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Physiological Responses of Holstein Steer Calves to Winter Climatic Conditions

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PHYSIOLOGICAL RESPONSES OF HOLSTEIN STEER CALVES TO WINTER CLIMATIC CONDITIONS

By

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PHYSIOLOGICAL RESPONSES OF HOLSTEIN STEER CALVES

TO

WINTER CLIMATIC CONDITIONS

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor Date

Head, Agricultural Engineering Department Date

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INTRODUCTION

A major concern of livestock producers is maximum animal growth and product yield. Most animals can grow and produce normally over a wide range of ambient temperatures, air velocities, relative humidities, and solar radiation conditions, but under extreme conditions stresses will develop in unprotected animals. South Dakota winter weather is often severe with low temperature, high wind velocity, high humidity, and freezing rain or snow occurring simultaneously. Stresses caused by this combination of weather conditions are the greatest hazard faced by livestock wintered outdoors, Winchester (42). Windbreaks and other forms of shelter are commonly used to reduce the effects of one or more of these environmental factors. While information is available concerning high temperature and humidity effects on livestock production and physiological stress, only limited data on the effects of cold climatic conditions on livestock stress are available, espectially under actual winter conditions.

Agriculturalists need information concerning the combination of winter climatic factors causing stress to properly develop shelter and housing design recommendations for improved cold climate livestock production. Specifically, research based on the physiological reactions of animals to varying climatic conditions is needed to develop effective temperature indices for individual types of livestock that relate combinations of climatic conditions to livestock comfort.

When a warm blooded animal, homeotherm, is subjected to an environment colder than body temperature, according to the physical laws of heat and mass transfer, heat dissipation from the animal will be increased. Left unchecked the body temperature will drop, homeothermia, possibly resulting in death. The animal compensates for this heat loss by increasing heat production and/or reducing heat loss by a number of chemical or physical adjustments. One such adjustment is vasoconstriction, which reduces blood flow to the surface, thereby, reducing the temperature of the skin and extremities, with peripheral temperatures of some homeotherms dropping to slightly above freezing without injury or apparent discomfort, Scholander (31). The blood flow to the surface is further reduced by a decreased pulse rate, resulting in less heat transfer from within the body to the surface. With the skin temperature reduced, heat loss to the environment by convection, radiation, and conduction is reduced, because the surface and ambient temperature difference is lessened.

Respiration rates of animals subjected to cold environments are reduced to minimize evaporative and sensible heat loss from the respiratory system. Many types of animals will acclimate to the environment by increasing the thickness of the insulating hair coat and the subcutaneous fat layer. By increasing the insulating properties of the outer surface, heat loss is reduced. Increasing heat production is another factor in an animal's acclimatization and is accomplished by increasing the basal metabolism rate. For abrupt changes in environment, increased heat production takes the form of increased metabolism and muscular activity such as shivering. Pilomotor reflexes provide another adjustment to falling temperature by erecting hair or feathers.

Ambient temperature, relative humidity, wind velocity, and solar radiation are factors affecting comfort and production of livestock. A knowledge of the significance of each of these factors on skin temperature, rectal temperature, pulse rate, and respiration rate of cattle would be useful in determining stress causing conditions. Activities of the chemical and physical mechanisms to maintain constant body temperature are minimum at critical temperature, which varies with type and age of livestock. Increased activity of these homeothermic mechanisms indicate animal discomfort and reflect energy uses not available for production. Relationships between climatic conditions and animal comfort are essential in the design of improved shelters and housing systems. Therefore, a study was initiated with the following objectives:

1. To relate the winter climatic factors of ambient temperature, wind velocity, relative humidity, and solar radiation to dairy calf rectal and skin temperatures, pulse rate, and respiration rate.
2. To develop a cold weather effective temperature index for dairy calves from the skin and rectal temperatures, pulse rate, and respiration rate responses to natural winter climatic factors.

REVIEW OF LITERATURE

Heat Production

The environment circumscribes all non-genetic influences affecting calves. To obtain an estimate of the influence attributed to environment either a physiological or a productive response is measured. Physiological responses such as rectal temperature, respiration rate, pulse rate, and skin temperature provide a measure of animal comfort.

Experiments designed to determine the influence of low temperature, under controlled conditions on the very young calf, are few. However, according to Appleman and Owen (1) there are numerous reports of calves being kept outdoors during cold weather without adverse effects. Erb (8) raised calves in open sheds at temperatures to -20 F with a death loss of two percent. Murley and Culvahouse (28) housed three day old calves in an open shed at temperatures down to 13 F with no adverse effects. Work at South Dakota State University by Jorgenson (14) and at Purdue by Willet (41) substantiated the previous findings.

Calves and other animals can experience low temperatures and the accompanying winter environmental factors without adverse effects, if they maintain homeothermy through appropriate physiological responses. Increased heat production is one homeothermic response to low temperatures. Blaxter, et. al. (2) found that young calves begin to increase heat production when air temperature drops below 55 F. McDowell (26) showed that mature animals do not increase heat production until air temperature is about 44 F and yearling heifers appeared to have about the same response.

Thompson (36) in studies of Jersey, Brahman, Brown Swiss, and Holstein dairy cows found that decreasing the temperature from 90 to 10 F increased total heat production from 2600 Btu/hr/1000 lb to 3800 Btu/hr/1000 lb. Kibler and Brody (17) concluded that gradually decreasing temperature from 50 to 5 F caused a 30 to 35 percent increase in heat production of lactating Jersey cows, and a 20 to 30 percent increase in heat production for lactating Holstein cows. Gradually increasing temperatures from 50 to 100 F caused a 20 to 30 percent decrease in heat production above 70 to 80 F.

Kibler and Brody (20) found that increasing wind velocity from 0.5 to 10.0 mph caused an increase in heat dissipation to the extent that heat production increased from 20 to 30 percent while rectal temperatures for Holstein, Jersey, and Brown Swiss cows remained normal. Brahman cows increased heat production by 60 percent but had a decrease in rectal temperature of approximately 1 F. Blaxter, et. al. (2) studied the effects of air velocity on critical temperature of steers and stated that low air velocities have a profound cooling effect, especially below critical temperatures. Increasing air velocity from 0 to 1.6 mph had no effect on heat production of steers at 68 F but at 32 F with a 0.4 mph wind velocity, heat production increased 4 percent. At 32 F and a 1.6 mph wind, heat production increased nearly 10 percent.

Air movement can cause an increase in the critical temperature so that heat production begins at a higher temperature. Studying 800 lb cross bred calves, Webster (38) concluded that the critical temperature was increased from 16 to 38 F by increasing the wind velocity from zero to 12 mph. Webster (40) compiled critical temperatures for 1 month, 1 year and 4 year old range cattle at zero and 10 to 16 mph wind velocities. Wind velocity increased critical temperatures 24 F for the 1 month old calves, 30 F for the yearlings, and 35 F for the 4 year old animals. Critical temperatures of the yearling and 4 year old cattle increased by as much as 42 F when the cattle were being fed a low energy diet.

Heat Dissipation

Worstell and Brody (43) concluded that heat loss from the body as a whole tends to follow Newton's Law of cooling and heat flow from the body interior to the surface tends to be proportional to the peripheral tissue conductance, which is vasocontrolled by blood flow. A gull studied by Scholander (31) did not lose much heat at -40 F from its long, thin, naked legs because of the greatly reduced blood flow. The blood flow was reduced by vasoconstriction which also reduced the conductance of the peripheral tissue and therefore reduced the surface temperature to slightly above freezing. According to Worstell and Brody (43), Hart (13) reported that in quiet mice, heat production and heat loss are proportional to the surface-to-environmental temperature gradient when ambient temperature is below critical temperature. In the study of artic animals Scholander (31) reported that heat loss is essentially proportional to the body-to-air temperature difference below the thermoneutrality zone.

Hardy (12) concluded that in man the rate of cooling followed Newton's Law of cooling and was a constant 5.3 Cal/m^2/hr per degree difference in skin and calorimeter temperature.

The literature contains reports on heat loss by cattle at various ambient temperatures. Yeck (46) reported that the average rate of heat dissipation decreased from 4720 Btu/hr/1000 lb cow at 10 to 40 F to 2820 Btu/hr/1000 lb of body weight per degree Fahrenheit as ambient temperature increased from 65 to 90 F.

Heat transfer can occur by vaporization without a temperature gradient even though the rate of vaporization is directly related to the temperature. Yeck (46) found that the rate of moisture dissipation from Jersey and Holstein cows increased from 0.77 lb/hr/1000 lb of body weight at 10 to 40 F to 2.41 lb/hr/1000 lb at 70 to 100 F. In a study of the effect of climatic factors on dairy cows Worstell and Brody (43) showed that heat loss by vaporization approaches zero at low temperatures and that nearly all heat transfer occurs by convection, conduction, and radiation. However, as ambient temperature approaches body temperature, heat loss by conduction, convection, and radiation approach zero and heat is dissipated mostly by vaporization. According to Kibler and Brody (22) respiratory vaporization proved to be an important means of heat dissipation. At 50 to 110 F and 60 to 110 F, as much as 35 percent of the heat produced was dissipated by respiratory vaporization, but at 10 to 40 F only approximately 6 percent of the heat was lost due to respiratory vaporization. Kibler, Yeck, and Berry (24), concluded that respiratory vaporization accounted for approximately 8 percent of the heat loss at 50 F and approximately 12 percent at 80 F. Skin vaporization accounted for approximately 16 percent of the losses of body heat at 50 F and 41 percent at 80 F. Results from studies by Cargil and Stewart (5) showed that evaporative heat transfer is inversely related to relative humidity. At a temperature of 80 F, increasing relative humidity from 30 to 80 percent reduced total vapor dissipation from 2.33 lb/hr to 1.74 lb/hr.

Worstell and Brody (43) reported that cattle in mountain states are wintered outdoors without injury at temperatures as low as -40 F, which produces a temperature gradiant of approximately 140 F.

Thompson, et. al. (36) studied the effects of wind on vaporization from the surface of dairy cattle and found no noticeable effect of increasing air velocity on the vaporization rate at 18 F, but at 50 F, the effect was uncertain. However, at 60 to 80 F, an increasing wind velocity reduced the vaporization rate due to surface cooling by convection. In man the convective heat loss does not increase linearly with an increase in air velocity, but approximately with the square root of velocity, Gagge, et. al. (11).

<u>Pulse and Respiration Rates, Rectal and Skin Temperatures</u>

Animal comfort determination and its relationship to environmental conditions was one of the concerns of this study. The following physiological responses were selected as indicators of comfort: respiration rate, pulse rate, rectal temperatures and skin temperatures, since previous research has indicated their relationship with animal comfort.

Studying the effects of air velocity on heat dissipation Kibler and Brody (20) concluded that rectal temperature should be given considerable attention for determining the upper limits of the comfort zone for cattle. At low temperatures, however, rectal temperature may not be a good index of comfort, since heat production rises and milk production may be depressed before rectal temperature falls below normal values. The study pointed out that rectal temperature is the best available index of an animal's ability to maintain homeothermy, however, it is a local measurement and may reflect local conditions rather than general conditions. The local effects would presumably diminish with increased depth of temperature sensor insertion.

Respiration rate and pulse rate have also been found to be good indices of livestock comfort in studies of environmental effects. Kibler and Brody (17) found that respiration rates at 5 F were approximately 0.4 that at low temperatures and there was no evidence of breed differences. In the winter minimal rates of 10 to 15 respirations per minute were observed at 4 F. The gradual decrease of ambient temperature from 50 to 5 F showed no significant change in rectal temperatures but an increase in pulse rate of approximately 8 percent was noted. Worstell and Brody (43) found no change in rectal temperature from about 32 to 60 F, but respiration rate decreased gradually for temperatures from 40 to 8 F in a comparative study of European and Indian evolved cattle. In an experiment with Shorthorn, Brahman, and Santa Gertrudis calves, Kibler (15) used flank movements for counting respiration rates and a stethoscope for counting pulse rate of calves. Results revealed that age had little effect on respiration but was a factor in pulse rates. At temperatures of 50 to 80 F maximum heart rates were noted at 4 to 6 months, accompanied by a rapid decrease for ages 6 to 8 months, and a lesser decrease thereafter.

Kibler and Brody (19), in a study of the effects of temperatures from 50 to 105 F and 50 to 9 F on heat production and cardiorespiratory activities in Brahman, Jersey, and Holstein cows, found that rectal temperatures remained nearly normal from 50 to 9 F. Pulse rates increased with decreasing temperature, and respiration rates decreased from approximately 25 to 15 per minute in the Holsteins, from 20 to 14 in the Jerseys, and from 14 to 12 in the Brahmans as temperature decreased from 50 to 9 F. Working with nonlactating Holstein cows Kibler, et. al. (23) studied the effect of temperatures from 2 to 35 C on energy metabolism, ventilation rate, vaporization rate, respiration rate, pulse rate, and rectal, skin and hair temperatures. This study agrees with earlier studies concluding that cold exposure from 2 to 10 C tended to increase pulse rate and decrease respiration rate. In studies using a heat chamber, Cartwright (5) found that relative humidity and age were significantly correlated with body temperature and respiration rate. Nelson (29) found that mean respiration rates were higher by 9.8 counts per minute for Brahman heifers, 19.1 for Santa Gertrudis, and 43.7 for Shorthorns at 80 F than at 50 F. In calculating thermoregulation time constants, Stewart and Baily (33) measured rectal and hypothalmic temperatures, respiration rate, and pulse rate of heifers subjected to an abrupt ambient temperature change from 24 to 35 C. Pulse rate appeared unreliable for young cattle with part of the error in the time constants attributed to differences in basal metabolism between the two heifers. In the previously mentioned study by Kibler and Brody (20), it was noticed that at about 17 F, increasing the air velocity from 0.5 to 10 mph caused a significant increase in pulse rate of 5 to 9 beats per minute for Holstein cows. Respiration rate showed from little change to a slight decrease.

Kibler and Brody (22) noticed that in a study of the physiological effects of diurnal temperature cycles, during 10 to 40 F temperature periods rectal temperatures were relatively constant for dairy cows. There was a slight rise between 3 and 6 P.M. and a slight fall between 8 A.M. and noon, but at no time did the amplitude of the rectal temperature cycle exceed 2 F. Respiration rates were found to be insensitive to temperature changes between 10 and 40 F but showed differences between size and breed. Pulse rates changed with ambient temperature, however, there was no sharp diurnal pattern. Pulse rates also increased at feeding time.

Thompson, et. al. (36) reported that increasing air velocity reduced the skin and hair temperatures of dairy cows roughly in proportion to the decline in environmental temperature. The lowering of the surface temperature with increasing air velocity was due to increased convective cooling since increased air velocity did not increase the vaporization rate, except at 95 F. Also the lower the ambient temperature the greater the depression of the skin temperature with increasing air velocity. In a study of the effects of growth and environmental temperatures on surface temperatures of beef calves, Stewart and Shanklin (34) concluded that at 50 or 80 F, increasing body weight is associated with decreasing skin temperature. Kibler and Brody (20) concluded that at 45 F air temperature, respiration rate, pulmonary ventilation rate and evaporative cooling increased moderately with increasing radiation intensity. These increases were persumed related to increased skin temperature rather than heat strain, as there were essentially no changes in rectal temperature or heat production. At 80 F rectal temperatures increased in European evolved cows by 0.5 to 5 F. Relating environmental temperatures to the skin and hair temperatures of European and Indian evolved cows led Thompson, et. al. (35) to the conclusion that skin temperatures increased linearily with ambient temperatures from zero to 65 F and then continued to increase but at a reduced slope.

At high temperatures, according to Appleman and Owen (1), high humidity has the effect of reducing heat loss by evaporation, thus adding to the heat stress. Heat loss by evaporation at low temperatures is minimal but a high relative humidity causes dampness of the coat and bedding so that vapor from these surfaces may increase the unfavorable effect of low temperatures. Early work at Missouri failed to show any measurable effect from humidity when temperatures ranged from zero to 70 F, but Kibler (16) demonstrated a close relationship between rectal temperature, respiration rate, and pulse rate and the temperature-humidity index (THI). It was suggested that this relationship may be applicable to cattle as well as man. According to Appleman and Owen (1), Findlay (10), and Preston (30) concluded that high humidity may have some effect due to condensation and damp bedding, but there is no evidence to suggest that high humidity itself has any effect on the animal at low temperatures.

Acclimatization

One adaptation to the environment by animals is the development of an insulating hair coat which is accomplished by reduced shedding. Webster (38) observed that total hair cover and mean hair coat depth of 600 pound cross bred calves kept outdoors from January through March was almost double that of calves housed at 70 F. Webster, et. al. (39) reported that cattle kept outdoors under extreme cold conditions became more cold tolerant than protected animals. The cold tolerant calves, however, became intolerably heat stressed when subjected to a 70 F climate. According to Appleman and Owen (1), Webster (40) found that sudden periods of mild weather may impose a more severe stress on cold tolerant cattle than prolonged periods of severely cold weather. Appleman and Owen (1), from field observations of Holstein and Brown Swiss calves, confirm the opinion that calves started outside were more cold tolerant than those started in a heated barn. All calves started outside rapidly developed hair coats and thrived well outside. Kibler and Brody (22) studied the effects of diurnal temperature cycles on heat production and cardiorespiratory activities in Holstein and Jersey cows and found that temperature increase from 80 to 110 F by increments of 5 to 10 F at 1 to 2 week intervals, depressed heat production by 40 to 45 percent. When the temperature changed rapidly or diurnally from 60 to 110 F, the change in heat production was about 5 percent. The difference in responses was thought to be due to acclimatization. Wyndham and Jacobs (44), working with miners, found that if a man acclimated to work in the heat of a mine is kept on the surface for 6 days, much of his acclimatization is lost. Depocas, et. al. (7), in a study of acclimatization of white rats, reported that rats acclimated to 30 C could withstand temperatures down to -15 C. Whereas, rats acclimated to 6 C had a lower limit of -35 C. The cold acclimated rats acquired the ability to reach high heat production and maintain high heat production for long periods.

PROCEDURE

The effects of temperature, relative humidity, wind velocity, and solar radiation were evaluated from December 1, 1973 to March 7, 1974 on respiration rate, rectal temperature, heart rate, and skin temperature of three Holstein steer calves maintained under winter climatic conditions. All tests were conducted on the South Dakota State University, Dairy Research Farm located approximately two miles north of Brookings, South Dakota.

The calves, 14 weeks of age at the beginning of the study, were wintered outdoors with access to cold housing in a free stall barn with all feed and water provided outdoors. During the tests the calves were removed from this lot and tied in stalls in an open field away from buildings and trees. The stalls were constructed to give minimum interference to wind and solar radiation, and could be rotated and secured at any angle so that the calves faced normal to the wind direction, Figure 1, exposing the largest calf area to the wind for maximum convective cooling. The calves remained in the stalls for 30 minutes before tests were initiated to eliminate handling effects on physiological responses. All tests were performed during daylight hours.

Ambient temperatures as well as rectal and skin temperatures were monitored with copper-constantan thermocouples and were recorded by a strip-chart potentiometer. Rectal temperatures were detected by thermocouples imbedded in plexiglass tubes, which were inserted to a depth of approximately 10 inches. Two thermocouples were used on each

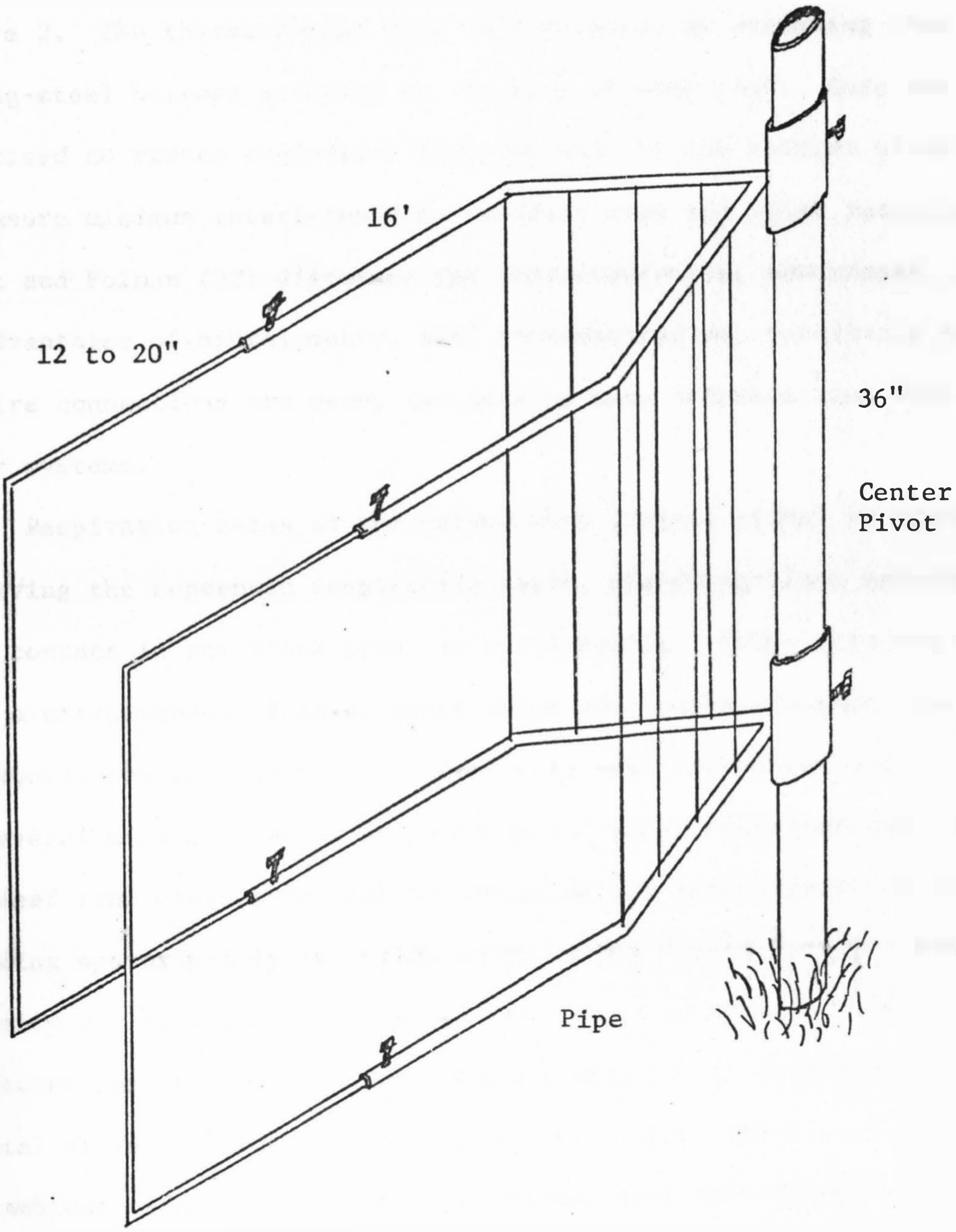

Figure 1. Variable Size Calf Stall

side of each calf to measure skin temperature of the trunk region, Figure 2. The thermocouples were held in place by attaching them to a spring-steel harness attached to the back of each calf. Care was exercised to reduce conduction from the skin by the harness wires and to insure minimum interference to incident wind and solar radiation. Scott and Polman (32) discussed the characteristics, advantages, and disadvantages of biotelemetry, SAMI instrumentation, concluding that, if wire connections are used, the data is more reliable than with other systems.

Respiration rates of the calves were counted either by visually observing the condensed respiratory vapor, observing flank movements, hand contact in the flank area, or by listening. Pulse rate was detected with a stethoscope. Initial heart rates were usually higher than subsequent counts, therefore, pulse rates were determined over a period of several minutes. Relative humidity and solar radiation data were obtained from weather records monitored at the Agricultural Engineering Building approximately two miles south of the research site. Wind velocity was measured at the site with a vane anemometer. Data were collected for the three calves simultaneously on 12 different days giving a total of 96 respiration rates, 109 pulse rates, 368 rectal temperatures, 377 ambient temperatures, and 15 different wind velocities.

Step-wise multiple and polynomial regression analyses were used to establish the correlations between the measured climatic factors and the physiological responses.

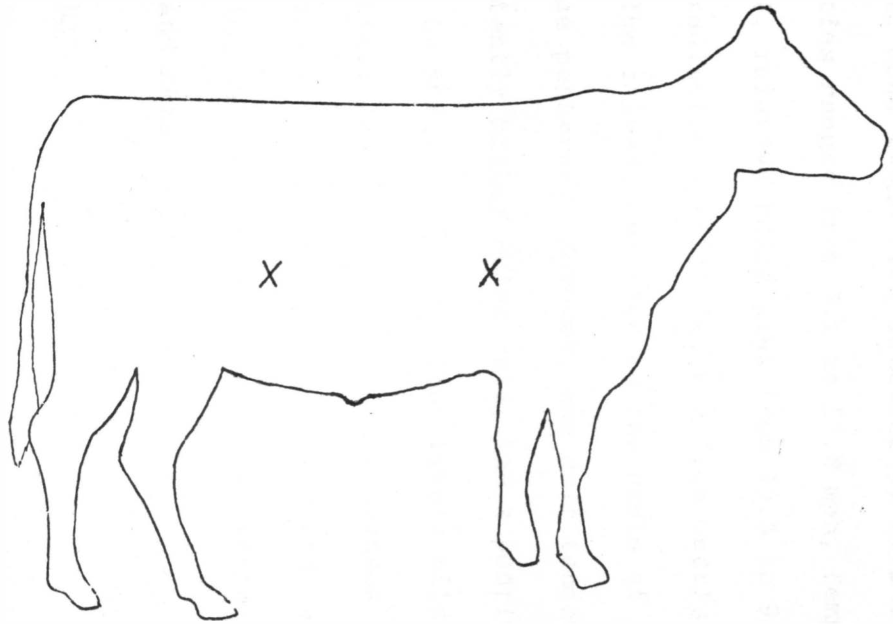

Figure 2. Side View of Calf Showing Location of Skin Temperature Sensors

RESULTS AND DISCUSSION

Pulse rates, rectal temperatures, respiration rates, and skin temperatures were monitored for three Holstein steer calves under actual climatic conditions from December 1, 1973 to March 7, 1974. Wind velocities ranged from 3.1 to 15.8 mph, temperatures from 37.5 to -12.0 F, relative humidities from 49.5 to 90.0 percent, and the range of solar radiation intensities was from nearly zero to 0.6 gm-cal/cm^2.

The calves, selected on the basis of age and sex showed similar response patterns. However, one calf tended to be nervous, had a consistently higher pulse rate, had a poorly developed hair coat, and tended to shiver even at comparatively mild weather conditions. All statistical analyses reflect the responses of the three calves taken collectively. Results will be presented and discussed under the following sub-headings: pulse rate, rectal temperature, respiration rate, and skin temperature.

Pulse Rate

The range of pulse rates for the three calves was from 60 to 138 beats per minute with the pulse rate of the nervous calf never lower than 74 beats per minute and the pulse rates of the other two calves never exceeding 122 beats per minute. Pulse rates generally tended to increase as temperature decreased, although the lowest pulse rate was recorded on the coldest day, -12.0 F, with a moderate wind velocity of 8.6 mph. This was probably due to acclimatization, which will be discussed later in this section.

Increasing wind velocity tended to decrease pulse rate according to the following significant* prediction equation, illustrated in Figure 3,

$$PR = 110.1 - 0.0126\ VW,$$

PR = pulse rate, beats per minute

VW = wind velocity, feet per minute

which explains 7.2 percent of the variation in pulse rate. This disagrees with research by Kibler and Brody (20) that revealed a 5 to 9 beat per minute increase in pulse rate of Holstein cows maintained at 17 F as wind velocity increased from 0.5 to 10 mph. However, Stewart and Baily (33) reported that pulse rate may not be a reliable physiological stress indicator for young cattle.

Pulse rate was not linearily related to any of the remaining climatic variables monitored or combinations of these variables. However, pulse rate varied curvilinearly with ambient temperature as indicated in the following sixth degree polynomial:

$$PR = 119.6 - 3.22\ TA + 0.16\ (TA)^2 + 0.023\ (TA)^3 - 0.0031\ (TA)^4 + 0.00012\ (TA)^5 - 0.0000014\ (TA)^6$$

TA = ambient temperature, F

which explains 68.1% of the variation in pulse rate. Figure 4 shows pulse rate data at various temperatures for each calf and the prediction equation. Although, there is considerable variation between calves the nature of the response is the same for all three calves at any given temperature. Kibler and Brody (17) and (18), and Kibler, et. al. (23) found a similar trend at temperatures from 30 to 5 F for Jersey, Holstein,

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* Significance in this paper is at the 5% level, Table 5.

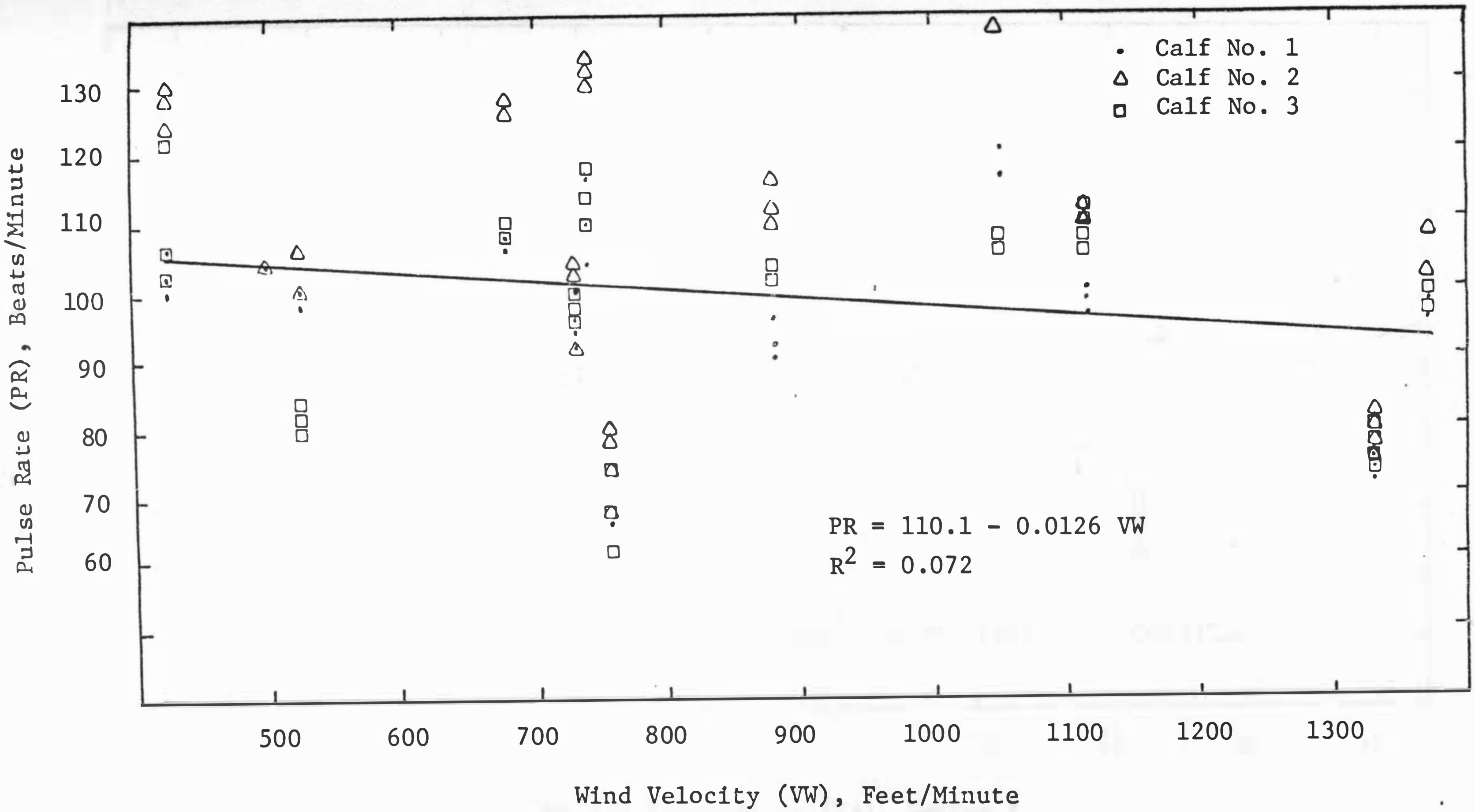

Figure 3. Pulse Rate of Holstein Steer Calves as Affected by Wind Velocity

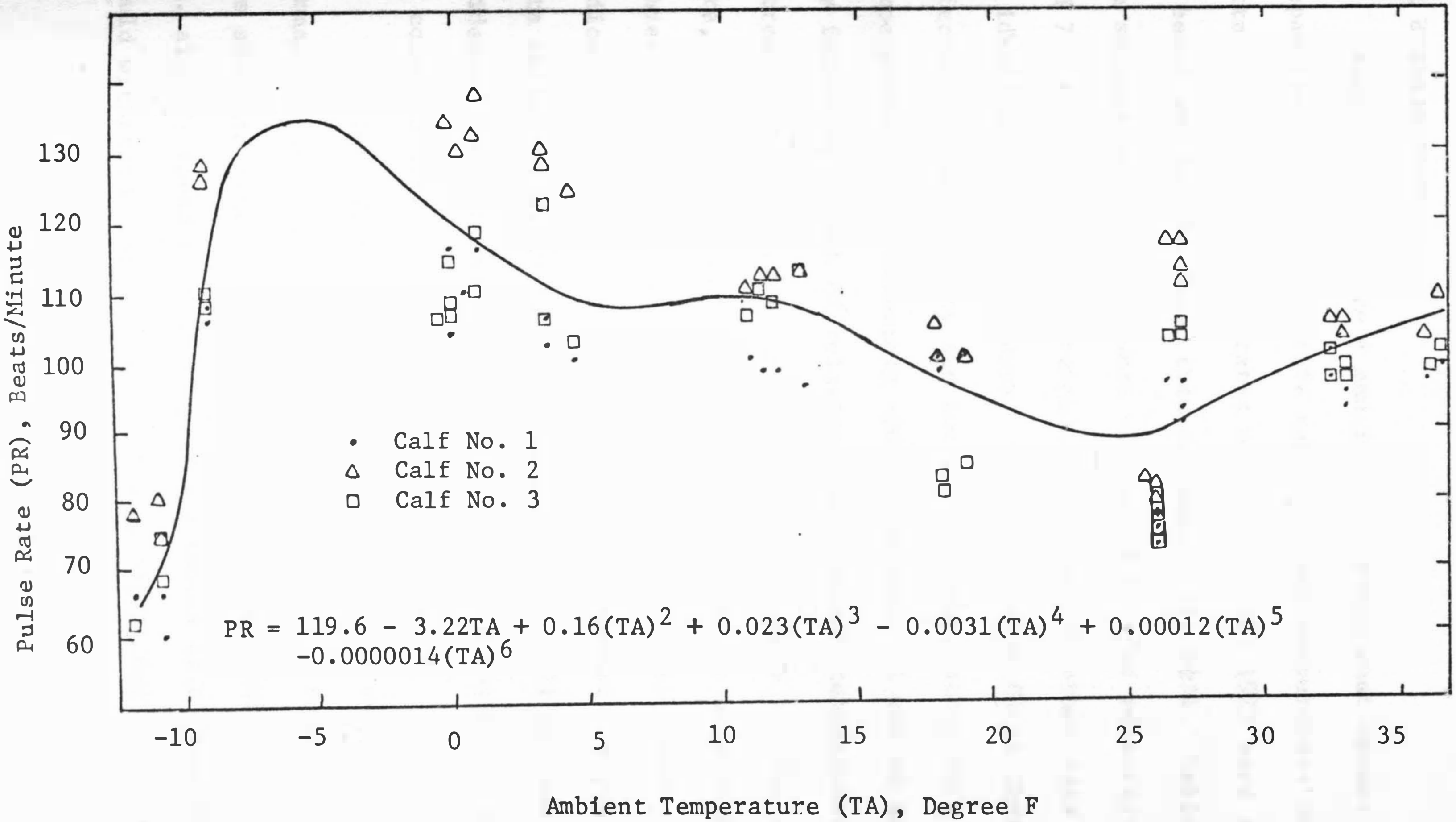

Figure 4. Pulse Rates of Holstein Steer Calves as Affected by Ambient Temperature

and Brahman cows.

Analysis of Figure 4 and Table 2 reveal what appear to be discrepancies between pulse rate responses and temperature conditions on certain days. The pulse rates on December 31, 1973 were approximately 45 beats per minute lower than on January 11, 1974. Table 2 shows that the ambient temperatures were -12 and -9 F, wind velocities were 8.6 and 7.7 feet per minute, respectively, and all other data were similar or identical for the two days. The Army's Wind Chill Chart (27) combines effects of wind velocity and low ambient temperature into an effective temperature of approximately -30 F. December 31 was an extremely cold day following a week of relatively mild winter temperatures with no extremely cold temperatures prior to that, Table 4. The calves, therefore, had no opportunity to become acclimated to cold conditions. The ambient temperatures remained extremely low until January 11, when data indicate that the calves had become cold tolerant. Using similar logic, data collected March 7, 1974 and January 24, 1974 produce additional evidence that acclimatization is an important factor in livestock response to cold weather.

The literature supports the importance of acclimatization of mammals to heat or cold. Wyndham, et. al. (44) reported that six days was adequate time for man to lose much of his heat tolerance. Depocas, et. al. (7) found that white rats acclimated to a temperature of 30 C could withstand temperatures as low as -15 C, but rats acclimated to

6 C could tolerate temperatures as low as -35 C. Webster, et. al. (39) reported that calves kept outside under extremely cold conditions became cold tolerant but were severely heat stressed at 70 F.

Some of the variation in pulse rates may be attributable to the differences in acclimatization of the calves on different days. The relationship of ambient temperature and pulse rate on the two days discussed may indicate one of the first responses to be expected when calves are exposed to low actual or effective temperatures to which they are not acclimated.

Rectal Temperature

Rectal temperatures are depressed by an increase in wind velocity, Figure 5, with 37.7 percent of the variation in rectal temperature accounted for by wind velocity. The following significant prediction equation

$$TR = 102.7 - 0.0013\ VW$$

TR = rectal temperature, degree F

shows the relationship of rectal temperature and wind velocity.

The relationship of rectal temperature and ambient temperature was

$$TR = 101.9 - 0.019\ TA,$$

which significantly explains 17.3 percent of the variation in rectal temperature, Figure 6. Over the temperature range of the study, a decrease in ambient temperature was accompanied by an increase in rectal temperature.

Ambient temperature and wind velocity combine to explain 42.4

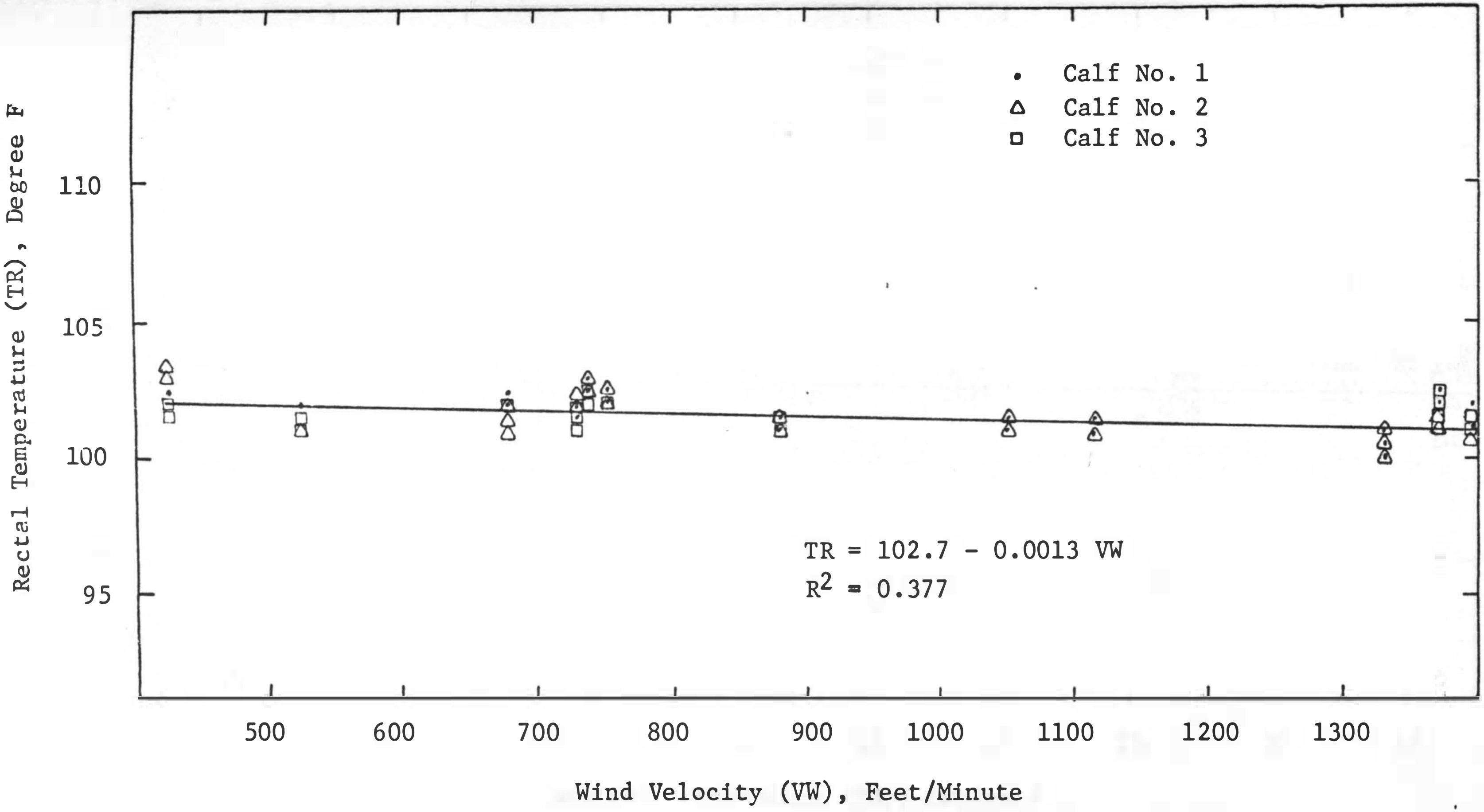

Figure 5. Rectal Temperature of Holstein Steer Calves as Affected by Wind Velocity

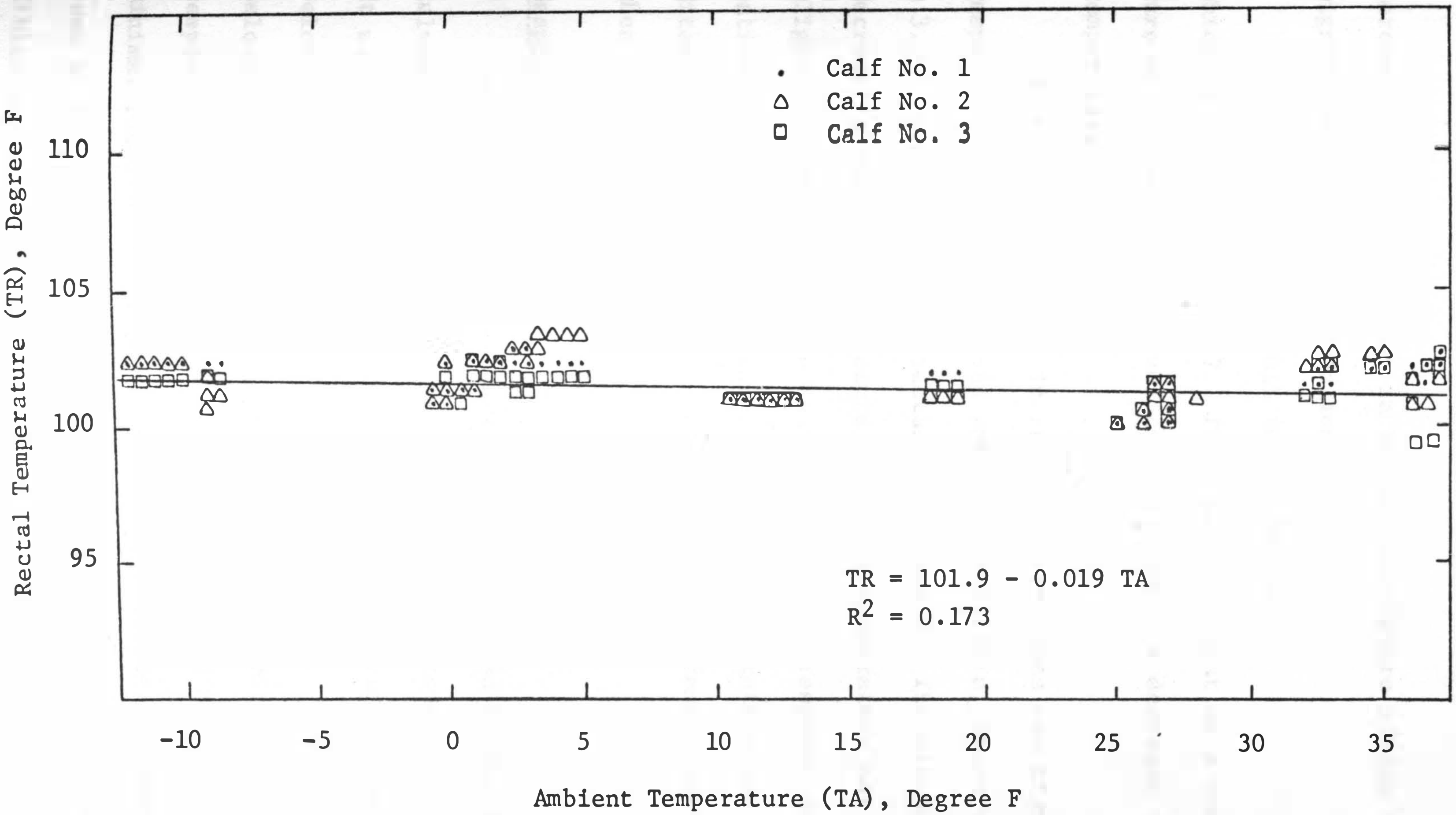

Figure 6. Rectal Temperature of Holstein Steer Calves as Affected by Ambient Temperature.

percent of the variability in rectal temperature giving the following significant prediction equation:

$$TR = 102.7 - 0.0011\ VW - 0.011\ TA$$

which is shown in Figure 7. This indicates that at a constant temperature an increase in wind velocity will cause a decrease in rectal temperature.

Although the change in rectal temperatures was significant with respect to wind velocity and ambient temperature, there was no more than a 3.5 F overall range in rectal temperatures. The elevating effect of decreasing ambient temperature on rectal temperature may be due to a slight overcompensation in heat production in response to heat dissipation. No significant change in rectal temperature was reported in the literature (17, 19, 43, and 20) until ambient temperature exceeded 80 F, then an increase was noted.

Respiration Rate

The winter climatic conditions experienced by the Holstein steer calves produced a 13 to 26 breaths per minute range in respiration rates. It was found that respiration rates decreased with an increase in wind velocity and a decrease in ambient temperature. Combinations of wind velocity and low ambient temperature had an additive effect in depressing respiration rates. Correspondingly, Kibler and Brody (17) reported minimal respiration rates of 10 to 15 per minute for Jersey and Holstein cows at 4 F and the respiration rate at 5 F was 0.4 of that at 50 F. Kibler and Brody (19) decreased ambient temperature from 50 to 9 F and

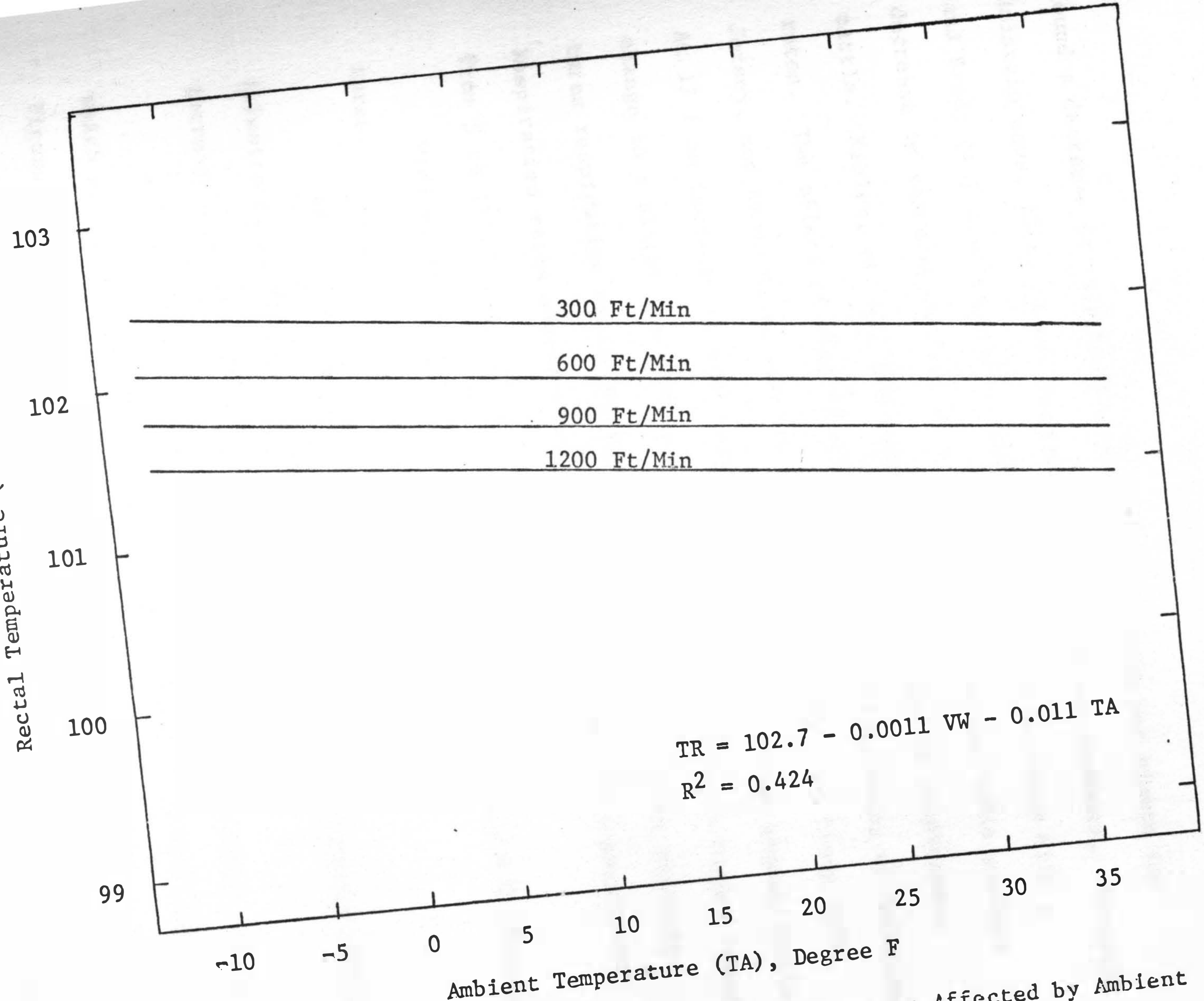

Figure 7. Rectal Temperature of Holstein Steer Calves as Affected by Ambient Temperature and Wind Velocity.

found a decrease in respiration rates from 25 to 15 per minute for Holstein cows, 20 to 14 for Jerseys, and 14 to 12 for Brahmans. Worstell and Brody (43) also reported a decrease in respiration rates with a decrease in temperature from 40 to 8 F for European and India evolved cattle. Kibler, et. al. (23) agreed with this trend in respiration rates. The effect of wind velocity on the respiration rates of Holstein, Jersey, and Brown Swiss cows was determined by Kibler and Brody (20). At 17 F an increase in wind velocity from 0.5 to 10.0 mph caused little change to a slight decrease in respiration rates, while at higher temperatures respiration rates decreased with an increase in wind velocity. Respiration rates showed a general increase for ambient temperatures from 5 to 105 F with a greater slope from 70 to 105 F.

Wind velocity explained 16.2 percent of the variation in respiration rates. The significant prediction equation

$$RR = 20.3 - 0.0031\ VW$$

illustrated in Figure 8, shows that respiration rate decreases with an increase in wind velocity.

Respiration rate is also reduced by decreasing ambient temperature, which accounted for 4.5 percent of the variation in respiration rate. Figure 9 illustrates the significant prediction equation:

$$RR = 17.5 + 0.037\ TA$$

Combining the effects of wind velocity and ambient temperature explained 25.4 percent of the total variation in respiration rate. The following significant prediction equation

$$RR = 20.0 - 0.0036\ VW + 0.054\ TA$$

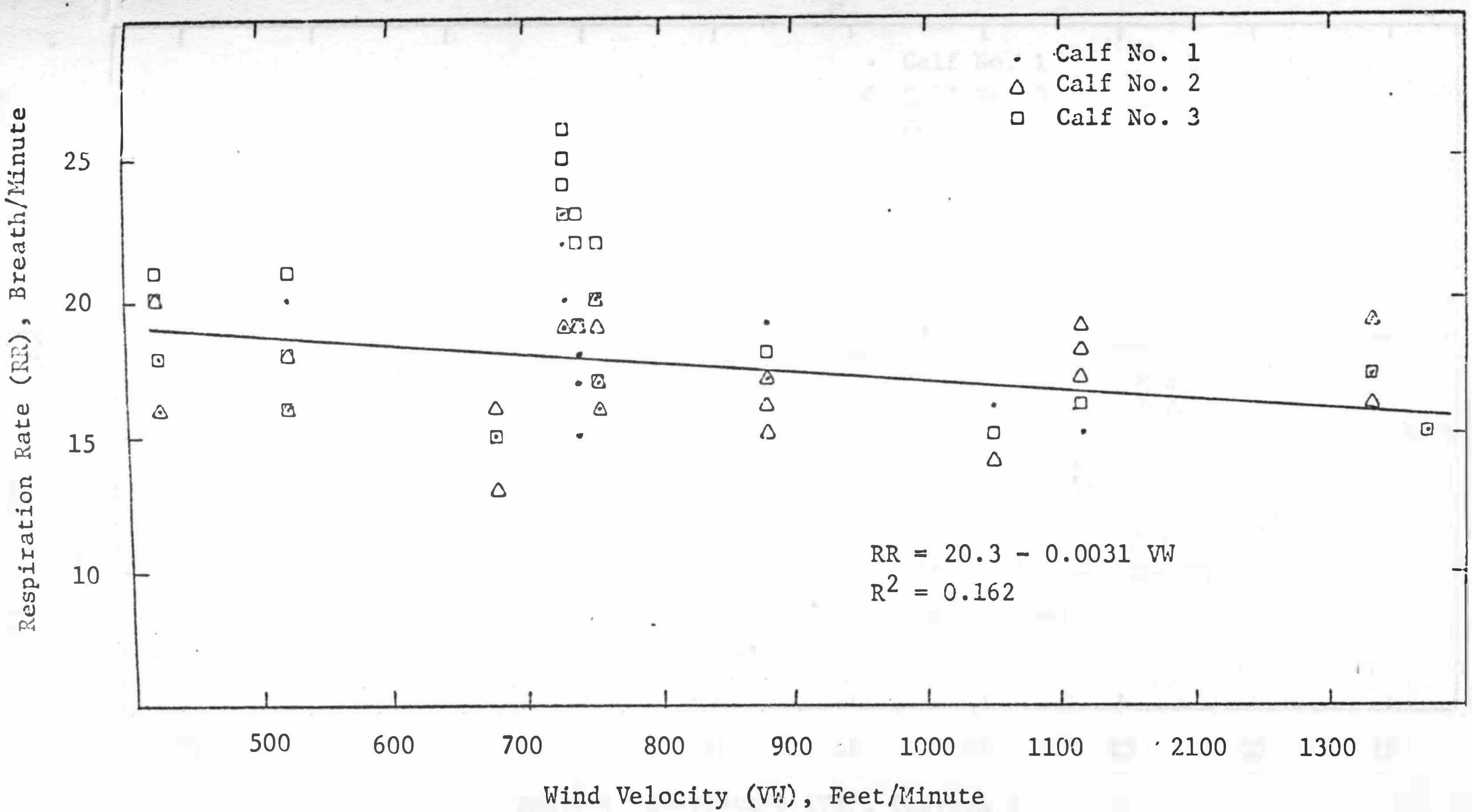

Figure 8. Respiration Rate of Holstein Steer Calves as Affected by Wind Velocity

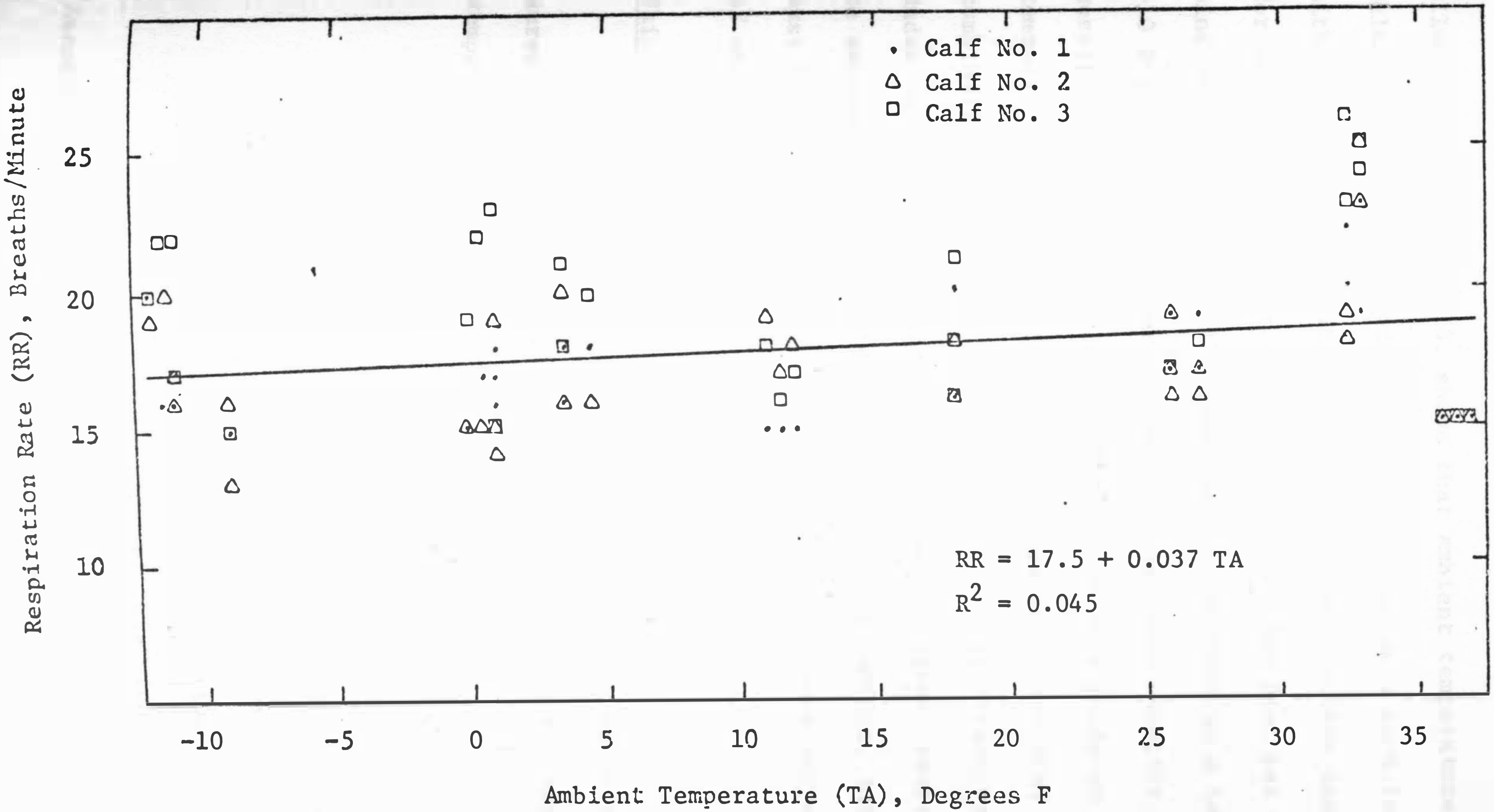

Figure 9. Respiration Rate of Holstein Steer Calves as Affected by Ambient Temperature

illustrated in Figure 10, shows that ambient temperature and wind velocity combine to produce the same effect as a much lower temperature with no wind. Figure 10 can be used as an effective temperature index, for example, it indicates that 30 F with a 900 feet per minute or 10.2 mph wind velocity produced the same respiration rate as a temperature of -10 F and a 300 feet per minute (3.4 mph) wind velocity. The constant respiration rate lines in Figure 10 serve as a guide to effective temperatures for comparing ambient temperature and wind velocity combinations. In order to use Figure 10 as an effective temperature index several assumptions need to be made. First, respiration rate must be assumed to be a good indicator of animal comfort, and secondly, it must be assumed that the data collected are representive of the response of other calves.

Skin Temperature

The effect of ambient temperature and wind velocity on skin temperatures was analysed using the differences between the rectal and skin temperatures for each side of the calf.

$$DTSR = TR - TSR$$

$$DTSL = TR - TSL$$

DTSR = temperature differential on right side, F

DTSL = temperature differential on left side, F

TSR = skin temperature of right side

TSL = skin temperature of left side

Assuming that the temperature differential was greater on the windward

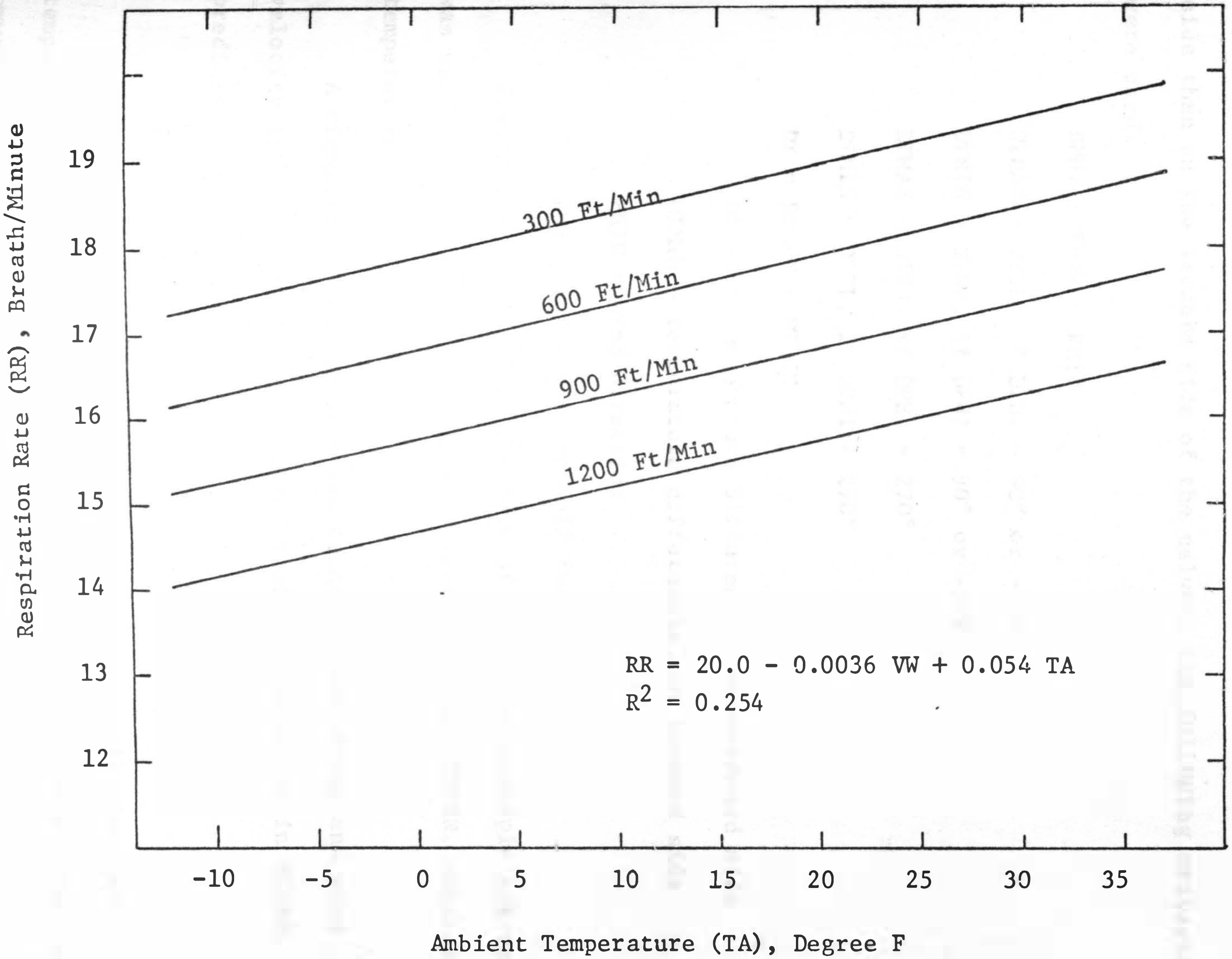

Figure 10. Respiration Rate of Holstein Steer Calves as Affected by Ambient Temperature and Wind Velocity.

side than on the leeward side of the calves, the following criteria were used:

DPHI = PHIW - PHIC

DTMAX = DTSL, if DPHI = 90° or -270°

DTMIN = DTSR, if DPHI = 90° or -270°

DTMAX = DTSR, if DPHI = 270°

DTMIN = DTSL, if DPHI = 270°

DT = DTMAX - DTMIN

DTMAX = temperature differential on windward side

DTMIN = temperature differential on leeward side

PHIW = wind direction

PHIC = direction of calf facing

Statistical analysis in the form of step-wise multiple regression was used to show the relationships between DTMAX and DTMIN, ambient temperature, and wind velocity.

A significant relationship was found between DTMAX and wind velocity that accounted for 4.7 percent of the variation in DTMAX. The prediction equation being:

DTMAX = 17.2 + 0.0056 VW.

Ambient temperature was more successful in predicting skin temperature, in that, it explained 20.2 percent of the variation in DTMAX. The significant prediction equation is as follows:

DTMAX = 25.9 - 0.25 TA

The combined effect of wind velocity and ambient temperature accounted for 35.2 percent of the variation in DTMAX with the significant relationship described in the following prediction equation:

$$DTMAX = 18.5 + 0.011\ VW - 0.33\ TA$$

Ambient temperature had no significant effect on the difference in rectal and leeward skin temperature. Relationships were also developed between temperature difference on the leeward side and wind velocity and ambient temperature. However, only 6.0 percent of the variation was accounted for. No significant differences were found in the regression of DT.

Some of the variation in skin temperatures is due to errors in data collection caused by displacement of the skin contact thermocouples by animal movement. The blank spaces in the skin temperature columns of Table 2 are the result of deleting the obviously erroneous data. Skin contact was difficult to maintain, therefore, further experimentation is needed along with refinement of skin temperature data collection techniques, if such data is to accurately represent a physiological response to winter climatic factors under natural conditions.

The difference in skin and rectal temperatures increased with increasing wind velocity and decreasing ambient temperature. This agrees with Thompson, et. al. (36), who reported that skin temperature of dairy calves decreased with increasing air velocity roughly in proportion to decreases in ambient temperature. Thompson, et. al. (35) found that skin temperatures increased linearly with ambient temperature from zero to 65 F and then continued to increase at a reduced slope.

CONCLUSIONS

The following conclusions were reached in this study:

1. Pulse rates ranged from 60 to 138 beats/min for a range of wind velocities from 3.1 to 15.8 mph and ambient temperatures from 37.5 to -12.0 F. There was a significant decrease in pulse rate with an increase in wind velocity.
2. A sixth degree polynomial was needed to show the relationship of pulse rate and ambient temperature. It was concluded from weather statistics, pulse rate data, and the literature that acclimatization of the calves on different days may have contributed to the nonlinearity of the pulse rate versus ambient temperature relationship. Pulse rates did generally tend to increase with decreased ambient temperature.
3. Rectal temperatures increased from 100.0 to 103.5 F with decreased wind velocity and ambient temperature.
4. Respiration rates decreased from 26 to 13 breaths per minute with increased wind velocity and decreased ambient temperature. The combined effect of wind velocity and ambient temperature on respiration rate gave some information concerning the effective temperatures of combinations of wind velocity and ambient temperature.
5. Increasing wind velocity and decreasing ambient temperature significantly depressed skin temperatures.

SUMMARY

Ambient temperature, wind velocity, relative humidity, and solar radiation were monitored along with the physiological responses of pulse rate, respiration rate, rectal temperature, and skin temperature, in an attempt to determine the combinations of natural climatic factors most influential on animal comfort. The study was conducted from December 1, 1973 to March 7, 1974 on the South Dakota State University Dairy Research Farm approximately two miles north of Brookings, South Dakota. Ambient temperatures ranged from 37.5 to -12 F and wind velocities from 3.1 mph to 15.8 mph. The three Holstein steer calves used in the study were wintered outdoors, and were moved from this somewhat sheltered lot to stalls in an open field for data collection.

Increased wind velocity tended to decrease pulse rate. There was no significant linear trend of increasing pulse rate with decreasing ambient temperature, but the variety of pulse rates recorded led to a significant sixth degree polynomial in order to explain the effect of ambient temperature. Acclimatization was likely a factor affecting the pulse rates of the calves.

It was also found that rectal temperatures, skin temperatures, and respiration rates decreased with an increase in wind velocity. Rectal temperatures increased while respiration rates and skin temperatures decreased with a decrease in ambient temperature.

The effects of wind velocity and ambient temperature on respiration rate were combined to form an effective temperature index which can be

used to compare wind velocity and ambient temperature combinations and predict respiration rates.

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APPENDIXES

APPENDIX A. List of Symbols

Table 1. List of Symbols

Symbol	Description
TA	Ambient temperature, degrees F
VW	Wind velocity, feet per minute
RH	Relative humidity, percent
SR	Solar radiation intensity, gm-cal/cm^2
PR	Pulse rate, per minute
TR	Rectal temperature, degrees F
RR	Respiration rate, per minute
TSR	Skin temperature right side, degrees F
TSL	Skin temperature left side, degrees F
PHIW	Wind direction, degrees clockwise from north
PHIC	Direction of calf facing, degrees clockwise from north
PHIS	Direction of the sun, degrees clockwise from north

APPENDIX B. Phyiological Responses to Winter Climatic Factors

Table 2. Phyiological Responses to Winter Climatic Factors

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1500	12	1	73	1	220	150	60	0.5	1392	58	36.5			101.5		
1500	12	1	73	1	220	150	60	0.5	1392	58	36.0	60.0	74.0	102.0		
1515	12	1	73	1	220	150	60	0.4	1392	58	36.5	62.5	73.0	102.0		
1515	12	1	73	1	220	150	60	0.4	1392	58	36.5	61.5	73.5	102.0		
1530	12	1	73	1	220	150	60	0.3	1392	58	37.5	64.0	77.0	102.0		
1500	12	1	73	2	220	150	60	0.5	1392	58	36.5	72.5	79.0	100.5		
1500	12	1	73	2	220	150	60	0.5	1392	58	36.0	75.0	80.0	100.5		
1515	12	1	73	2	220	150	60	0.4	1392	58	36.5	71.5	80.0	100.5		
1515	12	1	73	2	220	150	60	0.4	1392	58	36.5	76.5	80.5	100.5		
1530	12	1	73	2	220	150	60	0.3	1392	58	37.5	75.5	80.0	100.5		
1500	12	1	73	3	220	150	60	0.5	1392	58	36.5	69.0	81.0	101.0		
1500	12	1	73	3	220	150	60	0.5	1392	58	36.0		82.5	101.0		
1515	12	1	73	3	220	150	60	0.4	1392	58	36.5		81.0	101.0		
1515	12	1	73	3	220	150	60	0.4	1392	58	36.5	63.5	80.5	101.0		
1530	12	1	73	3	220	150	60	0.3	1392	58	37.5	70.0	80.5	101.5		
1500	12	7	73	1	220	190	100	0.3	1368	64	37.0		75.5	102.5		
1500	12	7	73	1	220	190	100	0.3	1368	64	37.0		81.0	102.5		
1515	12	7	73	1	220	190	100	0.3	1368	64	37.0			102.0		
1515	12	7	73	1	220	190	100	0.3	1368	64	37.0	76.0		102.0		
1530	12	7	73	1	220	190	100	0.2	1368	64	36.5	81.0	74.0	102.0	15.0	98.0
1530	12	7	73	1	220	190	100	0.2	1368	64	36.5	80.5	75.0	102.0	15.0	96.0
1545	12	7	73	1	220	190	100	0.2	1368	64	36.5	81.5		102.0		
1545	12	7	73	1	220	190	100	0.2	1368	64	36.5	77.0		102.0		
1600	12	7	73	1	220	190	100	0.1	1368	64	37.0			102.0		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1500	12	7	73	2	220	190	100	0.3	1368	64	37.0	82.5	82.0	101.5		
1500	12	7	73	2	220	190	100	0.3	1368	64	37.0	83.0	82.5	101.5		
1515	12	7	73	2	220	190	100	0.3	1368	64	37.0	84.0	82.0	101.5		
1515	12	7	73	2	220	190	100	0.3	1368	64	37.0	84.0	82.0	101.0		
1530	12	7	73	2	220	190	100	0.2	1368	64	36.5	82.5	82.0	101.0	15.0	108.0
1530	12	7	73	2	220	190	100	0.2	1368	64	36.0	84.0	81.0	101.5		102.0
1545	12	7	73	2	220	190	100	0.2	1368	64	36.0	85.0	81.0	101.5		
1545	12	7	73	2	220	190	100	0.2	1368	64	36.0	83.0	80.0	101.5		
1600	12	7	73	2	220	190	100	0.1	1368	64	37.0	82.0	82.5	101.0		
1500	12	7	73	3	220	190	100	0.3	1368	64	37.0	86.0	86.5	102.0		
1500	12	7	73	3	220	190	100	0.3	1368	64	37.0	85.0	86.0	102.0		
1515	12	7	73	3	220	190	100	0.3	1368	64	37.0		78.0	102.5		
1515	12	7	73	3	220	190	100	0.3	1368	64	37.0	88.0	86.0	102.0		
1530	12	7	73	3	220	190	100	0.2	1368	64	36.5	85.0	81.0	102.0	15.0	100.0
1530	12	7	73	3	220	190	100	0.2	1368	64	36.0	87.0	80.0	101.5		97.0
1545	12	7	73	3	220	190	100	0.2	1368	64	36.0	87.0	78.0	101.0		
1545	12	7	73	3	220	190	100	0.2	1368	64	36.0	87.0	79.0	101.5		
1600	12	7	73	3	220	190	100	0.1	1368	64	37.0	85.0	76.0	101.5		
1430	12	31	73	1	210	310	40	0.5	756	50	-10.5	80.0	69.0	102.0		
1430	12	31	73	1	210	310	40	0.5	756	50	-11.5	82.0	67.0	102.0		
1445	12	31	73	1	210	310	40	0.5	756	50	-11.0	81.0	69.0	102.0		
1445	12	31	73	1	210	310	40	0.5	756	50	-10.5	80.0	68.0	102.5		
1500	12	31	73	1	210	310	40	0.4	756	50	-10.0	82.0		102.5		
1500	12	31	73	1	210	310	40	0.4	756	50	-11.0	83.0		102.5	17.0	60.0
1515	12	31	73	1	210	310	40	0.3	756	50	-11.0	80.0	72.0	102.5	16.0	66.0
1515	12	31	73	1	210	310	40	0.3	756	50	-12.0	81.0	70.0	102.5	20.0	66.0
1530	12	31	73	1	210	310	40	0.3	756	50	-11.5	84.0	68.0	102.5	16.0	
1530	12	31	73	1	210	310	40	0.3	756	50	-11.0	83.5		102.5		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1430	12	31	73	2	210	310	40	0.5	756	50	-10.5	82.0	50.0	102.0		
1430	12	31	73	2	210	310	40	0.5	756	50	-11.5			102.0		
1445	12	31	73	2	210	310	40	0.5	756	50	-11.0			102.0		
1500	12	31	73	2	210	310	40	0.4	756	50	-10.0			102.5		
1500	12	31	73	2	210	310	40	0.4	756	50	-11.0	82.5	46.5	102.5	17.0	74.0
1515	12	31	73	2	210	310	40	0.3	756	50	-11.0	87.0		102.5	16.0	80.0
1515	12	31	73	2	210	310	40	0.3	756	50	-12.0	83.0		102.5	19.0	78.0
1530	12	31	73	2	210	310	40	0.3	756	50	-11.5	85.0	44.5	102.5	20.0	
1530	12	31	73	2	210	310	40	0.3	756	50	-11.0	82.5	56.0	102.5		
1430	12	31	73	3	210	410	40	0.5	756	50	-10.5	73.5	50.5	102.0		
1430	12	31	73	3	210	310	40	0.5	756	50	-11.5	74.5	47.0	102.0		
1445	12	31	73	3	210	310	40	0.5	756	50	-11.0			102.0		
1445	12	31	73	3	210	310	40	0.5	756	50	-10.5			102.0		
1500	12	31	73	3	210	310	40	0.4	756	50	-10.0	76.5		102.0		
1500	12	31	73	3	210	310	40	0.4	756	50	-11.0	80.0		102.0	22.0	74.0
1515	12	31	73	3	210	310	40	0.3	756	50	-11.0		53.0	102.0	17.0	68.0
1515	12	31	73	3	210	310	40	0.3	756	50	-12.0	76.0	60.0	102.0	20.0	62.0
1530	12	31	73	3	210	310	40	0.3	756	50	-11.5	85.5	64.0	102.0	22.0	
1530	12	31	73	3	210	310	40	0.3	756	50	-11.0	78.0	61.5	102.0		
1400	01	2	74	1	200	135	45	0.6	738	90	0.0	79.0	89.0	102.5		
1400	01	2	74	1	200	135	45	0.6	738	90	1.0	80.0	89.0	102.5		
1415	01	2	74	1	200	135	45	0.6	738	90	0.0	82.0	88.0	102.5		
1415	01	2	74	1	200	135	45	0.6	738	90	2.0	85.0	89.0	102.5		
1430	01	2	74	1	200	135	45	0.5	738	90	1.0	86.0	89.5	102.5	17.0	
1430	01	2	74	1	200	135	45	0.5	738	90	1.0	82.5	90.0	102.5	18.0	116.0
1445	01	2	74	1	200	135	45	0.5	276	90	0.0	81.0	90.0	102.5	15.0	104.0
1445	01	2	74	1	200	135	45	0.5	276	90	1.5	81.0	90.0	102.5	17.0	110.0

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1500	01	2	74	1	200	135	45	0.5	276	90	2.5	80.0	92.0	103.0		
1500	01	2	74	1	200	135	45	0.5	276	90	3.0	81.0	92.0	103.0		
1515	01	2	74	1	200	135	45	0.4	276	90	2.0	79.0	90.0	102.5		
1400	01	2	74	2	200	135	45	0.6	738	90	0.0		74.5	102.5		
1400	01	2	74	2	200	135	45	0.6	738	90	1.0		75.5	102.5		
1415	01	2	74	2	200	135	45	0.6	738	90	0.0			102.5		
1415	01	2	74	2	200	135	45	0.6	738	90	2.0	76.5	82.0	102.5		
1430	01	2	74	2	200	135	45	0.5	738	90	1.0	78.0	80.0	102.5	15.0	
1430	01	2	74	2	200	135	45	0.5	738	90	1.0		80.5	102.5	19.0	132.0
1445	01	2	74	2	200	135	45	0.5	276	90	0.0		79.5	102.5	15.0	134.0
1445	01	2	74	2	200	135	45	0.5	276	90	1.5		83.0	102.5	15.0	130.0
1500	01	2	74	2	200	135	45	0.5	276	90	2.5	76.5	80.0	103.0		
1500	01	2	74	2	200	135	45	0.5	276	90	3.0	79.0	77.5	102.5		
1515	01	2	74	2	200	135	45	0.4	276	90	2.0	78.5	82.5	102.5		
1400	01	2	74	3	200	135	45	0.6	738	90	0.0	83.5	80.0	102.0		
1400	01	2	74	3	200	135	45	0.6	738	90	1.0		80.0	102.0		
1415	01	2	74	3	200	135	45	0.6	738	90	0.0	81.5		102.0		
1415	01	2	74	3	200	135	45	0.6	738	90	2.0	85.0	80.0	102.0		
1430	01	2	74	3	200	135	45	0.5	738	90	1.0	89.5	81.0	102.5	23.0	
1430	01	2	74	3	200	135	45	0.5	738	90	1.0	88.5		102.0	23.0	118.0
1445	01	2	74	3	200	135	45	0.5	276	90	0.0		82.5	102.0	19.0	110.0
1445	01	2	74	3	200	135	45	0.5	276	90	1.5		83.0	102.0	22.0	114.0
1500	01	2	74	3	200	135	45	0.5	276	90	2.5		80.0	102.0		
1500	01	2	74	3	200	135	45	0.5	276	90	3.0		80.0	102.0		
1515	01	2	74	3	200	135	45	0.4	276	90	2.0		84.0	102.5		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1430	01	4	74	1	200	130	40	0.5	426	60	2.5			102.5		
1430	01	4	74	1	200	130	40	0.5	426	50	3.0			102.5		
1445	01	4	74	1	200	130	40	0.5	426	60	3.0	80.5		102.5		
1445	01	4	74	1	200	130	40	0.5	426	60	3.0	81.0		102.5		
1500	01	4	74	1	200	130	40	0.4	426	60	3.5	81.5		102.5	18.0	106.0
1500	01	4	74	1	200	130	40	0.4	426	60	3.5	81.0		102.5	16.0	102.0
1515	01	4	74	1	200	130	40	0.4	426	60	4.5	82.0		102.5	18.0	100.0
1515	01	4	74	1	200	130	40	0.4	426	60	4.0	80.0	88.0	102.5		
1530	01	4	74	1	200	130	40	0.3	426	60	5.0		87.0	102.5		
1530	01	4	74	1	200	130	40	0.3	426	60	5.0		85.5	102.5		
1430	01	4	74	2	200	130	40	0.5	426	60	2.5			103.0		
1430	01	4	74	2	200	130	40	0.5	426	60	3.0	79.0		103.0		
1445	01	4	74	2	200	130	40	0.5	426	60	3.0	81.0	80.0	103.0		
1445	01	4	74	2	200	130	40	0.5	426	60	3.0			103.0		
1500	01	4	74	2	200	130	40	0.4	426	60	3.5		79.5	103.0	16.0	130.0
1500	01	4	74	2	200	130	40	0.4	426	60	3.5	79.0	80.5	103.5	20.0	128.0
1515	01	4	74	2	200	130	40	0.4	426	60	3.5	80.5	80.5	103.5	16.0	124.0
1515	01	4	74	2	200	130	40	0.4	426	60	4.0	80.0	82.5	103.5		
1530	01	4	74	2	200	130	40	0.3	426	60	5.0		83.0	103.5		
1530	01	4	74	2	200	130	40	0.3	426	60	5.0	78.0	83.0	103.5		
1430	01	4	74	3	200	130	40	0.5	426	60	2.5		80.5	101.5		
1430	01	4	74	3	200	130	40	0.5	426	60	3.0		80.5	101.5		
1445	01	4	74	3	200	130	40	0.5	426	60	3.0		83.0	102.0		
1445	01	4	74	3	200	130	40	0.5	426	60	3.0			102.0		
1500	01	4	74	3	200	130	40	0.4	426	60	3.5			102.0	21.0	122.0
1500	01	4	74	3	200	130	40	0.4	426	60	3.5		81.0	102.0	18.0	106.0

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1515	01	4	74	3	200	130	40	0.4	426	60	3.5	81.0	80.0	102.0	20.0	102.0
1515	01	4	74	3	200	130	40	0.4	426	60	4.0	81.5	80.0	102.0		
1530	01	4	74	3	200	130	40	0.3	426	60	5.0	83.0	82.0	102.0		
1530	01	4	74	3	200	130	40	0.3	426	60	5.0			102.0		
1330	01	8	74	1	200	310	40	0.4	1050	60	0.0	88.5	79.0	101.5		
1330	01	8	74	1	200	310	40	0.4	1050	60	0.5			101.5		
1345	01	8	74	1	200	310	40	0.4	1050	60	0.0		77.0	101.0		
1345	01	8	74	1	200	310	40	0.4	1050	60	-0.5	88.5	79.5	101.0		
1400	01	8	74	1	200	310	40	0.3	1050	60	0.0	86.0		101.5		
1400	01	8	74	1	200	310	40	0.3	1050	60	0.0	88.5	77.0	101.5		
1415	01	8	74	1	200	310	40	0.3	1050	60	1.0	88.5	78.5	101.5	16.0	116.0
1415	01	8	74	1	200	310	40	0.3	1050	60	0.0		77.5	101.5		116.0
1430	01	8	74	1	200	310	40	0.3	1050	60	0.0	88.5		101.5		120.0
1430	01	8	74	1	200	310	40	0.3	1050	60	-0.5		77.0	101.5		
1445	01	8	74	1	200	310	40	0.3	1050	60	0.0		76.5	101.5		
1445	01	8	74	1	200	310	40	0.3	1050	60	0.0			101.5		
1330	01	8	74	2	200	310	40	0.4	1050	60	0.0	90.5	76.0	101.5		
1330	01	8	74	2	200	310	40	0.4	1050	60	0.5	92.0		101.5		
1345	01	8	74	2	200	310	40	0.4	1050	60	0.0			101.0		
1345	01	8	74	2	200	310	40	0.4	1050	60	-0.5			101.0		
1400	01	8	74	2	200	310	40	0.3	1050	60	0.0		75.0	101.5		
1400	01	8	74	2	200	310	40	0.3	1050	60	0.0	82.5	73.5	101.5		
1415	01	8	74	2	200	310	40	0.3	1050	60	1.0	83.5		101.5	14.0	138.0
1415	01	8	74	2	200	310	40	0.3	1050	60	0.0	84.5		101.5		
1430	01	8	74	2	200	310	40	0.3	1050	60	0.0			101.5		
1430	01	8	74	2	200	310	40	0.3	1050	60	-0.5			101.5		
1445	01	8	74	2	200	310	40	0.3	1050	60	0.0		75.0	101.5		
1445	01	8	74	2	200	310	40	0.3	1050	60	0.0		75.0	101.5		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1330	01	8	74	3	200	310	40	0.4	1050	60	0.0			101.0		
1330	01	8	74	3	200	310	40	0.4	1050	60	0.5		72.0	101.0		
1345	01	8	74	3	200	310	40	0.4	1050	60	0.0	88.0		101.0		
1345	01	8	74	3	200	310	40	0.4	1050	60	-0.5	88.0		101.0		
1400	01	8	74	3	200	310	40	0.3	1050	60	0.0	88.5		101.0		
1400	01	8	74	3	200	310	40	0.3	1050	60	0.0	89.0	72.5	101.5		
1415	01	8	74	3	200	310	40	0.3	1050	60	1.0	87.0	77.0	101.5		
1415	01	8	74	3	200	310	40	0.3	1050	60	0.0	86.0	75.0	101.5	15.0	108.0
1430	01	8	74	3	200	310	40	0.3	1050	60	0.0	87.0	77.0	101.5		106.0
1430	01	8	74	3	200	310	40	0.3	1050	60	-0.5	87.0		101.5		106.0
1445	01	8	74	3	200	310	40	0.3	1050	60	0.0			101.5		
1445	01	8	74	3	200	310	40	0.3	1050	60	0.0			101.5		
1430	01	11	74	1	210	310	40	0.6	678	70	-9.0			102.5		
1430	01	11	74	1	210	310	40	0.6	678	70	-8.5	87.0	75.5	102.5		
1445	01	11	74	1	210	310	40	0.5	678	70	-9.0		75.0	102.0		
1445	01	11	74	1	210	310	40	0.5	678	70	-9.0	87.0		102.0		
1500	01	11	74	1	210	310	40	0.5	678	70	-9.0	88.0	76.0	102.5		
1500	01	11	74	1	210	310	40	0.5	678	70	-9.0	87.5	77.0	102.5	15.0	106.0
1515	01	11	74	1	210	310	40	0.5	678	70	-9.0	89.5	76.5	102.5	15.0	108.0
1515	01	11	74	1	210	310	40	0.5	678	70	-9.0	92.0	80.5	102.5		108.0
1530	01	11	74	1	210	310	40	0.2	678	70	-8.5		79.0	102.5		
1530	01	11	74	1	210	310	40	0.2	678	70	-9.0			102.5		
1430	01	11	74	2	210	310	40	0.6	678	70	-9.0			101.0		
1430	01	11	74	2	210	310	40	0.6	678	70	-8.5			101.5		
1445	01	11	74	2	210	310	40	0.5	678	70	-9.0		73.0	101.5		
1445	01	11	74	2	210	310	40	0.5	678	70	-9.0	83.0	71.5	101.5		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1500	01	11	74	2	210	310	40	0.4	678	70	-9.0	83.0		101.5		
1500	01	11	74	2	210	310	40	0.4	678	70	-9.0	83.5		102.0	16.0	126.0
1515	01	11	74	2	210	310	40	0.3	678	70	-9.0			102.0	13.0	126.0
1515	01	11	74	2	210	310	40	0.3	678	70	-9.0	86.0	78.5	102.0		128.0
1530	01	11	74	2	210	310	40	0.2	678	70	-8.5	86.0	76.5	102.0		
1530	01	11	74	2	210	310	40	0.2	678	70	-9.0		74.0	102.0		
1430	01	11	74	3	210	310	40	0.6	678	70	-9.0	81.5		102.0		
1430	01	11	74	3	210	310	40	0.6	678	70	-8.5	82.0	74.5	102.0		
1445	01	11	74	3	210	310	40	0.5	678	70	-9.0	82.5	76.5	102.0		
1445	01	11	74	3	210	310	40	0.5	678	70	-9.0	84.5	75.5	102.0		
1500	01	11	74	3	210	310	40	0.4	678	70	-9.0	81.0	77.5	102.0		
1500	01	11	74	3	210	310	40	0.4	678	70	-9.0	82.0	78.0	102.0	15.0	110.0
1515	01	11	74	3	210	310	40	0.3	678	70	-9.0	81.5	77.5	102.0	15.0	110.0
1515	01	11	74	3	210	310	40	0.3	678	70	-9.0	83.0	77.0	102.0		108.0
1530	01	11	74	3	210	310	40	0.2	678	70	-8.5	82.5	79.0	102.0		
1530	01	11	74	3	210	310	40	0.2	678	70	-9.0	84.0	80.0	102.0		
0830	01	17	74	1	130	125	35	0.0	732	80	33.0	78.5	78.0	101.5		
0830	01	17	74	1	130	125	35	0.0	732	80	32.5	79.0		101.5		
0845	01	17	74	1	130	125	35	0.1	732	80	32.0			101.5		
0845	01	17	74	1	130	125	35	0.1	732	80	32.0	79.0		101.5		
0900	01	17	74	1	130	125	35	0.1	732	80	32.5	80.5	76.0	102.0		
0900	01	17	74	1	130	125	35	0.1	732	80	32.5	80.0	79.0	102.0	22.0	96.0
0915	01	17	74	1	130	125	35	0.2	234	80	32.5	81.0	77.0	102.0	20.0	100.0
0915	01	17	74	1	130	125	35	0.2	234	80	33.0	80.5	81.0	102.0	23.0	92.0
0930	01	17	74	1	130	125	35	0.3	234	80	33.0	83.0	82.0	102.0	19.0	94.0
0930	01	17	74	1	130	125	35	0.3	234	80	34.5	85.0	84.0	102.0		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
0945	01	17	74	1	130	125	35	0.3	234	80	34.5	91.0	84.0	102.0		
0945	01	17	74	1	130	125	35	0.3	234	80	35.0	92.0	88.0	102.0		
0830	01	17	74	2	130	125	35	0.0	732	80	33.0			102.0		
0830	01	17	74	2	130	125	35	0.0	732	80	32.5	79.0	74.0	102.0		
0845	01	17	74	2	130	125	35	0.1	732	80	32.0			102.0		
0845	01	17	74	2	130	125	35	0.1	732	80	32.0			102.0		
0900	01	17	74	2	130	125	35	0.1	732	80	32.5	80.5	77.0	102.0		
0900	01	17	74	2	130	125	35	0.1	732	80	32.5	82.0	76.0	102.0	18.0	104.0
0915	01	17	74	2	130	125	35	0.2	234	80	32.5	81.0	77.0	102.5	19.0	104.0
0915	01	17	74	2	130	125	35	0.2	234	80	33.0	82.0	78.0	101.0	23.0	102.0
0930	01	17	74	2	130	125	35	0.3	234	80	33.0	82.5	79.5	102.5	25.0	104.0
0930	01	17	74	2	130	125	35	0.3	234	80	34.5	84.0	79.0	102.5		
0945	01	17	74	2	130	125	35	0.3	234	80	34.5	88.0	80.0	102.5		
0945	01	17	74	2	130	125	35	0.3	234	80	35.0	92.0	82.5	102.5		
0830	01	17	74	3	130	125	35	0.0	732	80	33.0	76.0	79.0	101.0		
0830	01	17	74	3	130	125	35	0.0	732	80	32.5	76.5		101.0		
0845	01	17	74	3	130	125	35	0.1	732	80	32.0		78.0	101.0		
0845	01	17	74	3	130	125	35	0.1	732	80	32.0	79.0	79.0	101.0		
0900	01	17	74	3	130	125	35	0.1	732	80	32.5		83.0	101.5		
0900	01	17	74	3	130	125	35	0.1	732	80	32.5	87.0		102.0	23.0	100.0
0915	01	17	74	3	130	125	35	0.2	234	80	32.5			102.0	26.0	96.0
0915	01	17	74	3	130	125	35	0.2	234	80	33.0	88.5	84.5	102.0	25.0	96.0
0930	01	17	74	3	130	125	35	0.3	234	80	33.0		92.0	102.0	24.0	98.0
0930	01	17	74	3	130	125	35	0.3	234	80	34.5	94.0	95.5	102.0		
0945	01	17	74	3	130	125	35	0.3	234	80	34.5	98.0	96.0	102.0		
0945	01	17	74	3	130	125	35	0.3	234	80	35.0	93.5		102.0		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
0930	01	19	74	1		150	60	0.0	1116	90	10.5			101.0		
0930	01	19	74	1		150	60	0.0	1116	90	11.0			101.0		
0945	01	19	74	1		150	60	0.0	1116	90	11.0		70.0	101.0		
0945	01	19	74	1		150	60	0.0	1116	90	11.0	71.0	68.0	101.0		
1000	01	19	74	1		150	60	0.1	1116	90	11.0			101.0		
1000	01	19	74	1		150	60	0.1	1116	90	11.0			101.0	15.0	100.0
1015	01	19	74	1		150	60	0.1	1116	90	11.5	73.5		101.0	15.0	98.0
1015	01	19	74	1		150	60	0.1	1116	90	12.0		70.0	101.0	15.0	98.0
1030	01	19	74	1		150	60	0.1	1116	90	13.0	74.0	73.0	101.0		96.0
1030	01	19	74	1		150	60	0.1	1116	90	12.5	72.0	69.0	101.5		
1045	01	19	74	1		150	60	0.1	1116	90	12.5	75.0		101.5		
1045	01	19	74	1		150	60	0.1	1116	90	13.0	76.0	68.5	101.0		
0930	01	19	74	2		150	60	0.0	1116	90	10.5			101.0		
0930	01	19	74	2		150	60	0.0	1116	90	11.0			101.0		
0945	01	19	74	2		150	60	0.0	1116	90	11.0		68.0	101.0		
0945	01	19	74	2		150	60	0.0	1116	90	11.0			101.0		
1000	01	19	74	2		150	60	0.1	1116	90	11.0			101.0		
1000	01	19	74	2		150	60	0.1	1116	90	11.0			101.0	19.0	110.0
1015	01	19	74	2		150	60	0.1	1116	90	11.5	69.0		101.0	17.0	112.0
1015	01	19	74	2		150	60	0.1	1116	90	12.0		69.0	101.0	18.0	112.0
1030	01	19	74	2		150	60	0.1	1116	90	13.0	71.0	71.0	101.0		112.0
1030	01	19	74	2		150	60	0.1	1116	90	12.5	74.0	69.5	101.0		
1045	01	19	74	2		150	60	0.1	1116	90	12.5	73.0	67.0	101.0		
1045	01	19	74	2		150	60	0.1	1116	90	13.0	74.0	69.0	101.0		
0930	01	19	74	3		150	60	0.0	1116	90	10.5			101.0		
0930	01	19	74	3		150	60	0.0	1116	90	11.0	69.0	83.5	101.0		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
0945	01	19	74	3		150	60	0.0	1116	90	11.0	69.5	80.0	101.0		
0945	01	19	74	3		150	60	0.0	1116	90	11.0			101.0		
1000	01	19	74	3		150	60	0.1	1116	90	11.0	68.0		101.0		
1000	01	19	74	3		150	60	0.1	1116	90	11.0		76.0	101.0	18.0	106.0
1015	01	19	74	3		150	60	0.1	1116	90	11.5		74.5	101.0	16.0	110.0
1015	01	19	74	3		150	60	0.1	1116	90	12.0		74.5	101.0	17.0	108.0
1030	01	19	74	3		150	60	0.1	1116	90	13.0	69.0	75.0	101.0		112.0
1030	01	19	74	3		150	60	0.1	1116	90	12.5	71.0	75.0	101.0		
1045	01	19	74	3		150	60	0.1	1116	90	12.5	68.5		101.0		
1045	01	19	74	3		150	60	0.1	1116	90	13.0	72.5		101.0		
1430	01	24	74	1	210	165	75	0.5	882	75	27.0	80.0	94.0	101.0		
1430	01	24	74	1	210	165	75	0.5	882	75	26.5	81.0	85.5	101.0		
1445	01	24	74	1	210	165	75	0.4	882	75	26.5	81.5	85.5	101.5		
1445	01	24	74	1	210	165	75	0.4	882	75	26.5	81.5	86.5	101.5		
1500	01	24	74	1	210	165	75	0.3	882	75	26.5	78.0		101.5		
1500	01	24	74	1	210	165	75	0.3	844	75	27.0	79.0		101.5	19.0	96.0
1515	01	24	74	1	210	165	75	0.3	844	75	27.0	79.5	82.5	101.5	17.0	90.0
1515	01	24	74	1	210	165	75	0.3	844	75	27.0	79.5	83.5	101.5	17.0	92.0
1530	01	24	74	1	210	165	75	0.2	844	75	26.5	81.0	83.5	101.5		96.0
1530	01	24	74	1	210	165	75	0.2	844	75	27.0	77.5		101.5		
1545	01	24	74	1	210	165	75	0.2	844	75	26.5	77.0	82.5	101.5		
1545	01	24	74	1	210	165	75	0.2	844	75	27.0	78.0	83.5	101.5		
1430	01	24	74	2	210	165	75	0.5	882	75	27.0			101.0		
1430	01	24	74	2	210	165	75	0.5	882	75	26.5		87.0	101.0		
1445	01	24	74	2	210	165	75	0.4	882	75	26.5		87.0	101.5		
1445	01	24	74	2	210	165	75	0.4	882	75	26.5		86.5	101.5		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1500	01	24	74	2	210	165	75	0.3	882	75	26.5		86.0	101.5		
1500	01	24	74	2	210	165	75	0.3	882	75	27.0	78.5	86.0	101.5	17.0	110.0
1515	01	24	74	2	210	165	75	0.3	844	75	27.0		86.0	101.5	15.0	112.0
1515	01	24	74	2	210	165	75	0.3	844	75	27.0		87.0	101.5	16.0	110.0
1530	01	24	74	2	210	165	75	0.2	844	75	26.5	83.5	88.0	101.5		116.0
1530	01	24	74	2	210	165	75	0.2	844	75	27.0	84.0	88.0	101.5		
1545	01	24	74	2	210	165	75	0.2	844	75	26.5	83.5	88.0	101.5		
1545	01	24	74	2	210	165	75	0.2	844	75	27.0	84.5	87.5	101.5		
1430	01	24	74	3	210	165	75	0.5	882	75	27.0	88.0	90.0	101.0		
1430	01	24	74	3	210	165	75	0.5	882	75	26.5	85.0	89.0	101.0		
1445	01	24	74	3	210	165	75	0.4	882	75	26.5		91.0	101.0		
1445	01	24	74	3	210	165	75	0.4	882	75	26.5	86.0	91.0	101.0		
1500	01	24	74	3	210	165	75	0.3	882	75	26.5		91.5	101.5		
1500	01	24	74	3	210	165	75	0.3	882	75	27.0	85.0	91.0	101.5	18.0	104.0
1515	01	24	74	3	210	165	75	0.3	844	75	27.0			101.0	18.0	104.0
1515	01	24	74	3	210	165	75	0.3	844	75	27.0		89.0	101.0		102.0
1530	01	24	74	3	210	165	75	0.2	844	75	26.5	87.5	88.0	101.0		102.0
1530	01	24	74	3	210	165	75	0.2	844	75	27.0	87.5	89.0	101.0		
1545	01	24	74	3	210	165	75	0.2	844	75	26.5	85.0	87.5	101.0		
1545	01	24	74	3	210	165	75	0.2	844	75	27.0		90.0	101.0		
1400	02	14	74	1	210	110	20	0.6	522	75	18.5	93.5	96.5	102.0		
1400	02	14	74	1	210	110	20	0.6	522	75	19.0	93.5	96.5	102.0		
1415	02	14	74	1	210	110	20	0.5	522	75	18.5	93.5	98.0	102.0		
1415	02	14	74	1	210	110	20	0.5	522	75	19.0	94.0	98.0	102.0		
1430	02	14	74	1	210	110	20	0.4	522	75	18.0	94.0	98.5	102.0		
1430	02	14	74	1	210	110	20	0.4	522	75	18.0	95.0	97.0	102.0	16.0	100.0

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/min.	PR per/min.
1445	02	14	74	1	210	110	20	0.4	522	75	18.0	93.0	97.0	102.0	20.0	100.0
1445	02	14	74	1	210	110	20	0.4	522	75	18.0	93.0	97.0	102.0	20.0	98.0
1500	02	14	74	1	210	110	20	0.3	522	75	19.0	94.0	96.5	102.0		100.0
1500	02	14	74	1	210	110	20	0.3	522	75	18.5	94.5	97.0	102.0		
1500	02	14	74	1	210	110	20	0.3	522	75	18.5	91.5	96.5	102.0		
1400	02	14	74	2	210	110	20	0.6	522	75	18.5	87.0	85.5	101.0		
1400	02	14	74	2	210	110	20	0.6	522	75	19.0	86.0	86.5	101.0		
1415	02	14	74	2	210	110	20	0.5	522	75	18.5	87.5	88.5	101.0		
1415	02	14	74	2	210	110	20	0.5	522	75	19.0	92.0	87.0	101.0		
1430	02	14	74	2	210	110	20	0.4	522	75	18.0	90.5	90.0	101.0		
1430	02	14	74	2	210	110	20	0.4	522	75	18.0	87.5	90.5	101.0	18.0	106.0
1445	02	14	74	2	210	110	20	0.4	522	75	18.0	86.5	87.0	101.0	16.0	106.0
1445	02	14	74	2	210	110	20	0.4	522	75	18.0			101.0	16.0	100.0
1500	02	14	74	2	210	110	20	0.3	522	75	19.0			101.0		100.0
1500	02	14	74	2	210	110	20	0.3	522	75	18.5	89.0	88.0	101.0		
1515	02	14	74	2	210	110	20	0.3	522	75	18.5		88.5	101.0		
1515	02	14	74	2	210	110	20	0.3	522	75	18.5		88.5	101.0		
1400	02	14	74	3	210	110	20	0.6	522	75	18.5	91.5	88.0	101.0		
1400	02	14	74	3	210	110	20	0.6	522	75	19.0	91.5	88.0	101.0		
1415	02	14	74	3	210	110	20	0.5	522	75	18.5	93.5	86.0	101.0		
1415	02	14	74	3	210	110	20	0.5	522	75	19.0	90.0	87.0	101.0		
1430	02	14	74	3	210	110	20	0.4	522	75	18.0	93.0	86.5	101.0		
1430	02	14	74	3	210	110	20	0.4	522	75	18.0	90.0	87.0	101.0	21.0	80.0
1445	02	14	74	3	210	110	20	0.4	522	75	18.0		87.0	101.5	16.0	82.0
1445	02	14	74	3	210	110	20	0.4	522	75	18.0		86.0	101.5	18.0	82.0
1500	02	14	74	3	210	110	20	0.3	522	75	19.0	88.5	88.0	101.5		84.0
1500	02	14	74	3	210	110	20	0.3	522	75	18.5	88.5	87.5	101.5		

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
1515	02	14	74	3	210	110	20	0.3	522	75	18.5	87.0	85.0	101.5		
1515	02	14	74	3	210	110	20	0.3	522	75	18.5			101.5		
0930	03	7	74	1		60	330	0.2	1332	70	25.0	87.0				
0930	03	7	74	1		60	330	0.2	1332	70	25.0	89.0				
0945	03	7	74	1		60	330	0.2	1332	70	25.0	88.0		100.0	19.0	76.0
0945	03	7	74	1		60	330	0.2	1332	70	26.0	89.5		100.0	19.0	72.0
1000	03	7	74	1		60	330	0.3	1332	70	26.0	88.5		100.5	17.0	74.0
1000	03	7	74	1		60	330	0.3	1332	70	26.0	87.0		100.5	17.0	76.0
1015	03	7	74	1		60	330	0.3	1332	70	26.0	86.0				
1015	03	7	74	1		60	330	0.3	1332	70	27.0	86.0		100.5		
1030	03	7	74	1		60	330	0.3	1332	70	27.0	85.5		100.5		
1030	03	7	74	1		60	330	0.3	1332	70	27.0	88.0		100.5		
1045	03	7	74	1		60	330	0.3	1332	70	27.0	88.0		100.5		
1045	03	7	74	1		60	330	0.3	1332	70	27.0	87.0		101.0		
0930	03	7	74	2		60	330	0.2	1332	70	25.0	85.0	88.5			
0930	03	7	74	2		60	330	0.2	1332	70	25.0	86.0				
0945	03	7	74	2		60	330	0.2	1332	70	25.0	86.0		100.0	19.0	82.0
0945	03	7	74	2		60	330	0.2	1332	70	26.0	85.0		100.0	16.0	80.0
1000	03	7	74	2		60	330	0.3	1332	70	26.0	87.0		100.5	16.0	78.0
1000	03	7	74	2		60	330	0.3	1332	70	26.0	86.5		100.5	17.0	76.0
1030	03	7	74	2		60	330	0.3	1332	70	27.0	87.5	89.5	100.5		
1030	03	7	74	2		60	330	0.3	1332	70	27.0	87.0	89.0	100.5		
1045	03	7	74	2		60	330	0.3	1332	70	27.0	88.0	89.0	100.5		
1045	03	7	74	2		60	330	0.3	1332	70	27.0	88.0	89.0	101.0		
0930	03	7	74	3		60	330	0.2	1332	70	25.0	79.0	85.0			
0930	03	7	74	3		60	330	0.2	1332	70	25.0		85.0			

Table 2. Continued

Time	Month	Day	Year	Calf No.	PHIS	PHIW	PHIC	SR gm-cal/ cm^2	VW ft. per min.	RH %	TA °F	TSR °F	TSL °F	TR °F	RR per/ min.	PR per/ min.
0945	03	7	74	3		60	330	0.2	1332	70	25.0	78.0	85.0	100.0	17.0	76.0
0945	03	7	74	3		60	330	0.2	1332	70	26.0	78.5	86.0	100.0	17.0	74.0
1000	03	7	74	3		60	330	0.3	1332	70	26.0	77.0	86.0	100.5	17.0	78.0
1000	03	7	74	3		60	330	0.3	1332	70	26.0	78.0	86.0	100.5	17.0	80.0
1015	03	7	74	3		60	330	0.3	1332	70	26.0		87.5	100.5		
1015	03	7	74	3		60	330	0.3	1332	70	27.0	81.0				
1030	03	7	74	3		60	330	0.3	1332	70	27.0	82.0	86.5			
1030	03	7	74	3		60	330	0.3	1332	70	27.0		86.5	100.5		
1045	03	7	74	3		60	330	0.3	1332	70	27.0			100.5		
1045	03	7	74	3		60	330	0.3	1332	70	27.0		87.0	101.0		

APPENDIX C. The Army's Wind Chill Chart

Table 3. The Army's Wind Chill Chart

Wind Speed (mph)	Actual Thermometer Reading (°F.)							
	30	20	10	0	-10	-20	-30	-40
	Equivalent Temperature (°F.)							
calm	30	20	10	0	-10	-20	-30	-40
5	27	16	6	-5	-15	-26	-36	-47
10	16	4	-9	-21	-33	-46	-58	-70
15	9	-5	-18	-36	-45	-58	-72	-85
20	4	-10	-25	-39	-53	-67	-82	-96
25	0	-15	-29	-44	-59	-74	-88	-104
30	-2	-18	-33	-48	-63	-79	-94	-109
35	-4	-20	-35	-49	-67	-82	-98	-113
40	-6	-21	-37	-53	-69	-85	-100	-116

To use the chart, find the wind speed in the left-hand column and the actual temperature in the top row. The equivalent temperature is found where these two intersect.

For example, with a wind speed of 10 mph and a temperature of -10° F, the equivalent temperature is -33° F.

APPENDIX D. High and Low Daily Ambient Temperatures, Degrees F

Table 4. High and Low Daily Ambient Temperatures, Degrees F

Date	December High	December Low	January High	January Low	February High	February Low	March High	March Low
1	30	18	-10	-34	5	-8	57	26
2	40	27	-4	-25	10	2	67	31
3	35	24	4	-16	19	-12	64	32
4	30	14	8	-20	-1	-20	48	28
5	25	12	6	-19	19	-1	56	30
6	19	4	2	-14	19	9	56	35
7	28	4	4	-28	14	-14	41	21
8	39	18	-2	-28	15	-14		
9	49	15	2	-31	22	-18		
10	23	-1	-2	-27	32	0		
11	20	1	-1	-15	22	7		
12	33	16	-6	-31	43	8		
13	28	9	1	-18	46	8		
14	14	9	15	0	18	10		
15	12	-1	38	8	25	20		
16	12	-17	38	10	35	20		
17	18	-15	47	23	43	20		
18	23	17	39	20	43	27		
19	19	-14	20	-2	36	21		
20	10	-16	26	8	43	21		
21	10	-13	31	20	36	26		
22	22	9	25	12	29	8		
23	35	12	24	5	23	1		
24	25	16	32	6	13	-3		
25	23	20	35	9	20	-1		
26	23	13	36	17	39	4		
27	24	11	34	8	46	25		
28	25	4	27	9	49	18		
29	19	-2	35	9				
30	9	-28	45	23				
31	-10	-32	40	-8				

APPENDIX E. Multiple Regression Analysis

Table 5. Multiple Regression Analysis

Equation	R^2	D.F.	Mean Square Error	Reduction in Sum of Squares	F
Pr = 110.1 - 0.0126 VW	0.072	107	266.043	2203.726	8.28
PR = 119.6 - 3.22 TA + 0.16 $(TA)^2$ + 0.023 $(TA)^3$ - 0.0031 $(TA)^4$ + 0.00012 $(TA)^5$ - 0.0000014 $(TA)^6$	0.681	102	95.999	4017.570	41.85
TR = 102.7 - 0.0013 VW	0.377	366	0.341	75.437	221.22
TR = 101.9 - 0.019 TA	0.173	366	0.452	34.691	76.26
TR = 102.7 - 0.0011 VW - 0.011 TA	0.424	365	0.316	9.403	29.76
RR = 20.3 - 0.0031 VW	0.162	94	6.429	117.019	18.20
RR = 17.50 + 0.037 TA	0.045	94	7.325	32.804	4.48
RR = 20.0 - 0.0036 VW + 0.054 TA	0.254	93	5.788	66.052	11.41