berry et al., 2003). A large udder temperature rise (>1.0°C) is typically associated with clinical mastitis and may be observed even before clinical symptoms are evident, and as such, temperature increases arise from changes in vascularization (Hovinen et al., 2008) that may or may not be captured by milk temperature. Indeed, Hovinen et al. (2008) concluded that while infrared thermography may be useful to automate mastitis detection, increases in udder skin surface temperature actually lagged increased rectal temperature, possibly because acute response to infection leads to swelling that may reduce blood flow to the skin surface. This is consistent with earlier conclusions that infrared thermography may not advance the stage at which mastitis is observed relative to other measures, like visual observation and electrical conductivity (Schutz et al., 2001).

In a study of Holstein-Friesian cows in tie-stall barns, milk temperatures were monitored for a period of six years (Schlunsen et al., 1987). Temperature increases were caused by the following: estrus 26%, no disease 22%, medicinal treatment 16%, uteritis 15%, metabolic disorder 11%, mastitis 5%, and inflammation of claws and limbs 5%. Veterinary diagnosis suggested that changes in temperature were able to detect mastitis and uteritis, most effectively followed by metabolic disorder and inflammation of claws, with the least effectiveness in detecting estrus. Authors caution that because temperature is affected by so many variables, other physiological parameters are necessary for a complete diagnosis (Schlunsen et al., 1987). Maatje et al. (1987) found increases in temperature in 0 of 3 cases of retained placenta, 3 of 3 cases of retained placenta plus metritis, 1 of 1 case of metritis, 0 of 3 cases of milk fever, 4 of 5 cases of teat damage plus mastitis, 10 of 13 cases of mastitis, 3 of 4 cases of sole ulceration, and 0 of 6 cases of lameness. Utilizing an indwelling temperature and pH probe, AlZahal et al. (2008) found a convincing correlation between the nadir of rumen pH and time of peak temperature and determined that rumen temperatures could be useful in detecting SARA, given development of an effective rumen temperature monitoring system.

Temperature and Estrus

Detecting increases in temperature at estrus has been suggested as a strategy for estrus detection (Nakamura et al., 1983, Schlunsen et al., 1987; Fordham et al., 1988; Redden et al., 1993; Kyle et al., 1998; Piccione et al., 2003; Piccione and Refinetti, 2003). Debate exists in the literature with regard to whether or how much temperature increases during estrus (Fordham et al., 1988).

Wrenn et al. (1958) found a decrease in body temperature one to two days prior to estrus, a sharp increase in temperature on the day of estrus, and a gradual increase in temperature following estrus. Frequency of observation of temperatures may also determine the efficacy of temperature for predicting estrus (Gil et al., 1997; Schlunsen et al., 1987). It is not clear whether temperature increases during estrus for physiological reasons or simply as a consequence of increased activity levels during estrus (Kyle et al., 1998). Progesterone has been suggested as the substance responsible for cyclic temperature variation in cows (Wrenn et al., 1958).

As an example of several attempts to enhance estrus detection with temperature monitoring, McArthur et al. (1992) used an increase of 0.4°C above the average of the previous 3 days to identify a temperature increase and identified 2 estrus periods in 2 cows in a controlled experiment. With the same technology in a commercial study, these researchers also attempted to identify temperature increases with a threshold value from 38.8 to 39.2°C. The detection rate ranged from 24 to 71%, but the percentage of false positives was 90 to 95%. In the same data set, increases in temperature from 0.2 to 0.6°C above the previous 5-day average for the same milking identified 32 to 50% of estrus events, but the percentage of false positives was 65 to 86%. The duration of elevation in body temperature was 9 hours. The authors concluded that milk temperature alone is not a reliable predictor of estrus because the length of the temperature increase does not coincide with milking times for all cows and the amount of variation inherent in temperatures within and between cows.

The length of the increase in body temperature associated with estrus must be considered when evaluating the frequency of temperature readings. If the length of time between measurements is greater than the duration of an individual animal's temperature increase, the estrus event will not be detected by the temperature monitoring system (Gil et al., 1997; Schlunsen et al., 1987). Further, the inconsistency of temperature response to estrus may limit the value of temperature changes for estrus detection (Nakamura et al., 1983). Schlunsen et al. (1987) were only able to detect estrus in 42% of animals measuring milk temperatures at milking times. In a review of automation of estrus detection, Firk et al. (2002) concluded that body or milk temperatures are "not useful for practical application, because these traits are highly influenced by other factors."

Temperature and Heat Stress

Telemetric temperature monitoring systems have been proposed as a tool to use in management of the negative effects of heat stress in cattle (Al-Haidary et al., 2001; Araki et al., 1984; Bennett and Holmes, 1987; Hicks et al., 2001; Lefcourt and Adams, 1996; Spiers et al., 2001). Peaks in core body temperature lag behind ambient temperature peaks by 1 to 5 hours and typically occur late in the evening (Al-Haidary et al., 2001; Hahn et al., 1990; Lefcourt and Adams, 1996; Spiers et al., 2001). Frequent or continuous monitoring of temperatures would be advantageous in understanding animal responses to heat stress (Lefcourt and Adams, 1996, 1998). Beginning at 25.6°C daily maximum ambient temperature, maximum daily body temperatures increases linearly at a rate of 0.42°C per 5°C (Lefcourt and Adams, 1996). Temperature monitoring is more challenging in the summer because of these rises in temperature and the effects of cooling strategies (Maatje et al., 1987). Peaks in body temperature are difficult to identify when environmental temperatures decrease below -7.5°C (Lefcourt and Adams, 1998). During winter, body temperatures are not significantly affected by ambient temperatures; however, the occurrence of circadian rhythms during colder weather suggests that thermoregulation is related to other influencers, like day length and daily heat load in addition to temperature (Lefcourt and Adams, 1998). A better understanding of the patterns of body temperature under varying scenarios may be useful in determining management strategies during heat stress (Al-Haidary et al., 2001). In one study, a vaginal telemetry temperature recording device identified a 1.5°C decrease in temperature following a cooling strategy (Nakamura et al., 1983). Data from telemetric temperature monitors could be fed into an immediate biological feedback loop designed to keep an animal in its thermoneutral zone (Lacey et al., 2000).

Continuous measurements of temperature could prove useful in evaluation of cooling and heat abatement strategies by providing a more accurate indication of cow response. Variation among cows may determine criteria for genetic selection of animals more tolerant of elevated temperatures. Nakamura et al. (1983) suggest that low early morning temperatures may be indicative of a cow's ability to dissipate heat.

Temperature and Calving

Automatic temperature monitoring systems for cattle have been proposed for use in identifying the onset of calving. The mechanism for this relationship is undetermined (Aoki et al., 2005), but it is common across species. The ability to predict calving time would be useful in assisting difficult births. Consequently, calf mortality rates may decrease and reproductive function of the dam could improve. Body temperature has been demonstrated to drop between 8 to 48 hours before calving. Temperatures increase 3 to 5 days before calving and begin dropping about 2 days before parturition (Metz et al., 1987). Temperatures may drop 1.0 to 1.6°C 1 to 2 days prior to calving (Wrenn et al., 1958). A research project using the CowTemp™ product demonstrated the ability to identify 9 cows soon to calve within 9 to 23 hours of parturition by identifying temperatures significantly lower than a rolling average of previous temperatures (Nielsen et al., 2001). Aoki et al. (2005) examined the ability of continuous vaginal temperatures to predict calving time in Japanese Black × Holstein-Friesian crossbred beef cattle. After identifying vaginal temperatures at a particular time in the day that were at least 0.3 or 0.5°C higher than temperatures at the same time on the preceding day for at least 3 consecutive hours, all cows in this study calved within 60 hours. When only maximum and minimum temperatures for the day were considered, the predictive ability decreased, likely because insufficient data were available to predict time of parturition.

The remainder of this report will provide a summary of research we have conducted with automatic temperature monitoring of cows to determine relationships with rectal temperature and impact of water consumption on reticular temperature. Work on cost-benefit implications will be examined briefly. While no endorsement is implied, the CTMS system (MaGiiX Inc., Post Falls, ID) was selected for work in this report to provide an example of how to approach profitability analysis of intervention technologies. At the time of selection, it was the only system commercially available and with an established pricing schedule. Tools established for cost-benefit analysis could easily be applied to other systems.

Relationship with Rectal Temperature

The magnetized, biologically inert CTMS bolus resides in the cow's reticulum and is queried each time the cow passes a reader. The intent of this experiment was to evaluate the association between rectal and reticular temperatures, and the results have been reported (Bewley et al., 2008a). Each lactating cow at the Purdue University Dairy Research and Education Center was administered a reticular bolus. Temperatures were collected for all cows for 4 consecutive milkings each during 4 collection periods selected to represent varying environmental conditions. Cows were managed in 3 housing systems: a freestall barn with 128 stalls in 4 quadrants, a bedded-pack barn with an open grass lot, and a geothermally-modified barn with tiestalls for overflow and sick cows and box stalls for recently fresh cows.

The 4 collections were conducted on May 30 and 31, 2006 (spring), September 27 and 28, 2006 (fall), January 31 and February 1, 2007 (winter), and July 25 and 26, 2007 (summer). The numbers of cows sampled during each collection period were 185, 187, 180, and 182 for spring, fall, winter, and summer, respectively, and ambient maximum temperature-humidity index **(THI)** and average THI for the collection days during these time periods are in Figure 2. Because of herd turnover and dry periods, 280 total cows were utilized across the entire study period, but only around 190 cows had temperatures collected for any one time period. All temperatures were recorded immediately after milking. Milking times were from 5:00 a.m. to 9:30 a.m. and from 4:00 p.m. to 9:30 p.m. for the a.m. and p.m. milkings, respectively.

Rectal temperatures were recorded using a GLA M750 digital thermometer (GLA Agricultural Electronics, San Louis Obispo, CA) for each cow as she left the milking parlor, and reticular temperatures were recorded for cows as they passed the stationary reader panels positioned before and after the scale in which rectal temperatures were recorded (Figure 1). The first reader panel was located in a single-lane exit alley from the milking parlor. After cows passed the first reader panel, they were diverted into a stationary scale where rectal temperatures were collected. Following collection of a rectal temperature, cows passed a second reader panel located in a pathway leading to the freestall barn. This second panel was added only after the spring collection period (and thus available for the fall, winter, and summer collection periods) to increase the percentage of cows with a valid reticular temperature reading. Adding a second panel proved beneficial by increasing the likelihood that a cow's temperature was measured at 1 of the 2 panels. Both panels used the same technology to read boluses and were close in proximity; consequently, variation in temperatures between panels was not a concern.

Reticular and rectal temperatures were recorded simultaneously in the milking parlor's exit lane in 4 consecutive milkings in each of 4 seasons, totaling 16 measurements per cow. Data were edited to remove reticular temperatures likely to have been impacted by a recent drinking bout. For the 2042 observations used in analyses, means (± SD) were 39.28 (± 0.41), 38.83 (± 0.36), and 0.45 (± 0.33) for reticular temperature, rectal temperature, and difference between reticular and rectal temperatures, respectively. The reticular and rectal temperatures were modestly correlated ($r = 0.645$, $P < 0.0001$). Numbers of paired observations and Pearson coefficients of correlations of reticular temperature with rectal temperature for season, milking, and housing system are in Table 1. Corresponding least squares means for reticular and rectal temperatures are in Figure 3 for levels of these effects. Within categories, average differences between rectal and reticular temperatures were quite consistent.

Because dairy producers and veterinarians are accustomed to viewing rectal temperatures, equations to adjust reticular temperatures to a rectal-based scale may increase the utility and interpretability of rumen temperatures. The resulting conversion equations were obtained from this work:

AM Milking: RECT = 19.23 + 0.496 (RETT)
PM Milking: RECT = 15.88 + 0.587 (RETT),

where RECT is rectal temperature and RETT is the measured reticular temperature.

Effect of Water Intake

While automated reticular temperature recording may allow early detection of disease, estrus, heat stress, and the onset of calving, one potential limitation to collection of reticular temperatures is the impact of water temperature and consumption on recorded temperatures. Two replicated 3 x 3 Latin Square experiments were conducted at the Purdue Dairy Research and Education Center to assess the impact of water intake on reticular temperatures using the Cattle Temperature Monitoring System (Bewley et al., 2008b). Nine high-producing, mid-lactation, 2nd parity cows with low somatic cell counts (SCC) were selected. Prior to administering a water treatment, access to feed and water was restricted for at least 2 hours. Baseline reticular temperatures were established from measurements prior to water intake.

In the first experiment, treatments were 25.2 kg (55.4 lb) of hot water (34.3°C ± 1.0), warm water (18.2°C ± 0.4), or cold water (7.6°C ± 0.4). Most of the water was infused by oral gavage. However, the length of time allotted for measuring cows was limited to 3 hours because the cows were deprived of feed and water during that time and because the cows had to be herded past the stationary panel readers. As the cows tired, it became more and more difficult to encourage them to move past the panels. As expected, following an initial dramatic drop in reticular temperature, a gradual rise toward baseline occurred. Least squares means for maximum drop in temperature were 8.5 ± 0.5, 6.9 ± 0.5, and 2.2 ± 0.5°C for cold, warm, and hot water treatments, respectively. It was somewhat surprising that during the entire 3 hours after water "consumption", reticular temperatures did not return to baseline. Therefore, water volume was reduced and a control group of cows that did not consume any water was added for a second experiment.

In experiment 2, treatments were 18.9 kg (41.6 lb) of body temperature water (38.9°C ± 0.2), cold water (5.1°C ± 0.4), or control (no water). Following water intake, reticular temperatures were collected for 3 hours. In experiment 2, control cows remained within the 95% confidence interval of the baseline through the observation period, and cows receiving body temperature water experienced an initial drop in temperature 0.4 ± 0.2°C, with a return to within the baseline confidence interval within 15 minutes (Figure 4). Cows receiving cold water did not return to within the baseline confidence interval after a large drop of 9.2 ± 0.2°C during the 3 hour observational period. Moreover, a regression analysis of continued ascent in temperatures predicted that temperatures would return to baseline within 3.5 hours. The volume of water fed to cows in this study was substantial, making the cold water treatment almost a worst case scenario. However, these results demonstrate that when cows consume large quantities of cold water, the impact of water intake is sizable and sustained. The value of reticular temperatures for daily monitoring in a production setting hinges largely on the implications of this impact. Technologies that record temperatures at specific times, such as after milking, as in this study, or when moving between housing and feed (Small et al., 2008), may not be greatly affected because of the time lag following water (or feed) consumption. Technologies that may log frequent recordings of rumen temperature must employ algorithms to smooth temperatures over periods of sharply decreased temperatures resulting from drinking bouts.

Utility of Automated Temperature Monitoring

Perhaps the largest single factor that will determine the rate of adoption of automatic temperature technologies is how quickly the technologies can move from the present, largely experimental stage to a more reliable and commercially viable stage. Reliability implies that the equipment is failsafe and mass produced to decrease initial investment and per animal costs. There is interest in the use of body temperature to manage physiological and infectious conditions of dairy cattle. We conducted a survey of 19 industry experts in the field of health and dairy cattle management and asked what conditions the availability of regular temperature observations would be likely to impact. In order, the responses ranked heat stress, mastitis detection, and estrus detection as most important, followed by metritis, respiratory disease, animal well-being, and pregnancy diagnosis (Table 2).

Care must be taken in comparing the costs and expected benefits of investment in temperature monitoring technologies, as many determinations depend intrinsically on the assumptions about the value of resultant management practices. Using an early version of a cost-benefit model, similar to that reported by Bewley and Schutz in another paper within this Proceedings to assess investment in automatic body condition scoring, the feasibility that investment in a temperature monitoring system would be profitable depended largely on the herd's current estrus detection rate and on the assumed improvement in estrus detection. However, this result was largely predicated by the extent to which one assumes periodic temperature observation may enhance estrus detection. The effect of herd size on such investment may partially arise from initial fixed cost of the system but may be more related to reduction in costs of days open that may be magnified in larger herds. But most other factors considered at the time this model was developed were based on lacking or incomplete information about the extent to which additional knowledge about cow temperatures might impact herd management decisions and the success of those decisions. Our knowledge about those factors is growing, but remains, at best, incomplete. Research is continuing to assess the ability of reticular temperature monitoring, perhaps in conjunction with other precision dairy farming tools, to allow earlier intervention with appropriate management, and outcome of early intervention will be the key to the ultimate success or failure of any temperature monitoring technology.

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Table 1. Numbers of paired observations (n) and Pearson correlation coefficients (r) between reticular and rectal temperatures between paired observations across categories (Bewley et al., 2008a)[1].

	Season			
	Spring	Summer	Fall	Winter
r	0.715	0.580	0.726	0.565
n	330	584	573	555

	Milking	
	a.m.	p.m.
r	0.547	0.729
n	999	1043

	Housing System[2]		
	FS	GM	BP
r	0.646	0.758	0.576
n	1539	210	293

[1] $P < 0.005$ for H_0: $r \neq 0$ for all correlations

[2] FS = Freestall, GM = Tie-Stall with geothermal modified ambient temperatures, and BP = Bedded pack.

Table 2. Results of a survey of 19 industry professionals asked to rank 1 to 7 the potential for automatic temperature recording to impact management of 7 infectious or physiologic conditions.

	Frequency of ranking by experts (1 = highest, 7 = lowest)							
Temperature Application	1	2	3	4	5	6	7	Mean
Heat stress monitoring	5	5	2	4	0	1	2	3.00
Mastitis detection	4	3	6	2	4	2	0	3.24
Estrus detection	1	5	3	3	4	5	0	3.90
Metritis detection	1	3	3	2	5	3	1	4.11
Pneumonia/respiratory disease detection	3	1	2	5	2	4	2	4.16
Animal well-being	2	2	4	0	3	4	2	4.18
Pregnancy detection	4	0	1	1	0	2	13	5.43

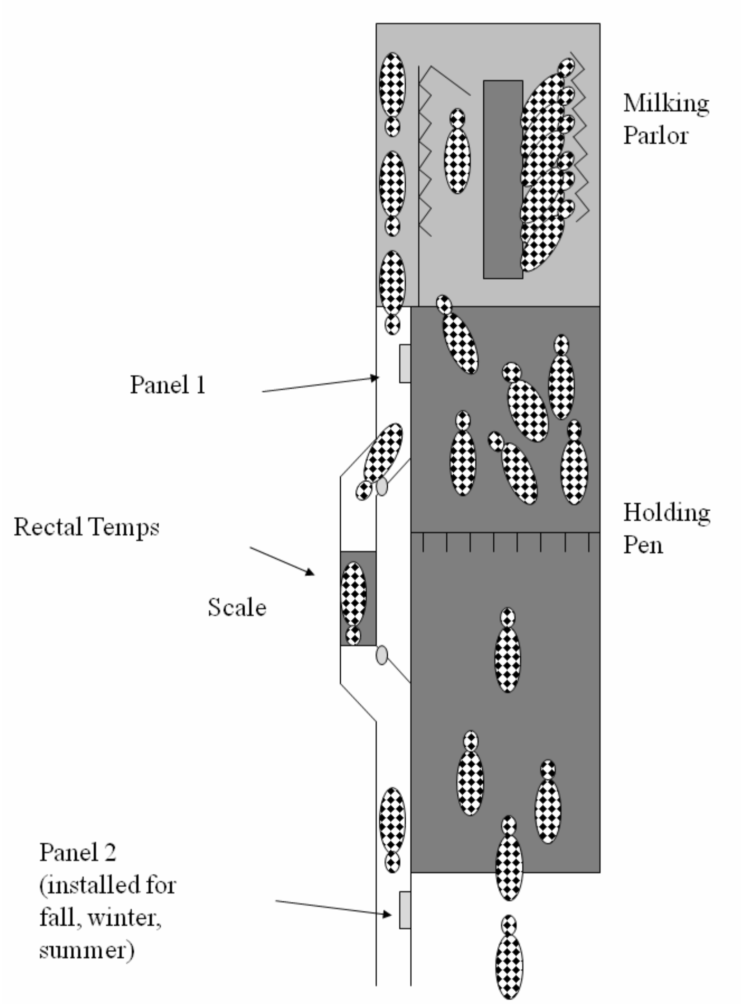

Figure 1. Schematic of layout of Cow Temperature Monitoring System as installed at Purdue University Dairy Research and Education Center.

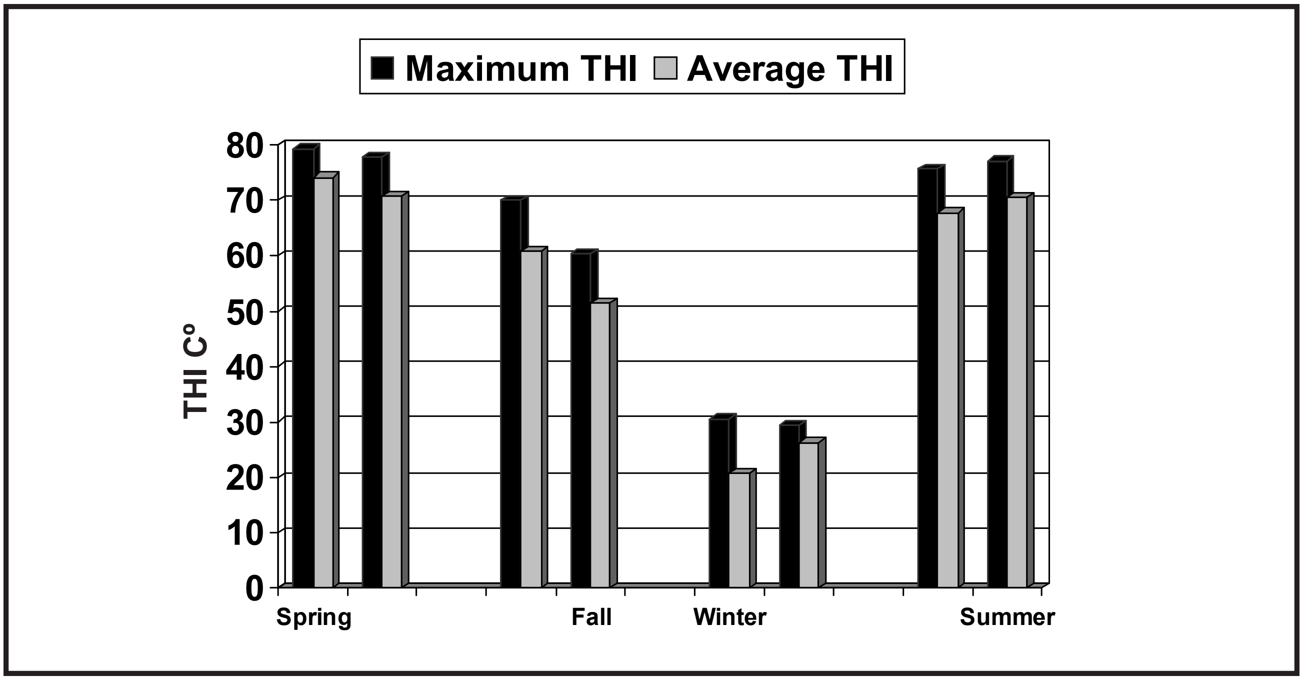

Figure 2. Maximum and average values for Temperature Humidity Index (THI) for the 2 days within each of the 4 collection periods.

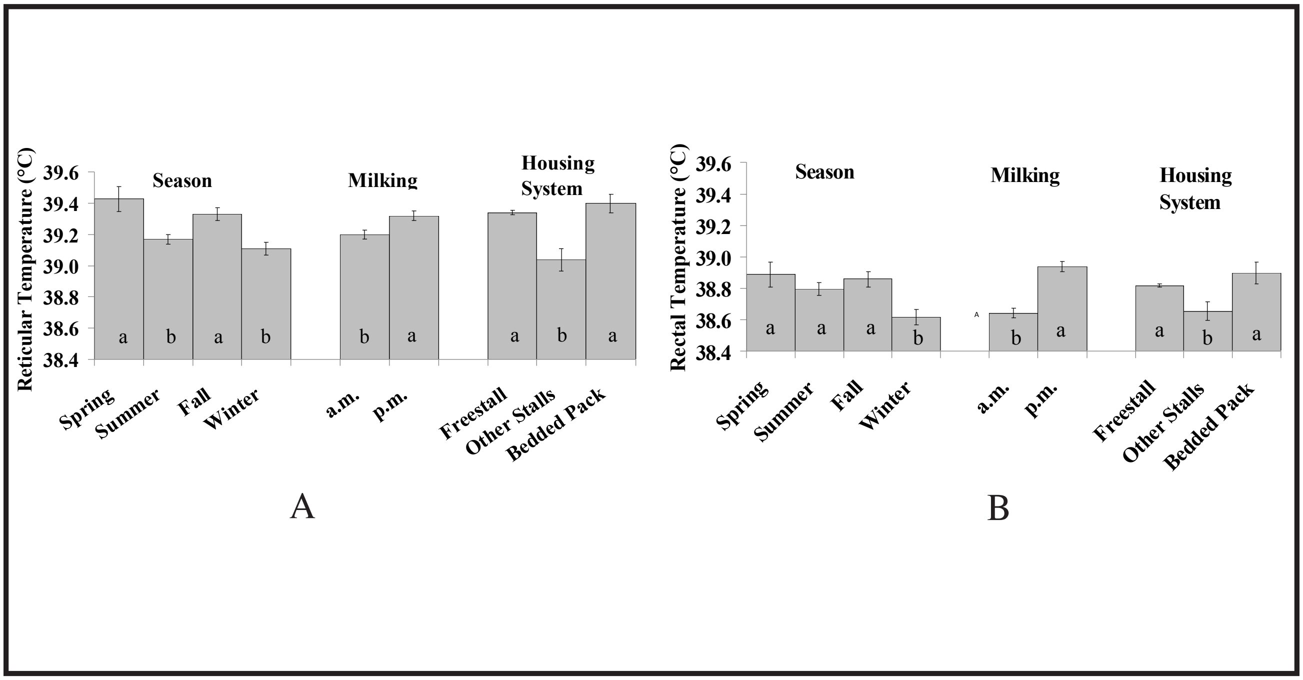

Figure 3. Least squares means for significant fixed effects in mixed models for reticular (Panel A) and rectal (Panel B) temperatures. Means within category with different letters were significantly different ($P < 0.05$) using Tukey's adjustment for comparison of means. For housing system, FS = Freestall, GM = Tie-Stall with geothermal modified ambient temperatures, and BP = Bedded pack.

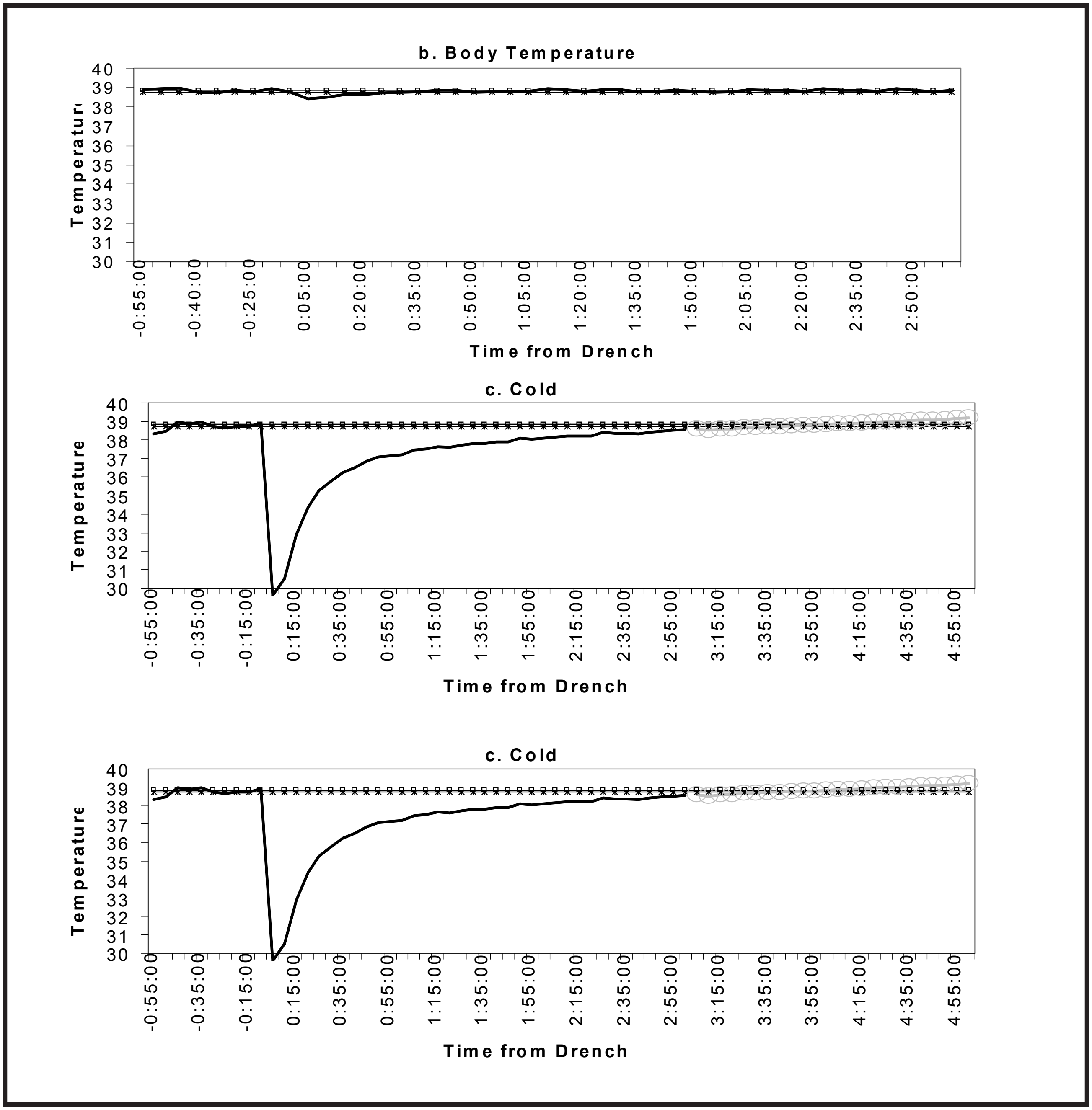

Figure 4. Reticular temperature response patterns for treatments involving consumption of no water (control) (a), body temperature water (b), and cold water (c) (Bewley et al., 2008b).