COMPARISON OF FREESTALL BEDDING MATERIALS AND THEIR EFFECT ON COW BEHAVIOR AND COW HEALTH

By

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I dedicate this thesis to my mom, Suzanne G. Crittenden. Thank you for allowing me to pursue my dreams, for instilling confidence and motivation in me, and for never giving up on me. You were and will always be my rock. I also dedicate this thesis to my grandparents, Mr. and Mrs. L. Earl Crittenden. Thank you for your giving spirit, guidance and motivation, support, and most importantly, your extreme love throughout my academic career.

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TABLE OF CONTENTS

page

ACKNOWLEDGMENTS 4

LIST OF TABLES 7

LIST OF FIGURES 8

ABSTRACT 10

CHAPTER

1 INTRODUCTION 12

2 LITERATURE REVIEW 15

Animal Behavior and Welfare 15
Animal Housing and the Environment 17
Milking Dairy Herd Housing Systems 17
Environmental Effects on Cow Physiology 19
Cow and Freestall Interaction 20
Cow Comfort Measurements 24
Dairy Freestall Design 26
Freestall Dimensions 27
Brisket Board 28
Freestall Partitions 29
Freestall Neck Rail 30
Health Concerns with Freestalls 31
Cow Hygiene 32
Hock Health 33
Lameness and Freestalls 35
Mastitis and Freestalls 36
Freestall Bedding 37
Cushion and Traction of Bedding Materials 38
Temperature Effect on Bedding Materials 40
Maintenance of Bedding Materials 43
Bacterial Environment and Bedding Materials 44
Various Bedding Materials 45

3 MATERIALS AND METHODS 52

Facility Description 52
Experimental Design 52
Video Surveillance 55
Environmental Monitoring 56

Hock Injuries and Leg Hygiene 56
Statistical Analysis...57
Cow Orientation 57
Hock Scores...58
Hygiene Scores 59

4 RESULTS AND DISCUSSION 63

Cow Behavior 64
Trial One...64
Trial Two 70
Hock Scores 75
Trial One...75
Trial Two 79
Hygiene Scores 82
Trial One...82
Trial Two 83
The Effect of the Bedding Material on the Culling Rate 85
Trial One...85
Trial Two 85
General Discussion 86

5 CONCLUSION...94

LIST OF REFERENCES 96

BIOGRAPHICAL SKETCH 100

LIST OF TABLES

Table page

2-1 Suggested freestall dimensions for various cow sizes 48

2-2 Suggested freestall dimensions based upon the body dimensions of a mature Holstein Cow 49

4-1 Trial 1 ANOVA table for orientation....................65

4-2 Trial 1 type III SS for orientation 66

4-3 Trial 2 ANOVA table for orientation....................71

4-4 Trial 2 type III SS for orientation 72

4-5 Trial 1 ANOVA table for hock scores 76

4-6 Trial 1 type III SS for hock score....................76

4-7 Trial 2 ANOVA table for hock scores 79

4-8 Trial 2 type III SS for hock score....................79

4-9 Trial 1 ANOVA table for hygiene scores 82

4-10 Trial 1 type III SS for hygiene score....................82

4-11 Trial 2 ANOVA table for hygiene scores 84

4-12 Trial 2 type III SS for hygiene score....................84

4-13 Number of culled cows for both trial one and trial two 86

LIST OF FIGURES

Figure page

2-1 Typical resting postures for dairy cattle......47

2-2 Typical freestall cross section......48

2-3 Location of cattle hock joints......49

2-4 Clegg Impact Soil Testers (ASTM Designation: D 5874-02). A) Light Impact Tester B) Standard Impact Tester......50

2-5 Freestall bedding preferences of 18 animals for 18 stalls......51

3-1 Bassett research freestall barn......60

3-2 Layout of Bassett research freestall barn......61

3-3 Head to head sand freestalls......62

3-4 Head to head waterbed freestalls......62

3-5 Head to head waterbed freestalls with 1.5 inches of sand on top......62

4-1 Typical barn temperatures for trial one......63

4-2 Typical barn temperatures for trial two......64

4-3 Trial 1 total percentage of orientations for each treatment......65

4-4 Trial 1 treatment main effect least square means for cow orientation......66

4-5 Trial 1 observation time of day main effect least square means for both sand and waterbed stalls combined......67

4-6 Trial 1 treatment*observation time of day interaction (trmt*obs)......67

4-7 Trial 1 average cow comfort index for time of day......69

4-8 Trial 2 total percentage of orientations for each treatment......71

4-9 Trial 2 treatment main effect least square means for cow orientation......73

4-10 Trial 2 observation time of day main effect least square means for both sand and waterbed stalls with sand on top combined......73

4-11 Trial 2 average cow comfort index for time of day......74

4-12 Trial 1 treatment main effect least square means for hock scores 77

4-13 Trial 1 location on hock main effect least square means for both treatments combined...78

4-14 Trial 1 treatment*location (trmt*location) interaction 78

4-15 Trial 2 treatment main effect least square means for hock scores 80

4-16 Trial 2 location on hock main effect least square means for both treatments combined...81

4-17 Trial 2 treatment*location (trmt*location) interaction 81

4-18 Trial 1 treatment main effect least square means for hygiene scores 83

4-19 Trial 2 treatment main effect least square means for hygiene scores 84

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COMPARISON OF FREESTALL BEDDING MATERIALS AND THEIR EFFECT ON COW BEHAVIOR AND COW HEALTH

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In order to ensure animal comfort which leads to increased production, the environment surrounding dairy cows must always be considered. The provision of properly designed freestalls with comfortable bedding materials is one aspect of the dairy housing system which must be considered. The freestalls must provide a place of rest for cows and a place where minimal harm is inflicted. Culling rates have been associated with increased instances of hock injuries and mastitis, all of which can be attributed to freestall design and bedding material.

With the increasing cost of production and waste management issues, sand has become problematic. As a result, new technologies have been developed, such as freestall waterbeds; however, these new technologies have received mixed reviews.

Cow comfort was evaluated in a freestall barn at the University of Florida Dairy Research Unit during the summer of 2008 by comparing the effects of three bedding materials on freestall usage, hock health, and leg hygiene. The bedding materials were sand, Advanced Comfort Technology Inc. waterbeds, and the waterbeds with approximately 1.5 inches of sand on top. Video surveillance was used to examine the interaction between the cows and freestalls for the 2

four week trials. Hock injuries and hygiene of the hind legs were evaluated using previously reported scoring systems.

Results indicated that the freestall bedding material had a significant effect on the overall behavior, leg hygiene, and hock injuries of cows. The sand bedded freestalls had a significantly higher frequency of lying cows in the stalls (52.95%) as compared to the waterbeds which had the highest frequency of empty stalls (49.02%). The overall interaction between the cows and the freestalls of the cows using the waterbeds with 1.5 inches of sand on top resulted in no statistical difference from the sand bedded freestalls. Adding approximately 1.5 inches of sand on top of the waterbeds had no significant effect on the hock scores when compared to the waterbeds alone. The sand bedded stalls had the lowest instance of hock injuries for both trials. The waterbeds had the greatest occurrence of dirty cows; however, adding sand on top of the waterbeds resulted in the lowest hygiene scores, resulting in the cleanest cows. Determining which bedding material is the best should be left up to the individual farmer. The farmer's decision must be based on whether or not the lying frequency, hock injuries, or leg hygiene is most important; the results vary between the three bedding materials.

CHAPTER 1
INTRODUCTION

Throughout the past 40 years, the Florida dairy industry has undergone many changes in an effort to increase milk production and remain competitive while dealing with the intense subtropical climate and state environmental regulations. These changes have included a shift from small dairy farms to larger ones. This change in dairy herd size has led to a movement from open lot pastures to confinement freestall housing systems.

The Florida Department of Environmental Protection, Florida Administration Code chapter 62-670, requires existing dairies with 70 or more cows and all new dairies to implement management practices to protect ground water quality for storm events up to and including the 25-year, 24-hour storm (Bardolph, 1996). These practices include both the wastewater generated by flushing and washing of barns, milking parlor, and other areas. The rule includes management practices that are potential threats to ground water quality, including unlined waste storage ponds, exposed manure storage piles, excessive accumulation of waste on the bare ground, and waste application in excess of agronomic rates. These regulations are particularly important for any dairy located in the Lake Okeechobee drainage basin. Regardless of the number of cows, every dairy in this basin must have a wastewater permit and implement all management practices. Also, pastured cows must be maintained at such a population density that the manure they deposit does not exceed the forage plant nutrient requirements. These new regulations have resulted in more cows being housed in confinement housing systems with permanent structures, making manure collection and nutrient balances easier for the dairymen.

This change to intensive confinement housing systems within the state of Florida has led to a shift in emphasis from worker comfort to cow comfort (Bethard et al., 2003). As a result, the overall cost of production for farmers has increased. In order to balance the cost of freestall barns, each cow must produce a greater quantity of milk. In order to maximize production, research has been conducted to evaluate the interaction between dairy cows and their housing environment. It must be noted that the most desirable working environment for workers may not be ideal for the animals. Any aspect of the housing system which can potentially stress the cows will inevitably affect milk production.

Many factors must be considered in developing appropriate indoor housing for dairy cattle. Among these factors is the provision of a comfortable bedded area that is well used by the cows which minimizes the potential for bodily harm and bacterial infection. Dairy cows should spend nearly half of their lives lying down, ideally 40-60% a day (12-14 hours/day) (Greenough, 2007). A reduction in the time cows spend resting can lead to physiological changes associated with stress which can ultimately affect the overall health and production of the cow. In particular, the freestall design can strongly affect the standing and lying behavior, the frequency of injuries to the hooves, hocks, and knees of the cattle as well as mastitis. Therefore, providing a well-designed space for this behavior is important. Freestalls for dairy cattle should provide the cow with a place which is clean, comfortable, dry, and should have resilient resting bedding materials for the ease of rising and lunging. The bedding material for the freestall should minimize moisture resulting from manure, urine, and milk buildup. The bedding is known to be an important factor influencing cow comfort, in particular, the surface softness and shock absorption is believed to be important.

This study focused on various cow bedding materials for freestalls. Previous research has indicated the overall comfort of the cow can be measured by the willingness of the cow to lie down. The percentage of time per day a cow lies down has a direct effect on the overall milk production. When a cow lies down, she increases the flow of blood to her udder, therefore, producing more milk. If the freestalls are appealing, cows will be more willing to rest. It is important to determine the ideal conditions for a cow within freestall confinement housing systems.

The objective of this study was to evaluate the effects of three different freestall bedding materials on the behavior and health of lactating Holstein dairy cows. This was performed by comparing stall usage, hock injuries and cleanliness. The three bedding materials were sand, the Advanced Comfort Technology Inc. dual chamber waterbeds, and the Advanced Comfort Technology Inc. waterbeds with approximately 1.5 inches of sand on top. The goal was to determine the frequency of cows lying down, the frequency and severity of injuries to the cows and leg cleanliness based on these three different bedding materials. This information will be used to determine the most comfortable and healthy resting environment for dairy cows.

CHAPTER 2
LITERATURE REVIEW

Animal Behavior and Welfare

In the past, design of animal housing has been concerned with climatic control, labor saving devices, and hygiene. Little attention has been focused on the effects of housing on animal behavior and welfare. However, recent research has found that the behavior and welfare or comfort of the animals does indeed have an effect on the overall production. Welfare has been defined as a term that embraces both the physical and mental wellbeing of the animal as well as a term that relates to the animal's ability to cope both with its surrounding external environment as well as its internal environment (Clark, 1981; Phillips, 2002). The external environment includes, but is not limited to, housing and weather. The internal environment involves nutritional and health status. Animal welfare is difficult to define and measure because it deals with feelings and behavior of animals. Since feelings are difficult to define and quantify, assessment is more likely to concentrate on quantifiable parameters such as the strength of preference for different environments.

When an animal moves from an ideal to worse environment it moves from a state of equilibrium to a state of non-equilibrium, where it recognizes an environmental deterioration (Clark, 1981). This type of behavior can be detected using preference tests to determine which environment the animal prefers. Preference tests can be performed with a person present performing walk-through evaluations or what researchers are using more today, video surveillance and time-lapse photography. However, it must be noted that preference tests must be treated with caution for several reasons: initially animals may exhibit an exaggerated response to a change in environment due to previous experiences, or they may not choose the best environment which would benefit them in the long term due to the attractiveness of one or more new environments.

When measuring animal welfare, researchers have focused more on objective evidence rather than the subjective feelings of the animals. The objective evidence, which is influenced by the physical environment of the animal, can include fear, frustration, as well as pain and discomfort. These factors can be influenced by environments which reduce the health status of the animal via climatic conditions or badly designed housing systems including flooring or resting areas for animals. Ekesbo found the incidence of trampled teats and clinical mastitis was higher when dairy cows were housed either without bedding or in stalls that were too short in length (Clark, 1981).

The greatest impact of environmental influence on dairy cattle is the housing system. Housing dairy cattle alters the typical social structure causing them to be closer than they would be if they were outside as well as the predisposition to specific diseases such as lameness and mastitis. However, it must be noted that dairy cattle seem to adapt to a variety of housing systems. Changes in environmental aspects, such as housing factors, can often result in abnormal behavior, such as tongue rolling caused by inadequate space and diet (Albright et al., 1997). Other behaviors including excessive licking and grooming are evidence of deficiencies in the environment. Temperature stress can also occur either inside or outside housing systems. The major form of temperature stress is heat stress on dairy cattle. The combination of intense humidity and high ambient temperature are the major cause of heat stress. Inadequate ventilation and increased radiant heat load due to a low roof can also contribute to increased instances of heat stress. Inadequate shade structures for cattle outside can increase radiant heat load which causes stress. Therefore animal welfare must always be kept in mind when designing environments for livestock.

Animal Housing and the Environment

In order to control and maintain the ideal environment for livestock, animal housing has to satisfy the animal's biological needs. The surrounding environment of animals affects the overall performance and health of the animal. Ambient air temperature, wind velocity, and relative humidity are three factors of the environment (stressors) which can affect (stress) the conditions of the livestock in housing environments. Biological aspects of animal housing are primarily concerned with maintaining the ideal temperature for the livestock of interest. This ideal temperature for livestock is known as the thermoneutral zone. However, recently, the focus has been on housing components.

The physiological condition of animals is not only influenced by their surrounding environment but also by management practices. Dairy cattle milk productivity is strongly affected by adverse environmental factors. If the cow becomes too hot she will decrease the amount of food intake in order to attempt to balance her body temperature. As a result, the milk production decreases and the farmer's revenue is decreased. This is a major issue for dairy farmers in the state of Florida due to the excessive heat and humidity. If housing components such as freestalls are not ideal for the cows, the overall production will adversely be affected. Therefore, farmers are looking for ways to make the cattle as comfortable as possible to ensure they will produce well.

Milking Dairy Herd Housing Systems

The housing systems in which milking dairy cattle are kept are diverse, ranging from highly mechanized systems where cattle are housed in doors year round (confinement), to extensive systems where the cattle are outdoors permanently (grazing), to combination systems where cattle are indoors and outdoors depending on the time of day (open lot). These housing systems can consist of restrained stall barns, freestall barns, or loose housing barns. These barn designs can use open sided structures utilizing thermal buoyancy or tunnel ventilation. Production levels vary from system to system depending on location, climate, and herd density. Climate and economics will largely dictate which option is feasible.

Open lots will typically cost 30-40% less than freestall barns (Bethard et al., 2003). Confinement housing is typically preferred in Florida followed by open lot then pasture housing systems. Since investment is highest for confinement facilities, they are built in areas where the additional cost can be justified. Higher milk production, improved milk quality, enhanced reproductive performance, and lower cull rates from reduced environmental stress provide the additional income to offset the higher investment of confinement housing systems. Although open lot investment is considerably less, design consideration is still crucial.

Restrained stall barns, or tie stalls allow for constant interaction between the dairymen and the cows, as opposed to freestall barns. The cows are restrained in their stalls by tethers or stanchions. Tie stalls allow the cows to rest, feed, and be milked within the same facility, therefore resulting in less space required per cow and as a result less economical investment is required. In freestalls and loose housing barns, the cows are free to move around within the barn as they please; however, a parlor must be constructed. This results in a higher cost for the dairyman. Each design has its benefits and downfalls.

The use of natural and tunnel ventilated barns is largely dictated by economical and climatic factors. Naturally ventilated barns capitalize on the stack affect and thermal buoyancy as cooling mechanisms in areas other than the southeast United States. This is due to air movement caused by breezes moving through the open sides or sidewall vents. However, naturally ventilated barns based on thermal buoyancy are not effective in the southeast United States because of the intense humidity and heat. They are most effective for winter ventilation in cold climates where cold outside air is warmed by the metabolic heat produced by cows. As a result, the two well known barn options are open sided structures with mechanical cooling systems or tunnel ventilated barns. The open sided barns are oriented east to west to ensure maximum exposure of shade throughout the average day. The open sided barns are equipped with mechanical cooling systems including fans, sprinklers and or foggers to ensure ideal temperature conditions for the cows. Tunnel ventilated barns are most widely used in poultry and swine housing systems. They were initially used in the northeast; however, in the past few years they have started seeing use in dairy housing systems in the southeast United States. These barns typically contain curtains on the side walls and one open end. The other end of the barn contains exhaust fans used to create a negative pressure ventilation system. The cows are kept cool by using foggers and low pressure sprinklers to capitalize on evaporative cooling. The choice between the two ventilation cooling systems is based on the initial construction costs and energy costs.

Environmental Effects on Cow Physiology

The physiology of the animal and its interaction with the surrounding environment must be understood in order to create the ideal environment. Dairy cattle are homeotherms, meaning they exhibit homeostasis. Homeostasis is the ability to maintain a constant body temperature by adjusting their physiological processes. Dairy cattle are one of the few homeotherms that have to work very hard to maintain a constant body temperature due to the intense heat production caused by lactating. The ideal ambient temperature for a lactating dairy cow is between 41° and 75° F (4° and 24° C). For the state of Florida dairy cattle struggle to maintain this temperature since the average yearly temperature of Florida ranges from highs in the mid 60s° F in the winter months to highs in the mid 90s° F in the summer months. At temperatures above 77° F, cows begin to use energy to cool themselves through heat loss via surface skin and the respiratory tract (Jones et al., 1999). As ambient temperature increases, it becomes increasingly difficult for a cow to cool herself adequately.

Dairy cows in peak lactation are most sensitive to heat stress due to the high metabolic heat production associated with milk production. The heat capacity of animals is the sum of the heat change due to metabolism and the heat change due to the environment.

$$\Delta H = \Delta H_m + \Delta H_e \tag{2-1}$$

Where: ΔH = total heat production
ΔH_m = metabolic heat production
ΔH_e = environmental heat production

For homeotherms, the body temperature must remain the same, therefore the change in the heat production due to metabolism must be equal to the negative change in heat production due to the environment. The physiology of dairy cattle is important with regard to housing and freestalls because in order to reduce stress to a cow, the environmental stressors must be reduced. Therefore cow comfort must always be taken into consideration when dealing with dairy cattle.

Cow and Freestall Interaction

The overall cow comfort of a dairy herd is based upon the interaction between the cows and the freestalls. This can be evaluated by focusing on the overall stall usage. Improving the cow comfort can directly affect the milk production and the overall dairy operation. In order to capitalize on ideal freestall usage for cows, all aspects of the freestall must be considered. Many researches have looked at the effect of various bedding materials, different neck rail heights, and various types of partitions on the overall behavior of the cows. All of these changes in the freestall have proven to affect the interaction between the cow and the freestall. Other researchers have focused solely on the effect of the bedding materials as well as environmental factors such as temperature, the location of the freestall within the barn as well as the barn orientation.

The bedding must be appealing to the cow as well as reduce the potential for bacterial growth and collection of milk, urine, and feces. The temperature factor is of utmost importance, especially in hot and humid climates such as in Florida. Monitoring stall usage is a difficult task because of the time and equipment required. Researchers have used the walk-through approach at different times of day as well as videotape images and time-lapse photography. Video surveillance is used more than on site observations because it removes the potential influence of human presence on the cow activity (Wagner-Storch et al., 2003). The most widely used method of evaluating the interaction between the freestall and the cow has been to focus on the various cow orientations within the stalls. These orientations have been quantified into four possibilities; lying in the stalls, standing with all four legs in the stalls, perching in the stalls (with two legs in the stalls and two in the alley), and lying or standing in the alleyways of the barn (empty stalls). The ideal orientation of the cows in order to ensure healthy living spaces and good production of milk is when the cows are lying within the stalls.

Environmental factors which can reduce a cow’s willingness to lie down are as follows: inadequate number of stalls and unattractive uncomfortable stalls (Greenough, 2007). Inadequate number of stalls is a problem for the timid cows. If there are not enough stalls, the timid cows will suffer the most. The lack of stalls can also result in cows lying in the alleyways of the barn. This can cause hock injuries and injury to the teats, possibly leading to mastitis. Stalls can be unattractive and uncomfortable to cows due to the incorrect dimensions for the cow and or stalls which contain dirty and uncomfortable bedding. Therefore all components of freestalls can strongly affect the comfort of the cow.

Cattle should be able and willing to lie down for an average of 11-14 hours a day. Lying enables better flow of blood to the teats as well as an increase in saliva production in the mouth which reduces the development of rumenal acidosis. A cow drinks approximately 20-30 gallons of water a day; as a result, a cow produces 108-308 liters of saliva a day (Greenough, 2007). This production is reduced when lying time is reduced. On average, 3 liters/minute of blood flows through the teats of standing cow while 5 liters/minute when they are lying down (Greenough, 2007). As a result, the more a cow lies down, the udder function and milk production increases. The lying behavior of the cattle can depend on the time of day and particularly, on the freestall design. Kammer (1982) observed four possible lying positions of cattle: the short, wide, narrow, and long positions (Figure 2-1). Albright (1997) noted that adult cows can be observed in the complete lateral recumbence position, however, only for short periods of time. Cows do not remain immobile while resting; changes in position are common for resting cows.

Standing time not only reduces the production of milk, it also has an adverse effect on the health of the cow claws. Standing for a prolonged time, due to the lack of space for the cow or discomfort of stalls, causes the blood pressure inside the claws to rise which is followed by a reduction in the perfusion of blood flow (Greenough, 2007). This causes an inadequate amount of oxygenation and nutrition of the horn-producing tissues. This reduction in circulation causes a decrease in the removal of toxins. This can lead to infections of the claw. This is intensified in freestall housing systems because of the concrete alleyways.

Gaworski et al. (2003) studied cow preference of various freestalls based on location within the barn. They housed cows in four different pens each with 12 head to head freestalls.

They evaluated the usage of freestalls adjacent to the feed bunk, adjacent to the back alley (away from the feed bunk), freestalls located in the center of the barn, and freestalls located on the perimeter (either near a wall or fence) of the barn. They found that stalls in the row adjacent to the feeder were occupied 41% more often than rows accessible from the back alley. The stalls located within the center of each row were used 25% more often than those stalls located on the perimeter of the row. These results suggested that the cows do have a preference when it comes to freestall locations within a barn. The stalls which are more convenient, the ones adjacent to the feeder, and the ones on the center of each row are more desirable to the cows. The stalls located on the perimeter of the barn may not be as desirable for the cow because of the varying weather conditions. During hotter days, those stalls may be hotter due to the sun and during colder days, those stalls may be colder.

Wagner-Storch et al. (2003) compared stall occupancy and cow position for six factors affecting stall usage: stall base, distance to water, stall location within stall base section, barn side, inside barn temperature, and length of time cows exposed to stall bases. The experiment was performed in a 4-row 104 tail to tail stall barn oriented east to west with natural ventilation and no insulation in Wisconsin. Five different bedding materials were used: rubber mat, waterbed, two different mattress types, sand, and concrete. The occupancy of the cattle within the freestalls was evaluated using a surveillance system. The orientation of the cattle was classified as followed: lying in stall, standing half-in-and-out of stall, standing in stall, empty stall, or unsure status. They found that stall base did indeed affect the stall preference of dairy cattle. Sand stalls had an overall higher occupancy percentage than concrete and rubber mats. The waterbeds took time for adjustment for the cows, however over time the stall occupancy increased. In agreement with Gaworski et al. (2003) the stalls on the exterior of the barn were not used as much as the interior stalls. Overall, Wagner-Storch et al. (2003) concluded that the location within the barn and the stall base are two major factors which affect cow stall usage.

Cow Comfort Measurements

Cow barns are usually designed to be convenient for the farm workers rather than for the comfort of the cows. Management risk factors have attracted a great deal of attention over the past 10 years, causing the subject of cow comfort to emerge as a science of real concern for farmers and researchers (Greenough, 2007). Cow comfort has become an interest of researchers recently because it is believed that negative factors within the environment, facilities, and management can cause stress on the animals. This stress can then have adverse effects on the well-being of the animal. Greenough (2007) defines cow comfort as “the quality of environment, including housing, husbandry system, management, and hygiene on which a cow depends to enable it to reach its genetic potential utilizing the nutrients with which it has been supplied”. Therefore, every aspect of the environment affects the condition of the dairy cow.

Qualitative cow comfort measurements have been used to determine the comfort of a herd in a given environment by focusing on freestall usage. Cow comfort is difficult to evaluate because of the time it takes to observe the cow behavior. Up to this point, most farmers perform walk-through assessments, where they periodically walk through the barn to observe the behavior of the cattle to identify whether they are lying, standing, or eating. However, this method is not recommended because of the interaction between the cows and the human that could occur. Previous researchers have attempted to quantify the cow comfort using the proportion eligible lying or free-stall-use index and the total proportion lying. The total proportion lying index is not used frequently because it fails to account for the impact of time spent eating (Overton et al., 2003). The freestall use index is used more often because it takes into consideration the number of cows eating (Overton et al., 2003).

$$FreestallUseIndex = \frac{numberLyingInStalls}{numberCowsNotEating} \tag{2-2}$$

However, the most widely used method of quantifying the cow comfort is the cow comfort index. This measurement considers the behavior of the cow within the freestall by observing the orientation of the cow. The orientation consists of either standing with all four legs in the stall, perching (two legs in the stall and two legs in the alley), lying in the stall, or (empty stalls) not touching the stall (Overton et al., 2003).

$$CowComfortIndex = \frac{numberLyingInStall}{numberCowsTouchingStalls} \tag{2-3}$$

The main concern among researchers when evaluating the cow comfort of a given herd is the optimum time to evaluate the cow orientation. Overton et al. (2003) evaluated the cow behavior using the freestall use index and the cow comfort index. They found the highest mean freestall use index (86%) was seen at 6:00am and a slightly lower index (81%) was seen at 10:00pm. Both of these times corresponded with 2 hours after morning and night milkings respectively. They concluded the cow comfort index is a good indication of overall cow comfort, with a target value of 85% for a given herd. However, for one-time visual appraisals of freestall usage without knowledge of feed delivery time or other management issues, freestall comfort index is the preferred index because it is much less susceptible to management or temperature effects and results in less variation between observation periods. They recommended that the best time to observe maximum stall usage was one hour after cows returned from the early morning milking (or two hours after cows left for milking).

Using Overton's results, Cook et al. (2004) observed the relationship between various cow comfort indices, observation time of day, and stall bedding type. The mean time spent standing in the stall was significantly higher in the mattress herd (3.44h/d) as compared with

1.83h/d in the sand herd. They concluded the cow comfort index was 0.76 for the mattress bedded freestalls and 0.86 for the sand bedded freestalls. They noted there was significant hourly variation in the results, suggesting that timing of measurements is very important, just as Overton et al. (2003) concluded. Cook et al. (2000) and Overton et al. (2003) recommend the cow comfort index to approximate the overall cow-freestall interaction of a given herd; however the time of the day does play a crucial role in determining the actual comfort of the herd.

Dairy Freestall Design

Since the behavior of the dairy cow has become an issue of interest, especially with regard to freestall design and components, every aspect of the freestall must be considered before designing a new or updating an existing facility. In recent years, the focus of dairy intensive housing systems has moved from worker comfort and feasibility to cow comfort and overall well being. Specifically, the comfort of the freestalls and its effect on cow behavior and health has become a focus. During the most recent decade, dairy producers have demanded freestall designs that provide their cows a comfortable resting space, promote cleanliness, and minimize injury. The freestall is a vital element in the cow's environment because it affects their overall comfort, cleanliness, and health. The cow should desire to enter the freestall to rest, but also feel free to enter and leave at will. The stall should be wide enough for the cow to lie comfortably, but narrow enough to prevent the cow from lying diagonally and turning around. The stall must be long enough for the cow to rest comfortably, yet short enough to prevent milk, urine, and feces from collecting on the stall bedding. The stall should be designed to prevent the cow from coming in contact with any part of the stall, in order to prevent injuring during lying and rising. Deficits in freestall design and maintenance have been recognized as significant risk factors for mastitis, hock abrasions, teat trauma, and laminitis (Nordlund et al., 2003).

Uncomfortable stalls result in less time spent resting and as a result, more time standing on the concrete alleys. This increased time standing on the concrete has led to increased incidences of lameness and reduced production. Important factors which must be considered when designing freestalls are the following: stall dimensions and all components of freestalls including partitions and neck rails, resting surface, and cushion and traction of bedding (McFarland, 2003). Even after several years of study, observation, and discussion there seems to be no consensus as to the best combination of these elements to provide the ideal resting surface for dairy cows (McFarland, 2003). However, what is known, is that a good dairy barn should provide a peaceful, clean, and health promoting environment for milking.

Freestall Dimensions

Dimensions for freestalls should represent a compromise between cow comfort and cow cleanliness (MWPS-7, 2000). If the freestall is too short for cows, they will lie with their hind legs partially in the alley. If the freestall is too long for a given cow, the cow will lie too far forward and as a result, manure will build up on the rear of the stall. If the stall is too wide, the cow will be able to turn within the stall and lie diagonally, increasing the chance of injury. If the stall is too narrow, the cow could get injured from the partition and neck rail. Dimensions for freestalls should be based on the largest cow within a herd, assuming that all cows in a given herd are all within the same weight range. Table 2-1 and Figure 2-2 show the suggested freestall dimensions for various size dairy cows based on cow mass.

Using the mass of the cows in a given herd seems to be the best method to approximate the needed freestall size. However, Irish and Merrill (1986) proposed a method of determining stall dimensions based on a relationship of animal dimensions, such as hip width, shoulder height, and body length. This method is not used as frequently due to the lack of a data reporting dairy cattle dimensions by age and breed (McFarland, 2003). However, Anderson (2007) created a table for determining the recommended freestalls dimensions based upon the rump height, foot width, and hook-bone width of a mature Holstein as seen in Table 2-2. No matter the method being used, certain considerations must be made. One particular important consideration is to ensure adequate space for the cow to lunge forward. This is especially important in head to head freestalls. Ideally, the cow should have no obstructions and interaction with the adjacent cow. If one cow occupies a stall on a head to head platform that is only 15 feet long, she becomes a social obstruction to front lunging for the cow in the adjacent stall in front of her. For the stalls to truly function with an ‘open front’, the head to head platform must be made longer. Anderson (2007) described the first head to head 2-row pen with an 18 foot stall platform. By separating the cows’ heads, he claimed improvements in cow lying position and in air quality and heat stress abatement. When altering the freestall dimensions to ensure adequate lunging space all other components must be considered.

There is more to freestall comfort than properly sized stalls. The components of a freestall work together to convince cows to enter, and provide a comfortable resting experience to ensure their return and continued use. Freestall components include the brisket board, stall partition, and neck rail. These components of a freestall can contribute to the overall cow freestall interaction.

Brisket Board

The brisket board helps define the available body space on the stall bed for the cow. If a brisket board is used, it is recommended by the University of Wisconsin school of veterinary medicine that it should not be more than 4 inches above the stall surface with an angle of 30-45^{o} away from the stall base (Cook et al., 2004). This enables the cow to rest with one leg forward if she chooses. The brisket board should be present to discourage the cow from being too far forward in the stall, but allow for proper forward lunging space. This helps maintain a clean stall by keeping the cow in the center of the stall, resulting in all urine and feces being deposited in the alleys, not the rear of the stall. As the bedding layer gets thinner with use, the brisket board becomes more exposed, controlling forward movement. In addition, the rear curb also becomes more exposed, reducing available body space. Therefore, the bedding material must be maintained on a regular basis in order to maintain the desired depth.

Freestall Partitions

Freestall partitions should guide the cow into and out of the stall, help position the cow, and provide protection from cows in adjacent stalls (McFarland et al., 2003). There are many different types of partitions, ranging from loop, wide bend, rear post, to European partitions. The loop and wide bend partitions are used for side lunging while the European and rear partitions are used for forward lunging. In a side lunge freestall, the cow should be able to turn and thrust her head into an adjacent stall as she rises. The Midwest Plan Service (2000) states that the lower rail of the partition should be either high enough in the front to allow the cow to thrust her head under the lower rail, or low enough to allow her to thrust her head over the lower rail without interference. It is recommended by the Midwest Plan Service (2000) that if the cow thrusts her head under the partition the bottom of the partition rail should be a minimum of 32 inches above the rear curb. If the cow thrusts her head above the bottom rail, the bottom partition rail should be a maximum of 11 inches above the rear curb. In a forward lunge freestall, additional stall length is needed in order to compensate for the cow lunging forward. The Midwest Plan Service (2000) recommends a minimum of 21 inches of open vertical space for a head to head freestall arrangement. Cook et al. (2004) recommends a space of 5 inches between the lower edge of the partition and the top of the brisket board in order to allow for a cow to get her leg free if it should get stuck.

The position of the partition can drastically affect the overall use of the freestall. In general, too little clearance distance between the partition and the stall bedding can present a leg injury hazard. Too much clearance may allow cows to shift under the divider while resting. The partitions should be installed to prevent the cow from lying diagonally. Mounting partitions too low will make it easier for the cow to turn around in the stall. McFarland (2003) recommends a stall partition length of approximately 12 inches (30 cm) less than the stall length. This reduces the chance of cow/partition contact as the cows enter and exit the stalls. If too much space is provided, 24 inches or more (60 cm or more), cows often choose to walk along the rear of the stall bed rather than the cow alley. Maintaining the needed depth of bedding material on the stall surface will enhance the purpose of the partition by preventing low spots or holes in the bedding which allow the cow to put her head or shoulders underneath the partition.

Freestall Neck Rail

The neck rail discourages the cow from moving too far forward when entering the stall and provides adequate lunge space for rising and lunging (McFarland, 2003). The neck rail location should allow each cow to place all four feet on the stall surface with her head below the rail, neck gently nudging it, so she can recline. It should encourage cows to back up when rising and prevent them from moving too far forward when standing within the stall. Previous research has found that the correct placement of the neck rail can drastically affect the use of the freestalls. The correct placement involves both the vertical distance above the stall bed as well as the horizontal distance from the rear curb. The height and body length of the largest cows in the group should determine the proper neck rail location (Cook et al. 2004). If a significant number of cows stand with their front feet in the stall and rear feet in the alley, or on the stall bed with their heads above the rail, the neck rail is placed too low and/or too far back. Another indication the neck rail is improperly positioned is that the cows will stand diagonally in order to obtain the footing needed to recline.

Cook et al. (2004) recommends a neck rail vertical height of 48 to 50 inches in mattress stalls. The Midwest Plan Service (2000) recommends a neck rail height to be between 44 and 48 inches above the top edge of the curb for a 1,400 pound cow. Certain herds have had trouble finding the correct height of the neck rail; however, Cook et al. (2004) recommends a neck rail that is higher than it should be is better than one that is too low because the higher the neck rail the less likely the cow will get entrapped and possibly break her back. In previous studies, the location of the neck rail has not had a significant effect on the lying and standing time; however, it did influence the type of standing behavior within the stall. High neck rail heights increased the amount of standing with all four feet in the stalls. With the neck rail located at 67 inches from the rear curb in a mattress stall, cows spent more time standing with all four legs on the stall platform and less time perching with only the front two legs in the stall, compared to when the neck rail was 60 inches from the rear curb (Cook et al., 2004).

Health Concerns with Freestalls

The freestall design and bedding material are not only important factors that affect the freestall use, but they can also have an adverse effect on the health of the cows. The major health concerns for dairymen are mastitis and damage to the hocks and knees which can lead to lameness. These health factors can be affected not only by the bedding and resting area of the freestalls, but also by the overall cleanliness of the freestalls. It has been estimated that one sick cow can cost the producer at least US$350, resulting in thousands annually (Greenough, 2007). This estimate includes: vet fees, the loss of milk production, the cost of medication, time spent caring for the cow, and the loss of body condition. The correct freestall design, including the use of the best bedding material, can drastically decrease the prevalence of dirty cows which can contribute to mastitis. Incorrectly dimensioned stalls and most importantly the bedding material can contribute to increased instances of hock and knee injuries. Lameness can be prevented or at least decreased in a herd by creating a resting area that is attractive to the cows. Lameness becomes prevalent in herds when the cows stand in the alleys rather than use the freestalls. Outbreaks of mastitis occur due to dirty freestalls and most importantly, when cows lie in the alleys on manure and urine because the freestalls are unattractive to them. As a result, it is imperative to create freestalls with bedding materials which are considered to be the best for the cows in order to ensure maximum comfort for them.

Cow Hygiene

The hygiene of dairy cattle not only affects the comfort of animals but also the quality of the milk being produced. Clean animals are more likely to remain disease free and at milking time are less likely to contaminate the milk with harmful bacteria. In order to prevent contamination of milk, the udders, flanks, hindquarters, abdomen, and tails should be cleaned prior to milking. The design of freestalls can drastically affect the overall hygiene of the herd. Most importantly, the bedding material should help minimize soiling and improve cow comfort.

Previous researchers have tested the effects of various bedding materials on the overall cow hygiene. Fulwider et al. (2007) concluded cows kept on rubber filled mattresses and waterbeds had better hygiene scores (cleaner) than the cows on sand bedded stalls. They concluded this was possibly due to the sand-laden manure which was more likely to cling to the legs. However, Bewley et al. (2001) concluded that sand resulted in the best score for udder health, cow cleanliness and cow comfort as compared to other bedding materials. These two different results with regard to sand bedded freestalls prove that not only is the bedding material a factor of cleanliness but there are many other aspects of the freestall that can affect the overall cow cleanliness.

Hock Health

All components of freestalls have proven to affect the health of cow hocks. Stalls that are too short cause injury to the hocks due to the rear concrete curb. However, bedding material has proven to affect the prevalence and severity of hock injuries as well. The locations on the hocks where the most prevalent skin lesions occur are the tuber calcis and tarsal joints (Figure 2-3). The tarsal joint is the side portion of the hock joint and the tuber calcis is the rear point of the hock joint of the cow. There is frequent hair loss on the tarsal joint due to sweat and abrasion from the bedding material in freestalls. The tuber calcis is usually harmed by the rear curb on stalls that are too short for the cows. Mattresses have resulted in less skin lesions because they cover the rear concrete curb while other bedding materials do not (Fulwider et al., 2007). Hock injuries can lead to increased culling rates and as a result, reduced production. Therefore, research has been performed to examine various bedding materials to determine which material the cows prefer and which ones cause the least injuries to the cows.

Mowbray et al. (2003) examined the effects of freestall designs on the development of hock lesions. The experiment examined geotextile mattresses versus stalls bedded with 8+ inches of sand over a 6 week period while every other aspect of the stalls were kept identical. Lesions on the tarsal joint of the hocks were more prevalent for the cows located on the geotextile mattresses; however, lesions on the tuber calcis were more prevalent for cows on the sand beds. They concluded the reason why the lesions located on the tarsal joint were more prevalent for the geotextile mattresses was because of the frictional heat built up between the cow and the mattress. The pressure created from the body weight of the animal reduces blood flow to skin over the area of contact with the lying surface; therefore causing skin lesions. The skin lesions for the sand bedded stalls were more prevalent on the tuber calcis because of the exposed rear concrete curb.

Weary et al. (2000) found very similar results in a study which compared the prevalence and severity of lesions on the hocks of lactating dairy cows in southern British Columbia. They examined three different bedding materials, sawdust, sand, and geotextile mattresses within 20 farms. The skin lesions were evaluated at five different locations on the hock using the severity scoring system on a scale of 1-2. The locations were; the dorsal, lateral, and medial surfaces of the tuber calcis, and the lateral and medial surfaces of the tarsal joint. The injury and severity of each lesion was scored as either 1 (area of hair loss less than 1.5 in^2 with no evidence of skin breakage) or 2 (broken skin, dark scab, or area of hair loss greater than 1.5 in^2). The cows housed with geotextile mattresses had the most occurrences of hock lesions with a 91% occurrence rate. Only 24% of the cows housed in sand beds had lesions. Overall, the prevalence and severity of injury to the hocks was the most in dairy cattle which were housed in geotextile mattress freestalls. The sawdust results were considered intermediate with the sand bedded freestalls causing the least amount of lesions to the cattle. With regard to the location of the injuries, the most common and severe lesions occurred with the geotextile mattresses on the lateral surfaces of both the tuber calcis and the tarsal joint. For the sawdust bedded stalls, the lesions were most common on the dorsal surface of the tuber calcis and the lateral surfaces of both the tuber calcis and the tarsal joint. With regard to the sand bedded stalls, the lesions were rare for the five points of the hock examined for this experiment. In conclusion, this experiment determined that geotextile mattresses caused the most injury to the hocks of the dairy cattle and the sand bedded stalls were most suited for the cows, causing the least amount of harm.

Fulwider et al. (2007) performed an experiment testing various bedding materials and their effect on the frequency of hock lesions and knee swellings using a 4 point scale: 0 (no hair loss or swelling), 1 (hair loss, no swelling), 2 (swelling), or 3 (severe swelling). Hair loss patches (score 1) were 0.7 inches in diameter or larger. They found that sand had less lateral tuber calcis lesions than waterbeds. However, they also found that sand had greater dorsal lesions than cows on waterbeds. With regard to knee swelling, they found that cows on waterbeds had much more swelling and hairless areas than cows on sand.

Lameness and Freestalls

Lameness, a tricky economical and welfare problem in dairy cattle, is directly influenced by the design of modern housing. In particular, concrete flooring and uncomfortable stalls are associated with increased incidence of lameness in freestall barns. The prevalence of lameness within dairy herds can vary depending on the housing system, freestalls or tie stalls. No matter the housing system, the main cause of lameness within dairies is due to concrete, which is used for freestalls, alleys, and parlors. Several studies have reported higher rates of lameness in freestall herds compared to tie stall herds (Cook et al., 2004). This result suggests that there are differences in environmental conditions between the two systems that are important to the incidence and prevalence of lameness. These may include differences in hoof hygiene, factors that influence freestall access, and differences in cow behavior relative to stall use. These factors may influence the onset of infections of the hoof, such as digital dermatitis, and also trigger claw horn lesions, commonly associated with laminitis (Cook et al., 2004).

Not only is the housing system a contributing factor to the prevalence of lameness, but if freestall barns are used, stall design and bedding are major contributing factors. The bedding material and stall design can contribute to lameness by causing a change in the daily interaction between the cow and the freestall. Specifically, reduced daily lying times, increased total standing time on hard surfaces, and increased perching with the 2 front feet on the stall platform have been associated with increased rates of lameness (Cook et al. 2004). The relative importance of each of these behavior patterns can vary depending on the type of housing system.

Cook et al. (2004) found significantly lower lameness prevalence in herds using sand stalls compared with those using other types of stall surfaces, which included rubber mats and rubber crumb-filled mattresses. Galindo et al. (2000) indicated that perching activity is important and cows that spend more time perching are more likely to become lame (Cook et al. 2004). Vokey et al. (2003) evaluated the effects of varying combinations of alley surfaces and stall surfaces. Freestalls with sand bedding with rubber mats on the alleys instead of concrete alleys led to the lowest net growth of the dorsal wall and maintained balance between the lateral and medial claw. In contrast, the animals in pens with concrete alleys and either sand or mattress stalls had significantly higher net growth rates and had the highest imbalance between the lateral and medial claws.

Mastitis and Freestalls

Studies comparing housing systems tend to show slightly lower mastitis incidence in freestalls than in tie stalls or loose housing (Rodenburg, 1996). Mastitis is one of the most common and costly diseases of dairy cattle. It can be controlled by applying a management program which includes: (1) a clean, stress-free environment; (2) proper maintenance and operation of milking equipment; (3) good milking procedures including teat dipping; (4) a dry cow treatment program; and (5) a program for monitoring udder health status (Rodenburg, 1996). The principal organisms associated with mastitis are *Streptococcus agalactiae, Streptococcus uberis,* and *Staphylococcus aureus.* These organisms usually cause a chronic mastitis and a loss in milk yield with or without the appearance of clinical symptoms. Mastitis reduces the milk yield and shortens the productive life of affected cows. While it is generally agreed that the immediate cause of mastitis is infection, a difference of opinion exists regarding the importance of management practices.

It has been proven over the years that there are a variety of factors that impact the bacteria load on the cow's teat. These factors do indeed include proper maintenance of freestalls. There are many references describing proper freestall design, however, even the most ideal design cannot function properly if freestalls are not maintained. Regular maintenance and management are required to ensure that freestalls provide a clean dry and comfortable environment. Spencer (1998) describes three areas which should be considered with regard to the proper maintenance of freestalls: daily maintenance, bedding maintenance, and stall bed maintenance. The daily maintenance should involve frequent raking and spot cleaning and should be conducted several times a day. Bedding maintenance is often the overriding factor in determining the frequency of stall maintenance.

When stalls are too small, a higher incidence of teat injuries occurs. In freestall barns, cows are less likely to lie in dirty alleyways if freestalls are of adequate size and appealing. Harder stall surfaces such as concrete or wood products reduce cow comfort and may increase teat injuries. Excessively large stalls promote a build-up of manure which increases exposure to mastitis causing organisms. No matter the freestall design, it is important to maintain a clean bacteria free place for the cows to rest. Sawdust and wood shavings have been shown to support growth of coliforms resulting in mastitis outbreaks (Bramley, 1985). Hogan et al. (1989) reported significantly higher moisture content and concentrations of gram negative bacteria, *Klebsiella,* coliforms, and gram positive *Streptococcus* in freestalls bedded with sawdust or chopped straw compared with those bedded with sand or limestone.

Freestall Bedding

Although a well designed, constructed, and managed freestall system offers a cow a comfortable place to lie, the success of the housing is largely dependant upon the bedding material used. Stall base and design influence cow acceptance and comfort. Stalls providing a comfortable and conforming base designed to allow for ease of rising and lying movements have resulted in longer bouts of lying. Cows increase their lying time by 1.8-4.0 hours per day on a soft bedded stall compared to concrete surfaces (Greenough, 2007). Common bedding materials used are sand, rubber mats with a light layer of sand, shavings, straw, concrete, and new to the industry, waterbeds. Factors which should be used when considering freestall bedding are the following: cushion and traction of the material, the effect of temperature, maintenance requirements, and the potential for bacterial growth.

Cushion and Traction of Bedding Materials

The cushion and traction of bedding materials have become a new focus in the dairy industry with regard to overall cow health and behavior. The amount of bedding used on a stall surface is a major issue for dairymen because it causes problems when trying to maximize both cow comfort and cow cleanliness. Increased amounts of bedding have proven to increase cow comfort and lying times, however, controlling bedding bacterial counts and udder health requires frequent removal of the bedding material. The buildup of excess bedding material can lead to high numbers of potential udder pathogens. Researchers recently have begun to focus on various bedding materials and how they benefit the dairymen as well as the cow.

The method of determining the surface cushion is rather subjective at this point, however, there has been recent success using the Clegg Impact Soil Tester to measure surface softness. This devise measures the peak deceleration of a weight hammer as it makes an impact from a selected height. The mass of the hammer and the drop height vary depending on the material being tested. The ASTM standard, D5874-02, recommends the light impact value tester (IV/L) for lower strength materials and fine grains (Figure 2-4a). The light impact value tester should be used with a 1 lb (0.5kg) hammer. For higher strength materials, the impact value (IV) should be determined by using the Clegg Impact Soil Tester with a hammer mass of 5 lbs (2.25kg), 10 lbs

(4.50kg), or 44 lbs (20kg) (Figure 2-4b). The Clegg impact value (CIV) is greater for materials that are harder and as the material increasingly becomes more compacted, the CIV increases.

Fulwider et al. (2004) compared the softness of one cork-filled mattress, four foam-filled mattresses, four rubber-filled mattresses, and four rubber mats using the Clegg Impact Soil Tester with a 55 lbs (25kg) hammer. They concluded that the hardest bedding material was the rubber mat with an average Clegg impact value (CIV) of 146. The softest and most preferred bedding was the rubber filled mattress with an average Clegg impact value of 40. The impact value is equal to 10* G_{max} where G_{max} is a gravity unit of peak deceleration. They concluded the hardness results correlated relatively well with cow preference and the CIV increased with increased wear/compaction of the material. Based on the recommendations of Dr. Baden Clegg for the operation of the Clegg Impact Tester, for the bedding materials that were used by Fulwider et al. (2004), the 55 lbs (25kg) hammer was too heavy. A 5 lbs (2.25kg), or 10 lbs (4.50kg), hammer would have been more ideal, based on the material properties of the various bedding materials. A 25kg hammer should be used for pavements, not freestall bedding materials (Clegg, 1983). This was taken into consideration when looking at the results from this study. The weight of the hammer has been proven to affect the overall CIV. Rogers and Waddington (1990) reported that the 1 lb (0.5kg) hammer will typically record G_{max} values that are 24 to 50 units higher than values produced by the 5 lbs (2.25kg) hammer. In agreement with Rogers and Waddington, Clegg (2005) noted that a 10 lbs (4.50kg) hammer might show a CIV of 80 where a 44 lbs (20kg) hammer might result in CIVs of 40 or 50.

The traction or abrasiveness of the bedding material affects the usage of the freestall by affecting the rising and lunging movement of the cow as well as the potential for injury to the hocks and knees. Research is lacking determining the mechanical properties of the bedding materials. However, research comparing the effects of various bedding materials on injuries to the hocks of dairy cows can be used to approximate abrasiveness of the bedding material. It is important to make sure the bedding material has enough traction to prevent the cow from slipping when rising, however, not too abrasive to cause harm.

Temperature Effect on Bedding Materials

Previous research has determined that the surrounding ambient temperature within freestall barns affects the behavior of cows. Thoreson et al. (2000) found sand (60.8% occupancy) was favored over mattresses (19.4 to 32.5% occupancy) and rubber mats (12.3% occupancy) during a summer trial. They concluded that sand stalls were used less during winter months (27%) as compared to summer months (60.8%). Wagner-Storch et al. (2003) results of lying and stall-occupancy for sand bedded stalls differed. They did find that the temperature did influence lying and stall occupied percentages for each stall base; however, they discovered that for all stall types the use decreased as temperature increased. Cows preferred to lie on sand bedded freestalls when the temperatures were warmer (21 to 60°F) while the waterbeds had the lowest (31.0%) lying percentage during warm temperatures of 81 to 100°F. Waterbed stalls (56.5%) had the highest lying percentage during cold temperature 1 to 20°F compared to rubber mats (29.8%) and concrete (20.7%). Mean percentage lying, across all stall bases, was low during warm temperatures of 81 to 100°F.

Even though these researchers have examined the effect of the ambient temperature on the behavior of the cows, there has not been research performed examining the effect of the actual temperature or the conductivity of the bedding materials on the behavior of cows. It is known that cows are homeotherms; therefore, they must maintain their body temperature within the thermal neutral zone. In cold climates, cows usually eat more to increase their heat production as well as huddle with others or lie down. However, in the warmer climates, as seen in Florida, the cow must produce as little heat metabolically as possible. In other words, the cow must reject as much heat to the environment as possible either through sensible heat or latent heat processes. The ability of the bedding to reject or absorb heat might affect the decision of the cattle to lie or stand in the stall. However, the effect of the varying temperature gradients between the cows while in contact with freestalls is unclear. It has been suggested that the various bedding material properties could assist in a better understanding of the heat transfer between the cow and the freestalls, based on conduction. Temperature can affect stall usage by affecting the thermal comfort of the bedding material. How well or poorly the bedding material can transfer heat could have an effect on the comfort of the cow while lying, depending on the surrounding environmental factors.

Conduction is dependant upon many factors; material density (ρ), specific heat (c_p), thermal conductivity (k), and thermal diffusivity (α). The basic equation which describes heat conduction is the Fourier-Biot Law (Equation 2-4). Heat conduction occurs when heat flows from a region of higher temperature to a region of lower temperature within a medium or between mediums in direct contact. It is dependant on the temperature difference, the surface area, and the thermal conductivity.

$$Q_{cond} = kA\Delta T \tag{2-4}$$

Where: k = thermal conductivity (W/mk)
A = cross sectional area of the flow path (m^2)
ΔT = temperature difference (K)

However, in order to better understand heat conduction within a single body, the first law of thermodynamics must be considered (Equation 2-5). The first law of thermodynamics explains the conservation of energy within a homogeneous isotropic object in which heat conduction occurs. When examining the interaction between a cow when lying and the freestall bedding material, the heat transfer properties must be understood. As a result, the specific heat and density of the materials must be known.

$$\frac{\partial Q}{\partial \tau} + \frac{\partial w}{\partial \tau} = \frac{\partial u}{\partial \tau} \tag{2-5}$$

Where: $\delta Q/\delta\tau$ = rate at which heat is added to the body by conduction (W)
$\delta w/\delta\tau$ = rate at which work is done on the body (W)
$\delta u/\delta\tau$ = rate of change of internal energy of the body (W)

The rate of heat flow added to a body is equal to the rate of heat flow in through the surfaces of a body minus the rate of heat flow out. As a result, the internal energy of the body, ($\delta u/\delta t$) is dependant on the mass density, specific heat, and the temperature. With the interaction of the specific heat and mass density of the object, a new term can be derived, the thermal diffusivity ($\alpha = k/(\rho c_p)$. Substances with high thermal diffusivity rapidly adjust their temperature to that of their surroundings. As the thermal diffusivity increases, meaning the density and specific heat decreases, the overall heat conduction of an object decreases. It is very unclear at this point how cows actually react to various freestall bedding materials with regard to the effect of conduction heat transfer. This is an area in need of work.

Once the conductivity of the bedding material is known, then a correlation of cow comfort and thermal conductivity could be created. This additional knowledge could lead to a better understanding of cow comfort with regard to freestall bedding material. From that, a conclusion could be made that could state what type of material conduction was more desired for a given environment.

The thermal conductivity of the bedding material is not the only factor which must be considered. The thermal mass of the materials can also affect the temperature of the freestalls. Thermal mass is a term used to describe the ability of materials to store heat, or the thermal storage capacity. The basic characteristic of thermal mass is the ability to absorb heat, store it, and release it at a later time. The thermal mass of the rubber on concrete is much different than the thermal mass of sand or straw on an earthen base. These differences will have an effect on the overall conduction of the bedding material, and as a result, the overall temperature of the bedding materials.

Various bedding materials are used throughout dairies in the United States, however, research on the effect of the conductivity and or the thermal mass of the materials is lacking. In the United States, sand bedded freestalls are widely used because it produces a poor environment for bacterial growth, and due to cow preference, as observed by previous researchers. However, sand bedded freestalls require additional maintenance as compared to other bedding materials. There is much room for research on the topic of the interaction between the conductivity of the bedding materials and cow comfort.

Maintenance of Bedding Materials

Maintenance is another issue which must be considered when deciding the best bedding material for dairy freestalls. Bedding maintenance will vary with the type of stall and bedding used. However, whether it is adding a thin layer of bedding on top of a mattress or adding sand to a stall, weekly attention is necessary to maintain stall acceptance and cow cleanliness. Regular maintenance is required in order to maintain the proper freestall longitudinal slope to encourage stall use and allow for proper positioning of the cow. Obviously, concrete stalls will not need to be leveled, while clay/sand beds and mattresses will. Bedding materials made of smaller particle size have to be replaced on a regular basis in order to maintain the needed bedding amount within the stall. Also, for stalls that have small particle bedding, such as sand or shavings, the alleys of the barn have to be scrapped periodically. Rubber bedding materials on an earthen base have to be remolded frequently due to the pressure created on a daily basis by the cows. If mats are used, they have to be cleaned on a daily basis to maintain a clean environment for the cows.

Equipment at farms using sand bedding has difficulty due to abrasion by sand particles. Therefore, farms that use sand bedding must have durable equipment that can handle the coarse particles of sand. Poor bedding and stall maintenance are major contributing factors of good freestall designs becoming completely dysfunctional and creating unclean and harmful environments for the cows.

Drissler et al. (2005) documented the effect of the depth of sand bedded freestalls on the lying behavior of dairy cows. They performed three different experiments over a 10 day period and found over time the bedding surface became concave with the deepest part of the stall at the center. They found that the daily lying time was 1.15 hour shorter in stalls with the lowest levels of bedding compared with stalls filled with bedding. Indeed, for every 0.39 in. (1 cm) decrease in bedding, cows spent 11 minutes less time lying down during each 24 hour period. As a result, they concluded that the concavity of the bedding material and the maintenance does indeed affect the lying behavior of cows.

Bacterial Environment and Bedding Materials

Freestall bedding materials should prevent a build up of bacteria. Freestalls bedded with sand have proven very effective in minimizing exposure of the udder to bacteria, because bacteria do not grow as quickly in sand as in organic bedding materials. However, sand is not always practical because it is extremely difficult to handle in most manure systems. Rodenburg (1996) discourages the use of organic materials such as hardwood sawdust because they have proven to cause an increased incidence of mastitis caused by a coliform organism called Klebsiella. Sawdust and shavings from kiln dried lumber present less risk, if kept dry in storage, and in the stalls, but incidence of Klebsiella infection is still higher than with straw (Rodenburg, 1996). Previous research has indicted that adding lime to sawdust has not proven to be beneficial in reducing mastitis on organic materials. Straw tends to harbor bacteria when it becomes damp, thus leading to increased incidence of mastitis caused by these organisms, however, clean dry straw has proven to be good bedding material. Researchers have found that mattresses with sawdust or sand on top can be just as good as the sand when it comes to decreasing the ideal environment for bacteria. Rubber mats improve cow comfort but still require bedding to keep stalls dry and improve footing. Though costly, these mats may prove more satisfactory than sand when little or no bedding material is available. With all bedding materials, replacing wet soiled material daily is the key to controlling growth of bacteria in the bedding and to reducing new mastitis infections.

Various Bedding Materials

Considering all the factors that must be considered when choosing the ideal bedding material for the cows, it is easy to run into a problem. There are many different types to choose from. No matter the type, the main considerations should be whether or not the material can absorb moisture and manure as well as whether or not it provides cushion. The most popular stall materials used by dairy producers are: sand bedded, mattresses, as well as waterbeds.

Sand bedded freestalls are widely used because sand is inorganic and provides a poor environment for bacterial growth as well as cow preference. The grains of sand tend to move as opposed to compact, therefore providing a comfortable cushion for the cows. McFarland et al. (1994) recommends a minimum of 6 to 8 in. (15 to 20 cm) of sand. Sand should be replenished every week to prevent the rear curb of the stall to protrude, presenting harm to the cows. The main disadvantages to sand bedding are the manure management and the ongoing expense.

Mattresses are widely used in place of sand bedded freestalls due to economical and maintenance reasons. There are many different versions of mattresses used by dairy farmers today. Fabric mattresses made with polypropylene can be filled with organic materials such as straw, sawdust, or shavings. Shredded rubber bedding has been used as an alternative to the fabric filled mattresses. These are used more than the fabric filled mattresses because shredded rubber has been proven to provide an excellent cushion resulting in good stall acceptance as well as preventing bacterial growth (McFarland, 1994). The rubber crumbs of the shredded rubber can cause a problem for the waste management facilities as well. As a result, geotextile mattresses have been used in their place. However, the geotextile mattresses must be placed on a concrete base, resulting in very little variation in cushion from the concrete. It must be noted, no matter the mattress, the major disadvantages are that over time they become deformed and must be replaced and they can become very slippery when wet.

Many researchers have studied the effects of different bedding materials on the overall behavior of the cows. Herlin (1997) compared cow preferences for concrete, rubber mats (0.60 in. thick), and comfort mats (0.80 in. thick), by offering 18 cows 18 stalls, 6 stalls of each type (Tucker et al. 2001). He found that cows were more likely to spend time lying down on comfort mats than on the rubber and they were more likely to use the rubber than the concrete (Figure 2-5). Jensen et al. (1988) also found that cows prefer the softer of the options presented to them. They compared concrete with a brand of mattress (Enkamat K), both covered with straw, using three groups of 14 cows, each presented with 14 stalls (seven of each type). The cows spent more time in the concrete stalls when stalls were freshly (and more deeply) bedded with straw, but cows preferred the Enkamat K stalls when straw bedding was minimal. O’Connell et al. (1997) compared four treatments: 1) concrete and sawdust, 2) concrete and paper, 3) mattresses (Enkamat) and sawdust, and 4) mattresses (Enkamat) and paper, using 64 cows for sixteen stalls of each type. Cows preferred to lie down in the stalls bedded with mattresses and sawdust and were least likely to use the concrete stalls with paper. The results of Gebremedhin et al. (1985) illustrated a preference by cows for stalls with more bedding. They found that cows were more likely to lie down in stalls when these had more bedding (achieved by adding a bedding retainer), regardless of whether the stall base was concrete, mat or carpet. Tucker et al. (2003) found that cows showed preference for sand and sawdust bedded freestalls as compared to geotextile mattresses.

It is clear that there are many aspects of dairy housing that can alter the overall behavior of the cows, specifically aspects of the freestalls. Dairy cows can adapt relatively well to new environments, however, those environments must be suited for them, not the workers. The freestall design has proven to affect the stall usage. In particular, the bedding material plays an important role in the attractiveness and comfort of the stall. Dairy farming is a competitive and difficult business; therefore any aspect of the housing system that can potentially increase the overall production should be examined further.

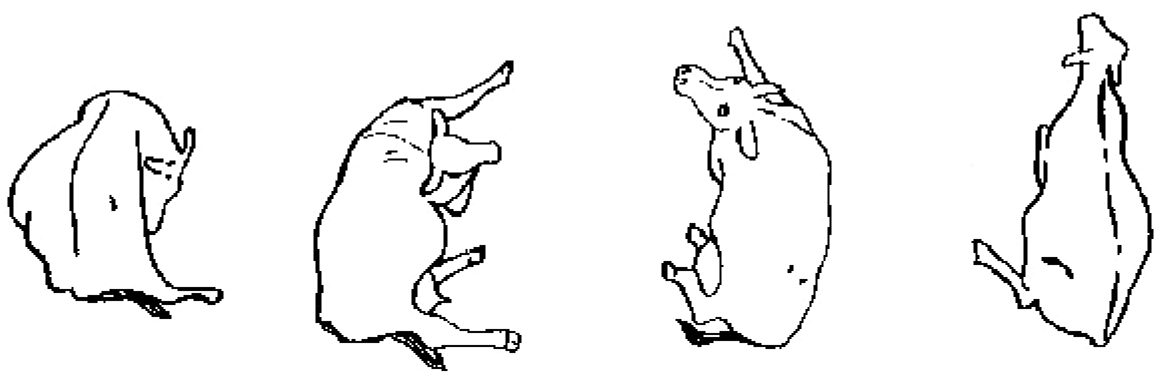


Figure 2-1. Typical resting postures for dairy cattle (adapted from Kammer, 1982; McFarland, 2003).

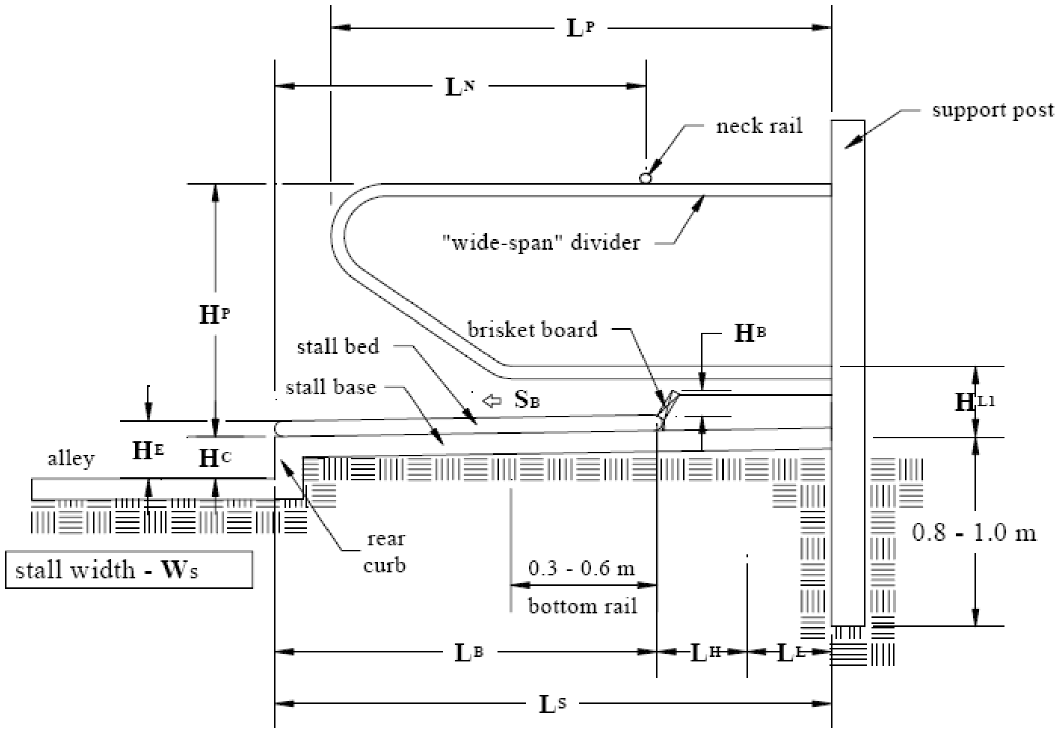


Figure 2-2. Typical freestall cross section (adapted from ASAE 2001).

Table 2-1. Suggested freestall dimensions for various cow sizes (adapted from ASAE 2001).

	Cow mass (kg)		
Dimension	550	650	750
L_S=total stall length (mm)	Open Front: 2030-2185 Closed Front: 2335-2490	OF: 2135-2285 CF: 2440-2590	OF: 2285-2490 CF: 2590-2745
L_H=head space length (mm)	430	455	480
L_L=lunge space length (mm)	355	380	405
L_N=length to neck rail (mm)	1575-1625	1675-1725	1775-1825
L_B=length to brisket board (mm)	1575-1625	1675-1725	1775-1825
L_P=stall partition length (mm)	(L_S-355) to L_S	(L_S-355) to L_S	(L_S-355) to L_S
H_N=height to neck rail (mm)	1065-1170	1120-1220	1170-1270
H_P=stall partition height (mm)	1065-1170	1120-1220	1170-1270
H_B=brisket board height (mm)	10-15	10-15	10-15
H_C=stall curb height (mm)	150-250	150-250	150-250
H_E=stall entry height (mm)	300	300	300
H_{L1}=lunge clearance lower, (mm, max)	280	280	280
H_{L2}=lunge clearance upper, (mm, min)	815	815	815
W_S=stall width (mm), center to center	1090-1145	1145-1220	1220-1320
S_B=stall base slope (%)	1-4	1-4	1-4

Table 2-2. Suggested freestall dimensions based upon the body dimensions of a mature Holstein Cow (Anderson 2007).

Stall Dimension	Ratio and Reference Body Dimension (in.)
Stall length from curb to solid front	2.0 x rump height
Stall length for open front head-to-head	1.8 x rump height
Bed length = imprint length	1.2 x rump height
Neck rail height above cow's feet	0.83 x rump height
Neck rail forward location = bed length	1.2 x rump height
Deterrent strap in open front stalls	0.7 x rump height
Stall width-loops on centers	2.0 x hook bone width
Space between brisket locator and loop	foot width

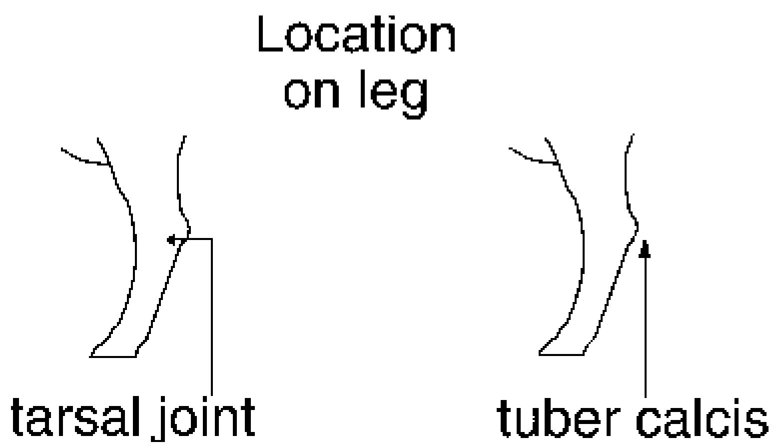
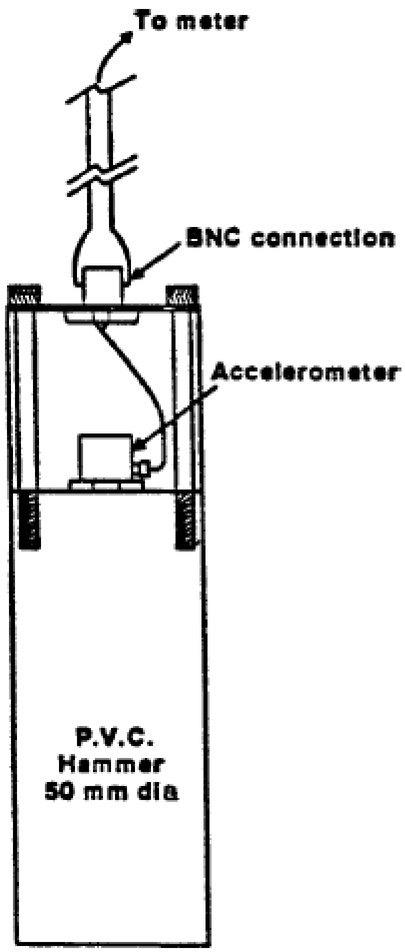
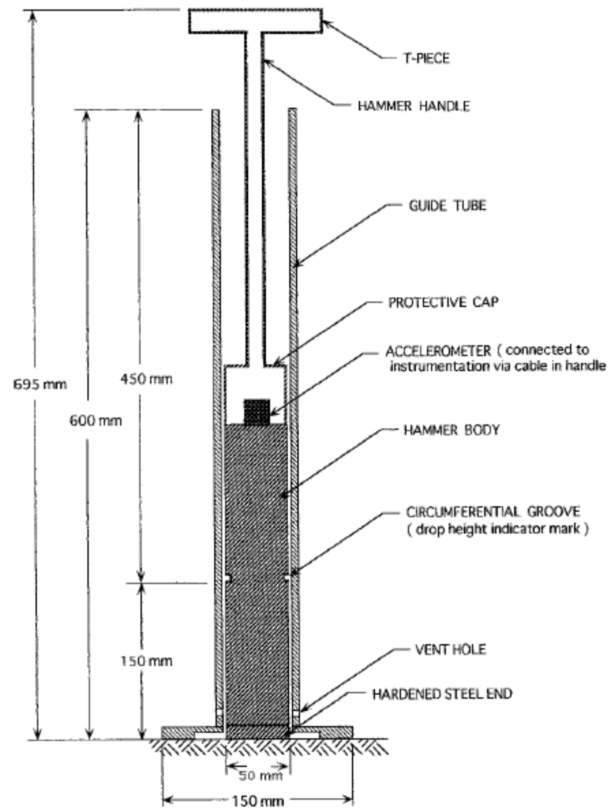


Figure 2-3. Location of cattle hock joints (Weary et al. 2000).



A



B

Figure 2-4. Clegg Impact Soil Testers (ASTM Designation: D 5874-02). A) Light Impact Tester B) Standard Impact Tester

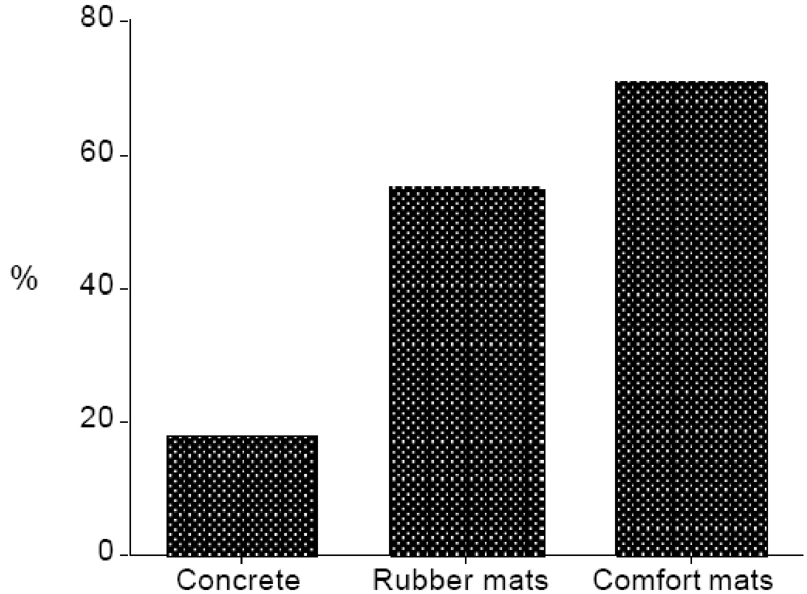


Figure 2-5. Freestall bedding preferences of 18 animals for 18 stalls (6 of each material). Adapted from Herlin (1997).

CHAPTER 3
MATERIALS AND METHODS

Facility Description

The experiment was conducted at the University of Florida Dairy Research Unit Bassett freestall barn located in Hague, Florida during the summer of 2008. The freestall barn housing the milking cows was an east to west orientated, four-row, 176 stall, head-to-head design with a center drive-through feed alley. The barn was open on all sides and equipped with supplemental cooling in the form of fans, foggers, and sprinklers. The fans, sprinklers, and foggers were controlled by temperature and came on when the ambient air temperature exceeded 75^{o}F. The barn was 200 feet long and 100 feet wide (Figure 3-1). The north side of the barn contained 94 sand bedded stalls and the south side contained 82 stalls bedded with the Advanced Comfort Technology Inc. waterbeds (Figure 3-2). The freestalls were designed with open front lunge space, cantilever dividers, and a lying surface 48 inches wide by 83 inches long (Figures 3-3,4,5). The rear curb was 8 inches high and each stall had an upward slope toward the front of the stall of 2 inches. There was no overcrowding present during the experiment and all aspects of the freestalls including the dimensions, the neck rail position, and brisket board were kept constant throughout the experiment in order to ensure a controlled experiment. The cows were milked and fed twice daily. The cows were away from the freestalls an average of 3 hours per day for milking, with each milking taking approximately 1.5 hours. The time away from the freestall barns was measured when the cows were taken to the waiting area before milking to when they all returned to the freestall barn.

Experimental Design

The effects of three different freestall bedding materials on cow behavior and health were evaluated during an eight week experiment. The cows used were mature lactating Holstein cows.

The experiment consisted of two four week trials, beginning on June 3 and concluding on July 29. The three bedding materials included sand, Advanced Comfort Technology Inc. waterbeds, and the waterbeds with approximately 1.5 inches of sand on top. Cow behavioral responses were observed using video surveillance within the barn. The behavior was quantified by looking at the cow orientation within the freestalls: empty stall (1), perching in the stall (2), standing in the stall (3), or lying in the stall (4). Lying included only cows that were observed in total lateral position within the confines of a freestall (Figure 2-1). Perching consisted of cows standing with the forelegs in the stall and hind legs in the alley. Standing in the stall consisted of cows standing with all four legs in the stall. Cow health effects were evaluated by evaluating hock injuries and leg cleanliness.

The cows for each trial were placed into each treatment a week before each trial began. This was performed in order to give the cows time to acclimate to each treatment. The first four week trial, starting June 3, 2008 and ending June 24, 2008, contained the observations of the sand bedded freestalls verses the freestalls using the waterbeds. These observations were made every Tuesday of each week and consisted of five different time instances per day. As a result, for each week of the trial, five different observations were made. For the second four week trial, starting July 8, 2008 and ending July 29, 2008, the cow-freestall interaction consisted of the sand bedded freestalls verses the freestalls with the waterbeds with approximately 1.5 inches sand sprinkled on top. As with the first trial, five time instances were observed for each 24 hour period per week. During morning milking, for all three treatments, the bedding material was cleaned or racked off in order to ensure a clean resting place. Approximately 40lbs of sand was reapplied to the sand bedded freestalls every Monday morning in order to ensure adequate comfort for the cows. In order to maintain the 1.5 inches of sand on top of the waterbeds for trail two, the sand was reapplied during the second week of the trial.

In order to capture the ideal observation times for cow-freestall interaction, the five time instances were determined based on the cows' daily events. The five time observations were as follows: one hour before morning milking (1), 20 minutes after returning from morning milking (2), two hours after morning feeding (3), middle of the day between morning milking and night milking (4), and one hour before night milking (5). These time observations were chosen as opposed to specific times of the day, because the milking and feeding at the dairy did not occur on a consistent basis from week to week as well as the sand and waterbed herds were milked and fed at different times. As a result, the actual times of day that the observations were made varied from week to week throughout the experiment. Due to health issues throughout the two trials, the number of cows used for the experiment varied from week to week. However, the ratio of cows to stalls did not fall below 1:1, to ensure equal opportunity for the cows to use each stall being observed. The total number of cows that were present for each week of trial one for the sand bedded freestalls was 49 and for trial two, 50. Of the 50 cows in trial two for the sand bedded freestalls, 39 of them were used for the entire trial one. As a result, only 11 new cows were introduced to the sand bedded freestalls for trial two. A total of 51 cows for the waterbed freestalls were present for each week in trial one. For the waterbeds with sand on top, 51 cows were present for the entire trial two. Of those 51 cows used in trial two, 40 of them were used for trial one. As a result, only 11 new cows were introduced to the waterbeds with sand on top herd for trial two. The acclimation time for trial two was the same as for trial one, one week. Therefore, the new cows that were added to the sand bedded and waterbeds with sand on top herd had a week to acclimate themselves to their new surroundings.

Video Surveillance

Eight color, night vision, closed circuit video cameras linked to a central monitor and recorder were placed in the freestall barn (Sentinel CCTV Observational System, model SC21FD3044-161, Baltimore, MD). Data were recorded using the NetViewer software and stored on external hard drives. Four cameras were placed on the sand bedded side, the north side, and the remaining four were placed on the south side which contained the stalls with the waterbeds (Figure 3-2). Each camera was placed approximately 15 feet above the barn floor. The location of the cameras varied within the barn in order to maximize the number of stalls being viewed at any given instance. Due to the limited viewing space of the video surveillance system and the large size of the barn, certain freestalls could not be seen. As a result, 38 sand and 26 waterbed freestalls could not be seen, resulting in only 56 sand and waterbed freestalls which were used for the experiment. The stalls which could not be seen were blocked off using nylon rope. This was performed in order to ensure the stalls which could be seen were the only option for the cows.

For each week of the experiment, one 24hr period was recorded using the surveillance system. The filming occurred on every Tuesday throughout the two four week trials, starting on Tuesday June 3, 2008 and ending on Tuesday July 29, 2008. The monitor displayed four camera views every 30 seconds in a sequential (sand then waterbeds or waterbeds with sand), repeating cycle. Behavioral observations were not recorded during milking and feeding times. The cow behavior (cow-freestall interaction) was analyzed by freezing the previously recorded frames using the Local Player Software provided by the Sentinel Observational System for the selected observation times per week of each trial.

Environmental Monitoring

Three thermocouple sensors were evenly placed within the barn to record the ambient temperatures throughout the barn (CR10 data logger). The sensors were placed on the east side, the center, and the west side of the barn on the waterbed side of the feed alley. Average temperatures of 10 minute increments were downloaded every 30 minutes. Previous research has indicated that cows tend to change their orientation and behavior relative to the temperature and other environmental factors such a rain. Wagner-Storch et al. (2003) found that the lying times for various bedded freestalls decreased as the ambient temperatures increased. The temperature conditions throughout the experiment were not ideal conditions for the cows; however, conditions were typical for summer weather in the southeastern United States. As a result, the temperatures were measured and recorded in order to have a record of the typical high and low ambient temperatures the cows were exposed to throughout the experiment. It was noted that the results from this study may differ depending on other locations within the United States due to varying environmental conditions.

Hock Injuries and Leg Hygiene

Hock injuries were recorded throughout the study using the James Nocek scoring system (Cornell Cooperative Extension). At the beginning of the study, all cows' hocks were evaluated. Thereafter, every Tuesday of each week throughout the experiment during the morning milking, each cow was observed for injuries. Five locations on the hock were evaluated: the medial, lateral, and dorsal sides of the tuber calcis and the medial and lateral sides of the tarsal joint. The hock injuries were scored based on a three point scale. A score of one had no swelling and no hair missing. A score of two had no swelling with a bald area on the hock. A score of three had evident swelling and/or had lesions through the hide.

Leg cleanliness was recorded throughout the study using the Nigel Cook scoring system (Cook and Reinemann, 2007). Every Tuesday of each week throughout the experiment during the morning milking, each cow was observed for hind leg cleanliness based on a four point scale. A score of one had little or no manure above the coronary band. A score of two had minor splashing above the coronary band. A score of three had distinct plaques of manure above the coronary band, but leg hair was visible. A score of four had a solid plaque of manure extending high up the leg. Due to health problems during the 2 four week trials, certain cows were not used for the statistical analysis because they were not present for all 4 days per trial. As a result, for trial one, a total of only 49 and 51 cows were used for the sand and waterbed freestalls respectively. For trial two, only 50 and 51 cows were used for the sand and waterbeds with sand on top freestalls respectively.

Statistical Analysis

Cow Orientation

The cow behavior was quantified into orientations based upon the three different bedding materials. The data were analyzed using the fixed and random effects models using SAS® V 9.1 programs PROC GLM and PROC MIXED. Data were analyzed separately for each trial. The ANOVA tables for the model for each trial are presented in the results. All effects were considered fixed except for those involving stall, which were considered to be random. This statistical design was supplied by Dr. Charles J. Wilcox (Retired Professor), geneticist from the Animal Science Department of the University of Florida.

The general linear model procedure tested the fixed main effects: treatment (trmt) (1df), week (week) (3df), and observation (obs) (4df) and their two way interactions: trmt*week (3df), trmt*obs (4df), obs*week (12df). The three factor interaction, trmt*week*obs (12df) was pooled with the residual (1320df). Significance of the fixed effects was evaluated using Type III sum of squares and $p < 0.0001$. The mixed model procedure tested the same fixed effects as the general linear model as well as the random effect of stall nested within treatment, stall(trmt) (110df). The random effect of stall was analyzed by testing the random effects two and three way interactions: stall(trmt)*week (330df), stall(trmt)*obs (440df), with the residual being stall(trmt)*week*obs (1320df). For the mixed model procedure a level of $p < 0.0001$ was used to determine significance of the fixed effects as well as the random effects.

Hock Scores

The hock scores were quantified into scores for each location on the hock; the dorsal, lateral, and medial sides of the tuber calcis (DTC, LTC, MTC) and the lateral and medial sides of the tarsal joint (LTJ, MTJ) based upon the three different bedding materials. A score of one had no swelling and no hair missing. A score of two had no swelling with a bald area on the hock. A score of three had evident swelling and/or had lesions through the hide. As with the cow behavior, the data were analyzed using the fixed and random effects models using SAS® V 9.1 programs PROC GLM and PROC MIXED. Data were analyzed separately for each trial. The ANOVA tables for the model for each trial are presented in the results. All effects were considered fixed except for those involving the cow, which were considered to be random.

The general linear model procedure tested the fixed main effects: treatment (trmt) (1df), week (week) (3df), and location (location) (4df) and their two way interactions: trmt*week (3df), trmt*location (4df), location*week (12df). The three factor interaction, trmt*week*location (12df) was pooled with the residual (1176df for trial one and 1188df for trial two). Significance of the fixed effects was evaluated using Type III sum of squares and $p < 0.0001$. The mixed model procedure tested the same fixed effects as the general linear model as well as the random effect of the cow nested within treatment, cow(trmt) (98df for trial one and 99df for trial two). The random effect of cow was analyzed by testing the random effects two and three way interactions. For trial one: cow(trmt)*week (294df), cow(trmt)*location (392df), with the residual being cow(trmt)*week*location (1176df). For trial two: cow(trmt)*week (297df), cow(trmt)*location (396df), with the residual being cow(trmt)*week*location (1188df). For the mixed model procedure a level of $p < 0.0001$ was used to determine significance of the fixed effects as well as the random effects.

Hygiene Scores

The hygiene scores were quantified into scores for each trial based upon the three different bedding materials. A score of one had little or no manure above the coronary band. A score of two had minor splashing above the coronary band. A score of three had distinct plaques of manure above the coronary band, but leg hair was visible. A score of four had a solid plaque of manure extending high up the leg. The data were analyzed using the fixed and random effects models using SAS® V 9.1 programs PROC GLM and PROC MIXED. Data were analyzed separately for each trial. The ANOVA tables for the model for each trial are presented in the results. All effects were considered fixed except for those involving the cow, which were considered to be random.

The general linear model procedure tested the main fixed effects: treatment (trmt) (1df) and week (week) (3df) and their two way interaction: trmt*week (3df). Significance of the fixed effects was evaluated using Type III sum of squares and $p < 0.0001$. The mixed model procedure tested the same fixed effects as the general linear model as well as the random effect of the cow nested within treatment, cow(trmt) (98df for trial one and 99df for trial two). The random effect of cow was analyzed by testing the random effects two way interactions. For trial one: trmt*week (3df) with the residual being cow(trmt)*week (294df). For trial two: trmt*cow (3df) with the residual being cow(trmt)*week (297df). For the mixed model procedure a level of $p < 0.0001$ was used to determine significance of the fixed effects as well as the random effects.

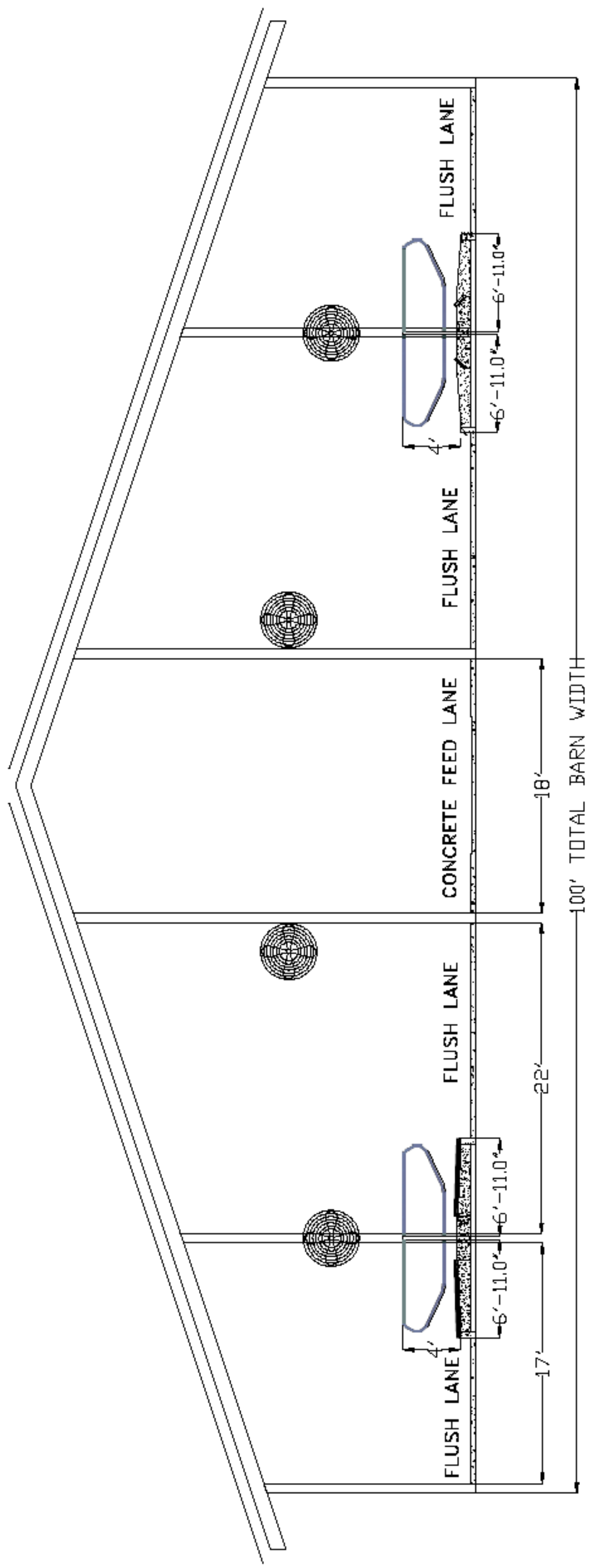


Figure 3-1. Bassett research freestall barn

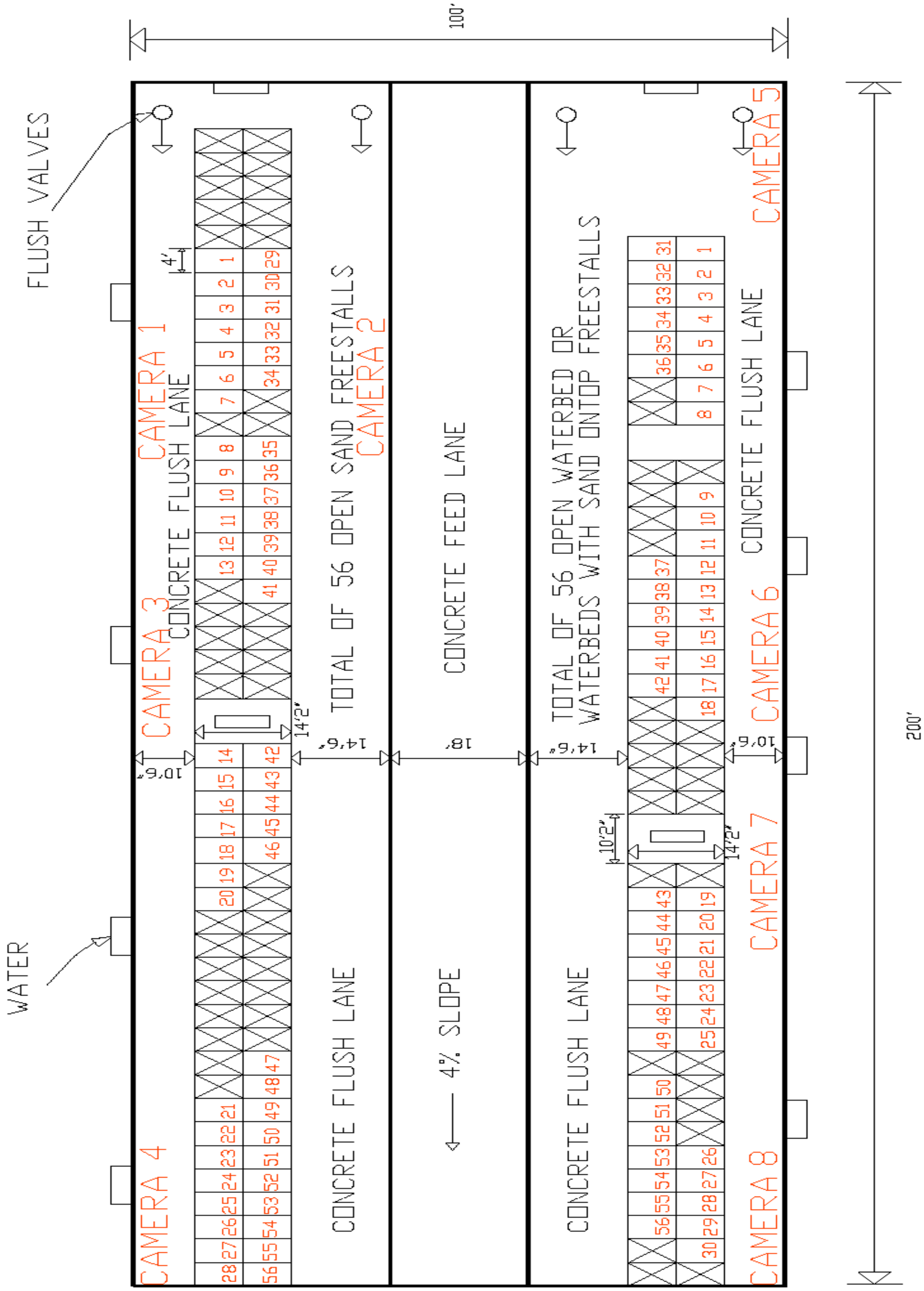


Figure 3-2. Layout of Bassett research freestall barn (X represents stalls that were not used)

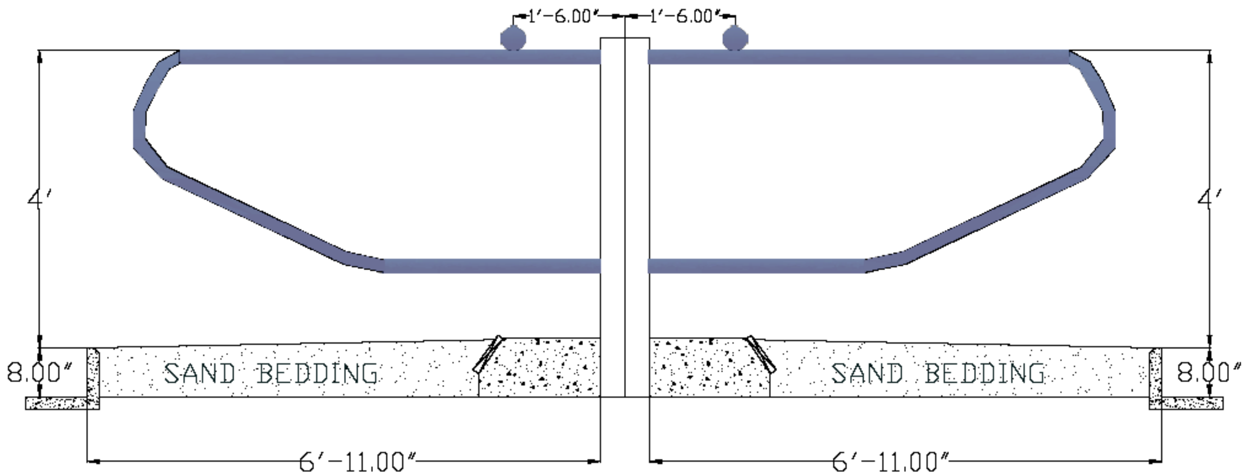


Figure 3-3. Head to head sand freestalls

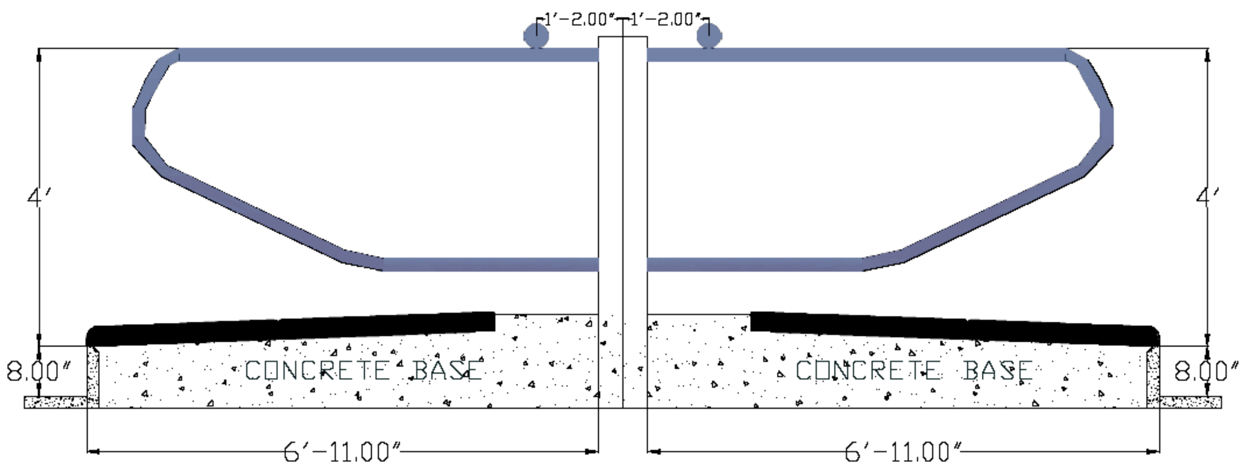


Figure 3-4. Head to head waterbed freestalls

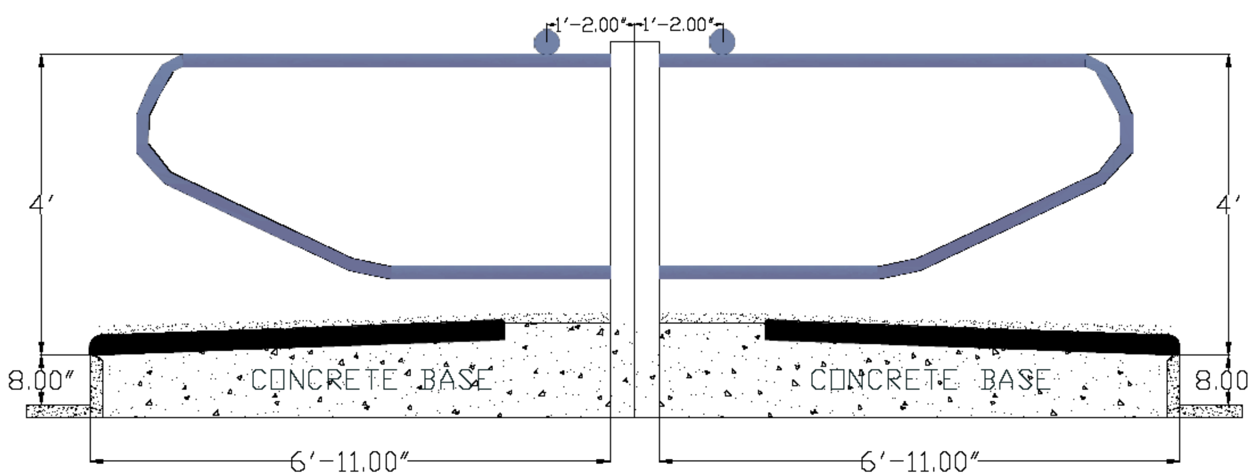


Figure 3-5. Head to head waterbed freestalls with 1.5 inches of sand on top

CHAPTER 4
RESULTS AND DISCUSSION

The experiment was conducted at the University of Florida Dairy Research Unit in Hague, FL, June 3-July 29, 2008 (Figures 3-1 and 3-2). Ambient air temperatures were monitored throughout the 8 week experiment using three thermocouples spaced evenly throughout the south side of the center feed alley in order to approximate temperatures of the eastern, central, and western sections of the barn. The ambient air temperatures for each Tuesday of each week, the day which was used to observe the cow behavior, were recorded and examined using SAS® V 9.1. The typical high and low ambient temperatures for trial one (June 3-June 24) were approximately 90°F and 72°F respectively. For trial two (July 8-July 29) the typical high and low temperatures were approximately 85°F and 74°F respectively. For both trials one and two, the hottest time of the day typically occurred during the third observation instance, 2 hr. after morning feeding, (Figures 4-1 and 4-2). For both trials, the typical lowest temperature corresponded to the first observation time instance, 1 hr. before morning milking, (Figures 4-1 and 4-2). This being said, it has been suggested by Wagner-Storch et al. (2003) that the temperature should have an effect on the overall behavior of the cows.

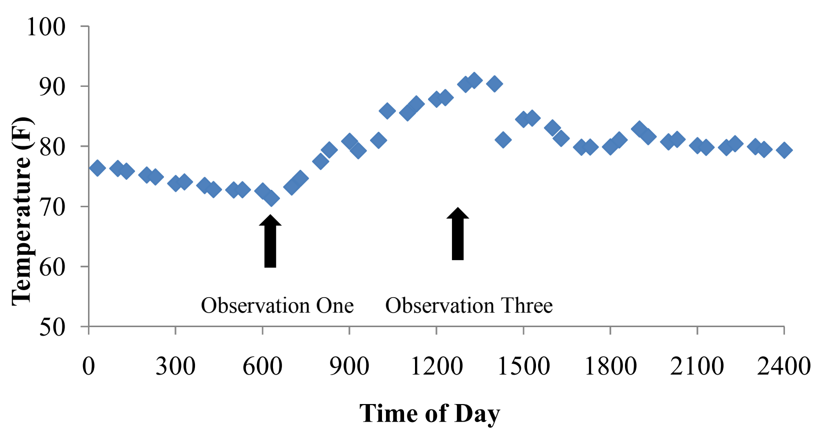


Figure 4-1. Typical barn temperatures for trial one

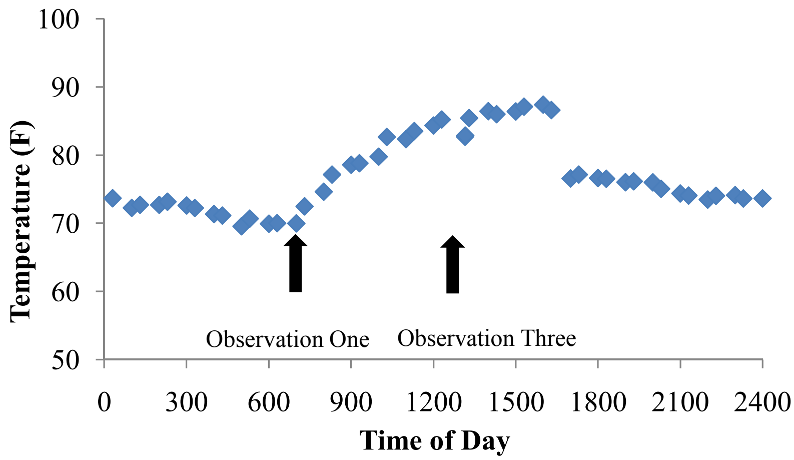


Figure 4-2. Typical barn temperatures for trial two

Cow Behavior

Trial One

For trial one, sand verses waterbeds, the analysis performed using SAS® V 9.1 programs, PROC GLM and PROC MIXED, showed the bedding material, the treatment (trmt), had a highly significant effect on the overall cow behavior with regard to the cow-freestall interaction ($p < 0.0001$). The highest percentage of cow behavior, orientation, corresponded to cows lying within sand stalls (52.95%) followed by empty waterbed stalls (49.02%) (Figure 4-3). The percent of cows lying was significantly lower in the waterbed stalls (32.23%). The percent of empty stalls was significantly lower for the sand bedded stalls (37.14%). When the cows were not observed lying, standing, or perching in the freestalls, the freestalls were observed as empty. This meant that there were cows eating, drinking water, standing in the alley ways, or even lying in the alleys, as seen via walk through observations within the waterbed herd. For this experiment it was not possible to see all activities of the cows per day, other than their interaction with the actual freestalls. The model used is shown in the ANOVA table (Table 4-1).

Table 4-1. Trial 1 ANOVA table for orientation

Effect	DF	F Value	Error Term
trmt	1	99.47	stall(trmt)
stall(trmt)	110	----	----
week	3	0.71	stall(trmt)*week
trmt*week	3	7.81	stall(trmt)*week
stall(trmt)*week	330	----	----
obs	4	39.28	stall(trmt)*obs
trmt*obs	4	12.9	stall(trmt)*obs
stall(trmt)*obs	440	----	----
obs*week	12	1.62	residual
trmt*obs*week	12	pooled	residual
stall(trmt)*obs*week	1320	----	----

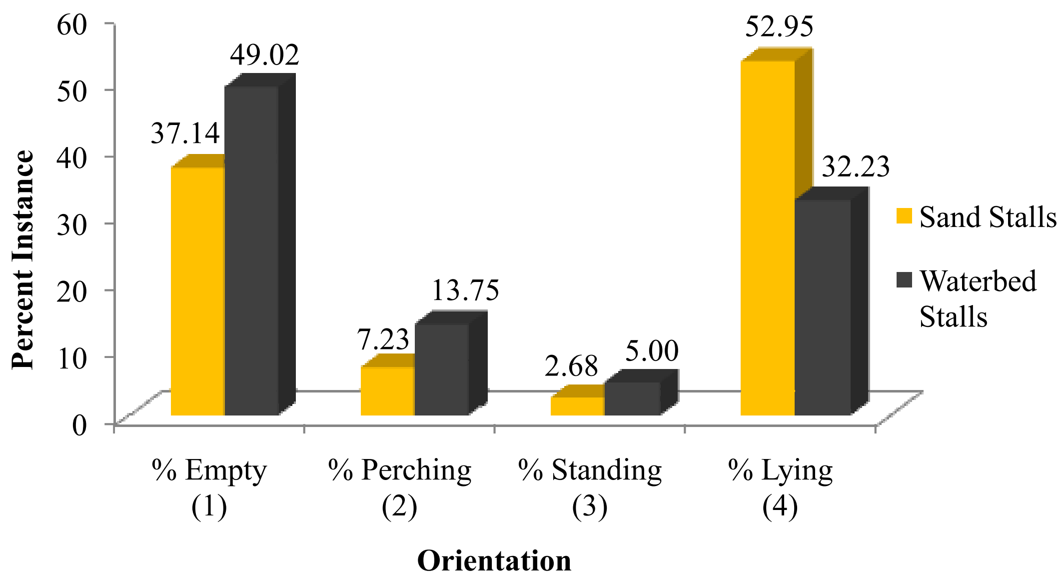


Figure 4-3. Trial 1 total percentage of orientations for each treatment

The Type III SS for all interaction terms are presented in Table 4-2. Table 4-2 fixed main effects (trmt) and (obs) and the fixed interaction term (trmt*obs) had a statistically significant effect on the orientation of the cows ($p < 0.0001$). The main effect (week) had no significant effect on the orientations or the treatments of the cows.

Table 4-2. Trial 1 type III SS for orientation

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
trmt	1	145.554018	145.5540179	83.04	<0.0001
week	3	3.1334821	1.044494033	0.6	0.6177
trmt*week	3	34.290625	11.43020833	6.52	0.0002
obs	4	229.885714	57.47142858	32.79	<0.0001
trmt*obs	4	75.5107143	18.87767858	10.77	<0.0001
obs*week	12	28.4892857	2.374107142	1.35	0.1809

Figure 4-4 to 4-6 summarizes the trends found for main effects (trmt) and (obs) and the 2-way interaction (trmt*obs) using PROC MIXED. The main effect treatment was significant with a least square mean orientation of 2.71 for sand and 2.20 for the waterbed stalls (Figure 4-4). This indicated that there were more cows that were lying down within the sand freestalls (score of 4) as compared to more empty waterbed stalls (score of 1).

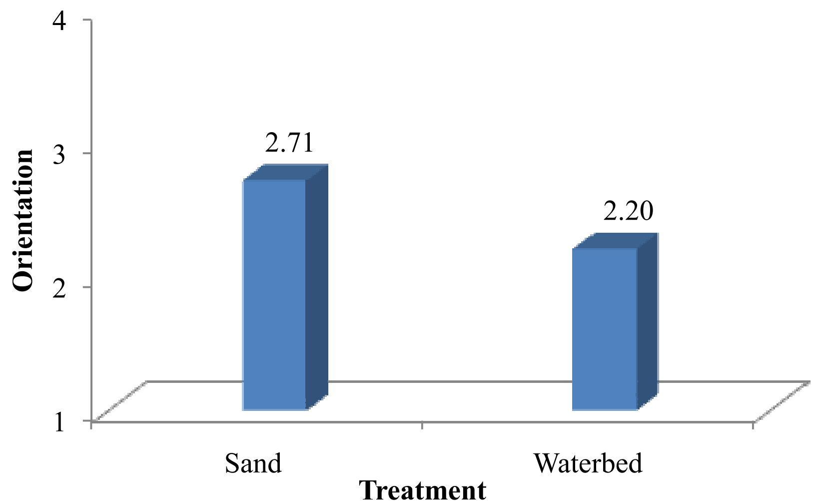


Figure 4-4. Trial 1 treatment main effect least square means for cow orientation (1-Empty, 2-Perching, 3-Standing, 4-Lying)

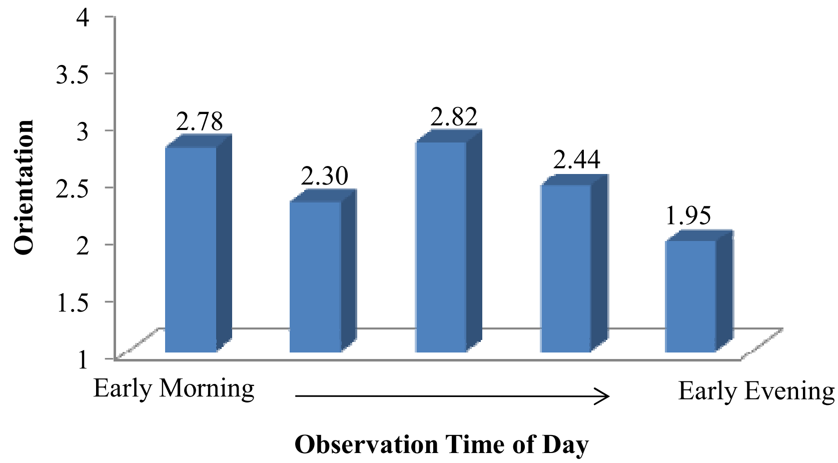


Figure 4-5. Trial 1 observation time of day main effect least square means for both sand and waterbed stalls combined

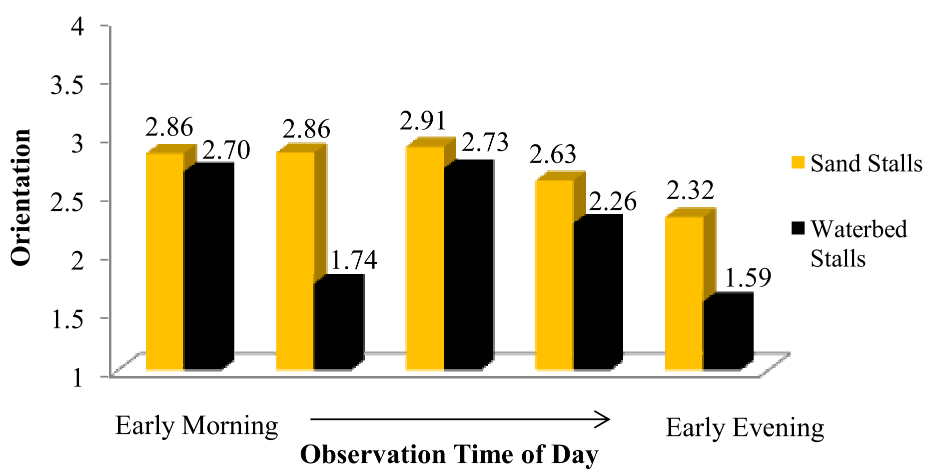


Figure 4-6. Trial 1 treatment*observation time of day interaction (trmt*obs)

Higher orientation least square mean values are desired because that indicates a higher frequency of cows lying within the stalls (4). Lower orientation values represent more empty stalls (1). It was assumed that each possible orientation value, 1, 2, 3, or 4 weighed the same within the analysis. Meaning, there was an equal opportunity for each orientation to occur and when analyzing the least square mean results, the ideal orientation, (4) lying within the stall, was weighed the same as the least desired orientation (1) empty stall. As a result, the least square mean values presented in this section represent the mean orientation based on each orientation weighing the same. A result, LSM value of 2.82 is indicative of more orientations of cows lying within the stall (4) as compared to 1.95 which represents more empty stalls (1). In future work, it might be desirable to weigh lying within the freestalls, which is the ideal or desired condition more, or have the least desired orientations, such as empty stalls, weigh more. With weighed orientations the analysis might be more indicative of the actual cow comfort.

In agreement with Figure 4-4, the overall orientation least square means were higher for the sand bedded stalls, no matter the observation time of day (Figure 4-6). The orientation least square means were the highest for trial one for observations 1 and 3. These observations corresponded to 1 hr. before AM milking and 2 hr. after morning feeding respectively. In agreement with Figure 4-5, the highest orientation least square means occurred at observation 3, (2.91) for sand and (2.73) for waterbeds (Figure 4-6). The lowest orientation least square means occurred at observation 5, (2.32) for sand and (1.59) for waterbeds. This observation corresponded with 1 hr. before PM milking.

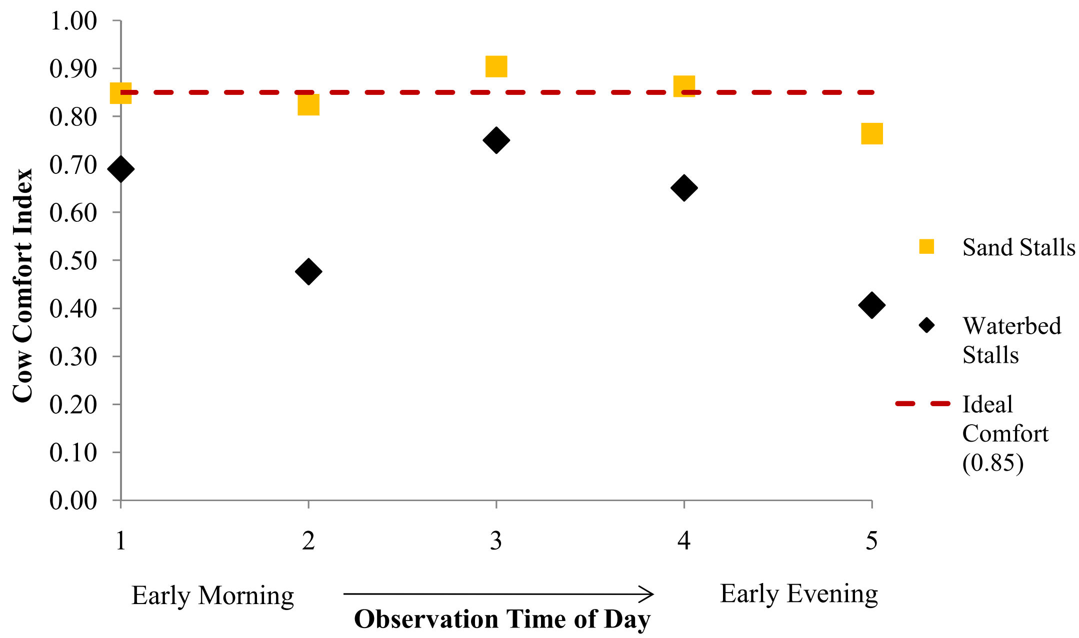


Figure 4-7. Trial 1 average cow comfort index for time of day

As described by Overton et al. (2003), the cow comfort index was averaged for the entire trial one (Figure 4-7).

$$CowComfortIndex = \frac{numberLyingInStall}{numberCowsTouchingStalls} \tag{4-1}$$

Overton et al. established a target value of 0.85 which indicated an ideal comfort for the cows. The higher the cow comfort index, the higher the orientation least square mean should be, indicating a greater number of cows lying within the stalls. Throughout the average day of trial one, the sand bedded freestalls had significantly higher cow comfort indexes as compared to the waterbed freestalls. The lowest cow comfort index for the sand freestalls was 0.76 which corrosponded to observation 5 (1 hr. before PM milking). All of the cow comfort indexes for the waterbed freestalls were lower than the target value of 0.85. The highest cow comfort index for the waterbed freestalls was 0.75. In agreement with Figures 4-5 and 4-6, the highest cow comfort indexes for both the treatments corrosponded with observation 3 (2 hr. after morning feeding).

Trial Two

Trial two compared the cow behavior for freestalls bedded with sand verses the waterbeds with approximately 1.5 inches of sand on top. The analysis performed using SAS® V 9.1 programs, PROC GLM and PROC MIXED, showed the bedding material (the treatment (trmt)) had no significant effect on the overall orientation of the herd. During the second trial, the Dairy Research Unit changed the daily schedule of feeding and milking. As opposed to the first trial, feed was available for the cows when they returned from morning milking. As a result, for observation 2, 20 minutes after morning milking, the majority of cows were observed eating. This resulted in an increase in the overall number of empty stalls for both the sand and waterbeds with sand herds; therefore, lower overall least square means (Figure 4-8). The statistical analysis was run for trial two including observation 2 as well excluding observation 2. The actual counts were different for both of these cases; however, there was no statistically significant difference between the two results. This being said, the results including observation 2 will be discussed below, in order to be consistent with trial one. The model used is seen in the ANOVA table (Table 4-3).

Table 4-3. Trial 2 ANOVA table for orientation

Effect	DF	F Value	Error Term
trmt	1	2.24	stall(trmt)
stall(trmt)	110	----	----
week	3	4.34	stall(trmt)*week
trmt*week	3	3.76	stall(trmt)*week
stall(trmt)*week	330	----	----
obs	4	108.21	stall(trmt)*obs
trmt*obs	4	4.86	stall(trmt)*obs
stall(trmt)*obs	440	----	----
obs*week	12	3.3	residual
trmt*obs*week	12	pooled	residual
stall(trmt)*obs*week	1320	----	----

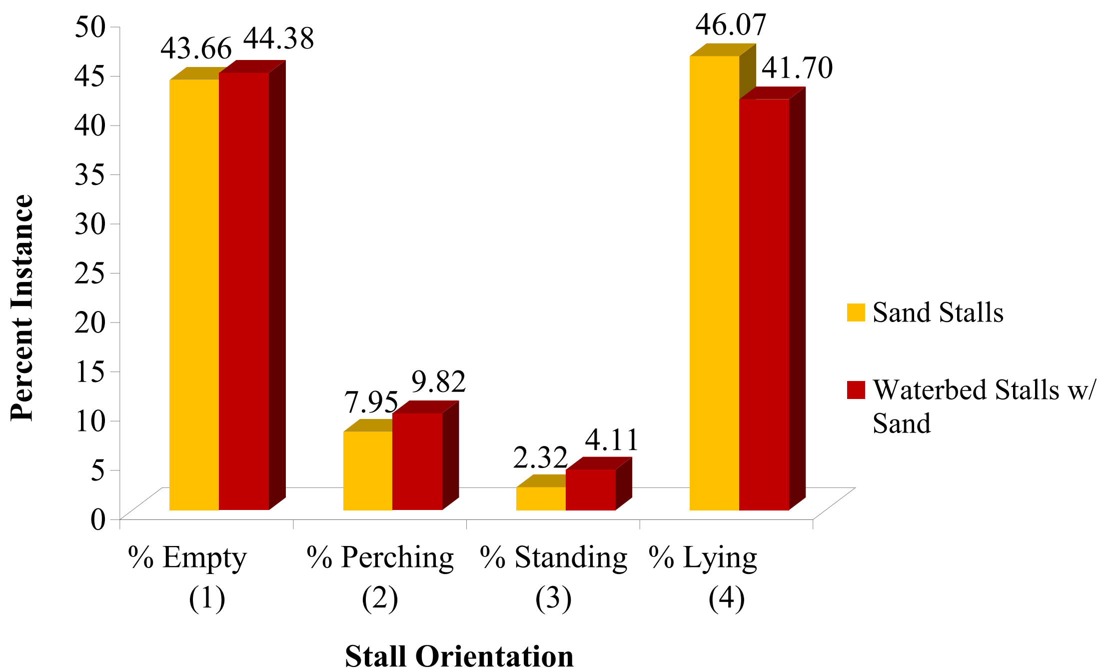


Figure 4-8. Trial 2 total percentage of orientations for each treatment

The Type III SS for all interaction terms are presented in Table 4-4. Table 4-4 fixed main effect (obs) had a statistically significant effect on the orientation of the cows ($p < 0.0001$). The treatment main effect (trmt) had no significant effect on the orientation. As with trial one, the main effect (week) had no significant effect on the treatment and orientation throughout the trial.

Table 4-4. Trial 2 type III SS for orientation

Source	DF	Type IV SS	Mean Square	F Value	Pr > F
trmt	1	3.3017857	3.3017857	1.96	0.162
week	3	19.1857143	6.3952381	3.79	0.01
trmt*week	3	16.6053571	5.535119033	3.28	0.0202
obs	4	637.225893	159.3064732	94.4	<0.0001
trmt*obs	4	28.63125	7.1578125	4.24	0.002
obs*week	12	58.2383929	4.853199408	2.88	0.0006

Figure 4-9 to 4-10 summarizes the trends found for the main effects (trmt) and (obs) using PROC MIXED. The main effect, treatment, was not significant with a least square mean orientation of 2.51 for sand and 2.43 for waterbed stalls (Figure 4-9). However, as found in trial one, the overall least square mean orientation was highest for the sand bedded stalls for both trial one and trial two, while the waterbeds with sand on top (trial two) had a higher value (2.43) as compared to the waterbeds (2.20). This indicated that more cows were lying down (scores of 4) in the waterbed stalls with sand on top as compared to the waterbed stalls. The main effect, observation (obs), had a significant effect on the overall orientation of the cows regardless of the treatment (Figure 4-10). The highest orientation least square mean value (3.10) occurred during observation 3, 2 hr. after morning feeding. This is in agreement with the results from trial one. The lowest orientation least square mean value (1.64) occurred during observation 2, 20 minutes after returning from morning milking. This was explained by the increase in the number of cows eating at that time instance.

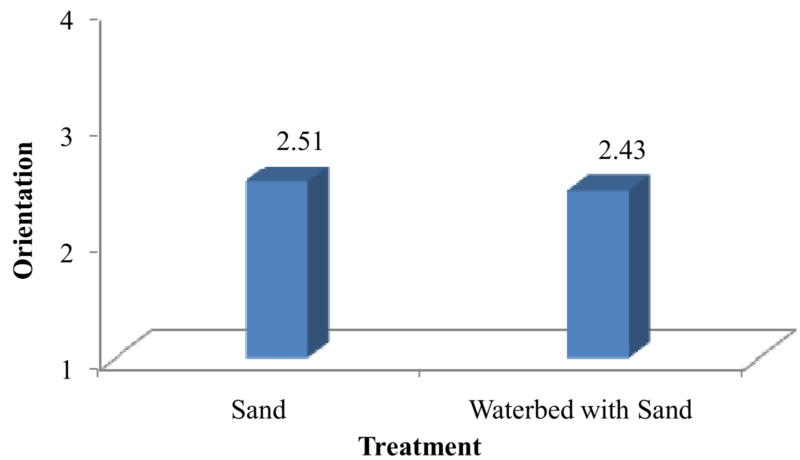


Figure 4-9. Trial 2 treatment main effect least square means for cow orientation (1-Empty, 2-Perching, 3-Standing, 4-Lying)

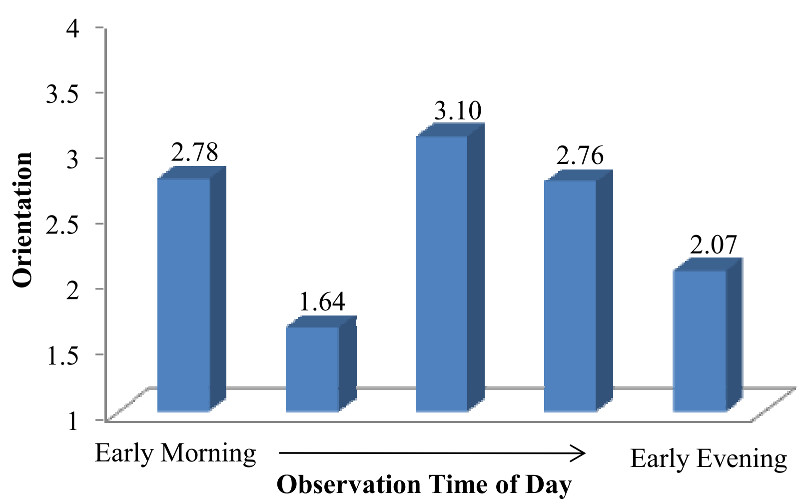


Figure 4-10. Trial 2 observation time of day main effect least square means for both sand and waterbed stalls with sand on top combined

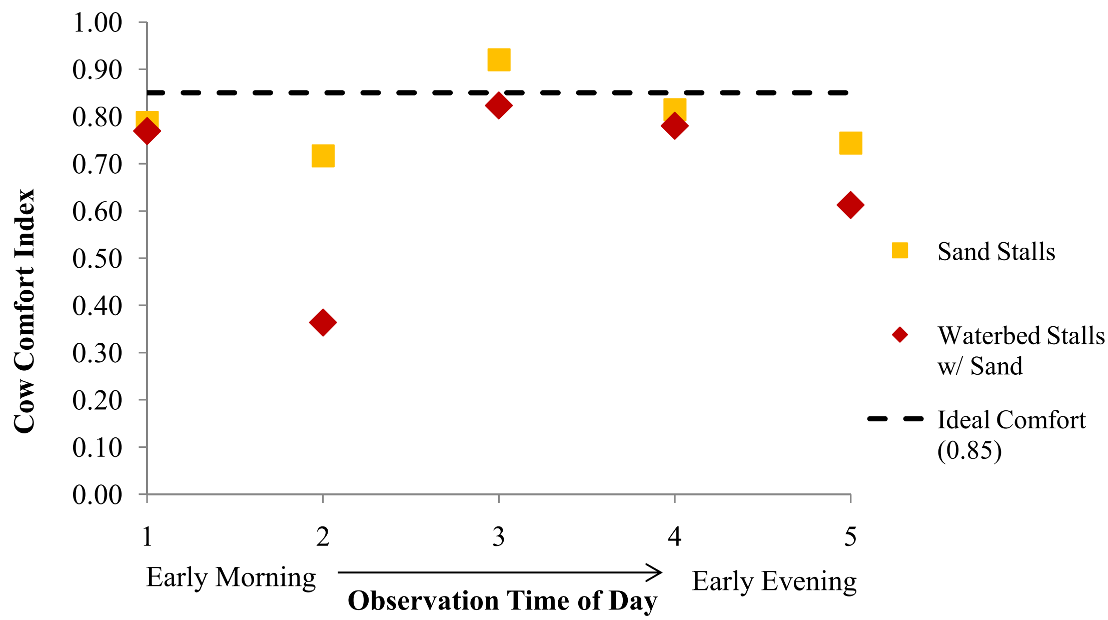


Figure 4-11. Trial 2 average cow comfort index for time of day

The average cow comfort index for both treatments, sand bedded freestalls and the waterbed freestalls with sand on top, follow the same trend (Figure 4-11). As for trial one, the target value was 0.85 to ensure the ideal comfort for the cows (Overton at el., 2003). For both treatments, the lowest cow comfort index corresponded with orientation 2, which corresponded to 20 minutes after returning from milking, 0.72 for sand and 0.36 for waterbeds with sand. In agreement with Figure 4-10, the highest cow comforts for both treatments occurred during observation 3, (2 hr. after morning feeding), 0.92 for sand and 0.82 for waterbeds with sand. Throughout the average day of trial two, the sand bedded freestalls had higher cow comfort indexes than the waterbeds with sand. However, excluding the second observation time, these results were not significantly higher. The cow comfort indices for the entire trial for the sand bedded freestalls were all lower than the target value of 0.85, except for observation 3. For the waterbed freestalls with sand on top, all of the cow comfort indices were slightly lower than the target value. In agreement with Figure 4-10, the higher the overall least square means orientation, the greater cow comfort index, and there was no significant difference between the two treatments.

Hock Scores

Trial One

For trial one, sand verses waterbed freestalls, the analysis performed using SAS® V 9.1 programs, PROC GLM and PROC MIXED, showed the bedding material, the treatment (trmt), had a highly significant effect on the overall hock injuries of the herds ($p < 0.0001$). The location on the hocks also varied significantly depending on the bedding material. The model used is shown in the ANOVA table (Table 4-5). As with the analysis of the cow orientation for both trials, the hock scores of 1, 2, and 3 were weighed evenly for the statistical analysis. As a result, the least square mean values are intermediate values based on the discrete hock scores of 1, 2, and 3. Ideally, in future studies, in order for the results to be more indicative of the severity of the injuries, the score of 3, the worst severity score, should be weighed more than a score of 1 (no injury).

The Type III SS for all interaction terms are presented in Table 4-6. The fixed main effects (trmt) and (location) and the fixed interaction term (trmt*location) had statistically significant effects on the overall hock scores for the cows ($p < 0.0001$). The hock scores for the five different locations on the hocks had statistically significant differences, independent of the treatment as well as dependent of the treatment. The main effect (week) had no significant effect on the severity of hock injuries or the treatments of the cows.

Table 4-5. Trial 1 ANOVA table for hock scores

Effect	DF	F Value	Error Term
trmt	1	138.26	cow(trmt)
cow(trmt)	98	----	----
week	3	7.10	cow(trmt)*week
trmt*week	3	0.57	cow(trmt)*week
cow(trmt)*week	294	----	----
location	4	53.04	cow(trmt)*location
trmt*location	4	64.86	cow(trmt)*location
cow(trmt)*location	392	----	----
week*location	12	1.94	residual
trmt*week*location	12	pooled	residual
cow(trmt)*week*location	1176	----	----

Table 4-6. Trial 1 type III SS for hock score

Source	DF	Type III SS	Mean Square	F Value	Pr > F
trmt	1	17.15267727	17.15267727	127.79	<0.0001
week	3	1.52375550	0.50845852	3.79	0.01
trmt*week	3	0.12137555	0.04045852	0.3	0.8244
location	4	26.31912645	6.57978161	49.02	<0.0001
trmt*location	4	32.18912645	8.04728161	59.95	<0.0001
week*location	12	1.66500000	0.13875000	1.03	0.4143

Figure 4-12 to 4-14 summarizes the trends found for main effects (trmt) and (location) and the 2-way interaction (trmt*location) using PROC MIXED. The main effect, treatment (trmt), was significant with the overall least square mean hock scores of 1.05 for sand and 1.24 for waterbed stalls (Figure 4-12). The waterbed stalls resulted in higher least square mean hock scores, which indicated more scores of 2 or 3 as compared to the sand bedded stalls. The location on the hock which had the highest overall least square mean score was the lateral (outer side) of the tuber calcis (back part of the hock joint) (LTC) with a score of 1.32 (Figure 4-13). Both the medial (inner side) tuber calcis (MTC) and tarsal joint (MTJ) had the lowest scores, meaning those locations had the least frequency of severe hock injuries.

For the sand bedded freestalls, there were no severe hock injuries of scores of 3 for the cows. This resulted in overall least square mean scores of 1.18, 1.04, 1.00, and 1.00 (Figure 4-14). The highest scores corresponded to the dorsal (back point) tuber calcis (DTC) while the lowest corresponded to both the medial (inner side) tuber calcis (MTC) and tarsal joints (MTJ). The waterbed freestalls had significantly higher hock scores of 1.60, 1.43, 1.07, and 1.03 (Figure 4-14). The highest least square mean hock score corresponded to the lateral tuber calcis (LTC). The lowest score corresponded to the medial tarsal joint (MTJ).

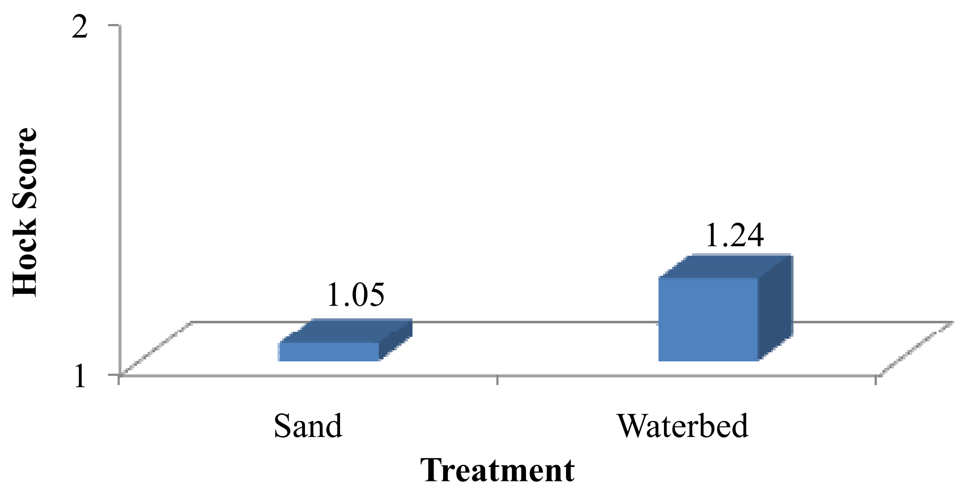


Figure 4-12. Trial 1 treatment main effect least square means for hock scores (1-No swelling or hair missing, 2-No swelling, but hair missing, 3-Swelling and/or lesions)

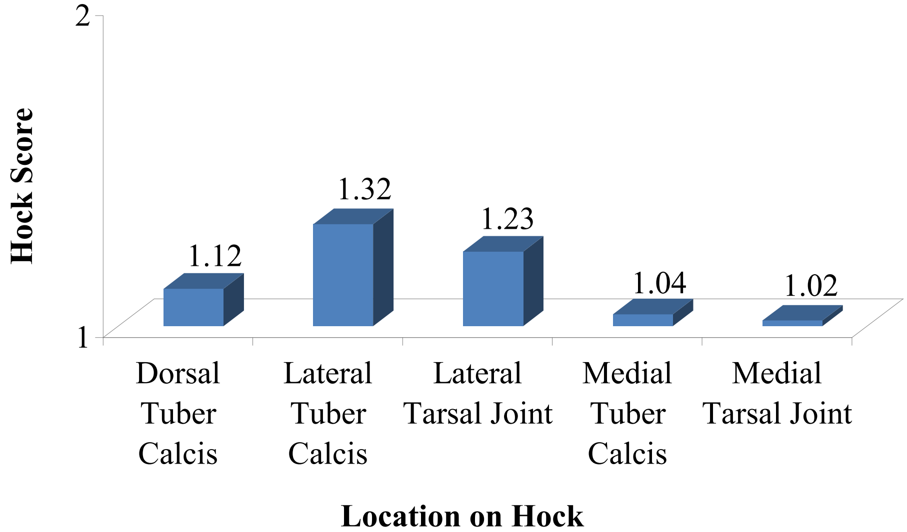


Figure 4-13. Trial 1 location on hock main effect least square means for both treatments combined

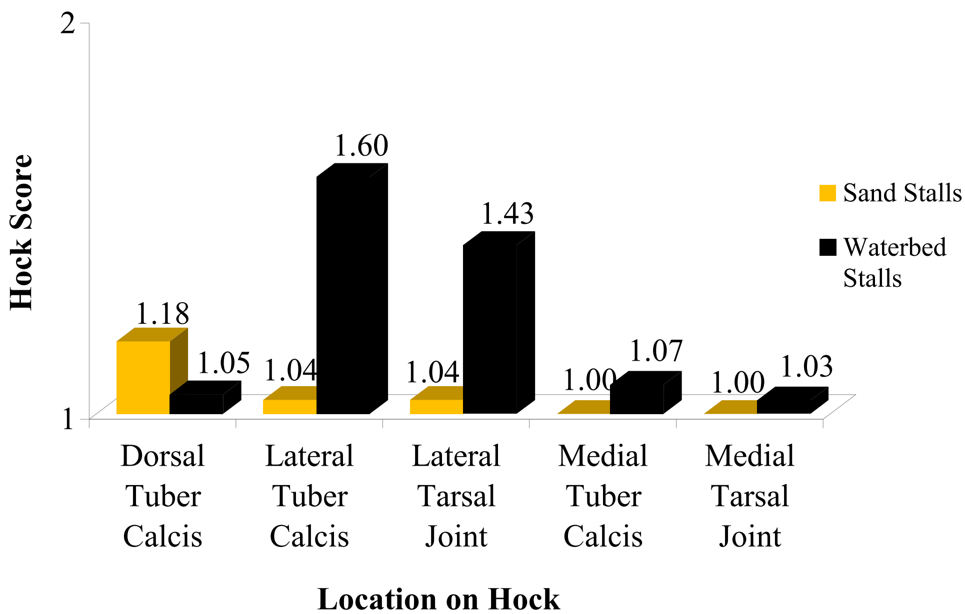


Figure 4-14. Trial 1 treatment*location (trmt*location) interaction

Trial Two

For trial two, sand verses waterbeds with 1.5 inches of sand on top, the analysis performed using SAS® V 9.1 programs, PROC GLM and PROC MIXED, showed the bedding material, the treatment (trmt), had a highly significant effect on the overall hock injuries of the herds ($p < 0.0001$). The location on the hocks also varied significantly depending on the bedding material. The model used is shown in the ANOVA table (Table 4-7).

The Type III SS for all interaction terms are presented in Table 4-8. The fixed main effects (trmt) and (location) and the fixed interaction term (trmt*location) had statistically significant effects on the hock scores of the cows ($p < 0.0001$). The hock scores for the five different locations on the hocks had statistically significant differences, independent of the treatment as well as dependant of the treatment.

Table 4-7. Trial 2 ANOVA table for hock scores

Effect	DF	F Value	Error Term
trmt	1	362.59	cow(trmt)
cow(trmt)	9	----	----
week	3	9.83	cow(trmt)*week
trmt*week	3	6.64	cow(trmt)*week
cow(trmt)*week	297	----	----
location	4	152.14	cow(trmt)*location
trmt*location	4	170.24	cow(trmt)*location
cow(trmt)*location	396	----	----
week*location	12	3.56	residual
trmt*week*location	12	pooled	residual
cow(trmt)*week*location	108	----	----

Table 4-8. Trial 2 type III SS for hock score

Source	DF	Type III SS	Mean Square	F Value	Pr > F
trmt	1	20.24953776	20.24953776	199.32	<0.0001
week	3	1.64684197	0.54894732	5.40	0.0011
trmt*week	3	1.11218851	0.37072950	3.65	0.0122
location	4	33.97224539	8.49306135	83.60	<0.0001
trmt*location	4	38.02967113	9.50741778	93.58	<0.0001
week*location	12	2.38415842	0.19867987	1.96	0.0246

Figure 4-15 to 4-17 summarizes the trends found for main effects (trmt) and (location) and the 2-way interaction (trmt*location) using PROC MIXED. The main effect, treatment (trmt), was significant with overall least square mean hock scores of 1.04 for sand and 1.24 for waterbed stalls with sand on top (Figure 4-15). The least square mean hock score for the waterbeds with sand on top was the same as for the waterbeds from trial one (1.24). The sand stalls did not vary much between the two trials either, 1.05 for trial one and 1.04 least square mean hock scores for trial two. The location of the most severe hock scores was the same for trial two as they were for trial one. The lateral tuber calcis and lateral tarsal joints had the highest hock scores for the waterbed with sand on top herd, while the dorsal tuber calcis had the highest hock score for the sand bedded freestalls.

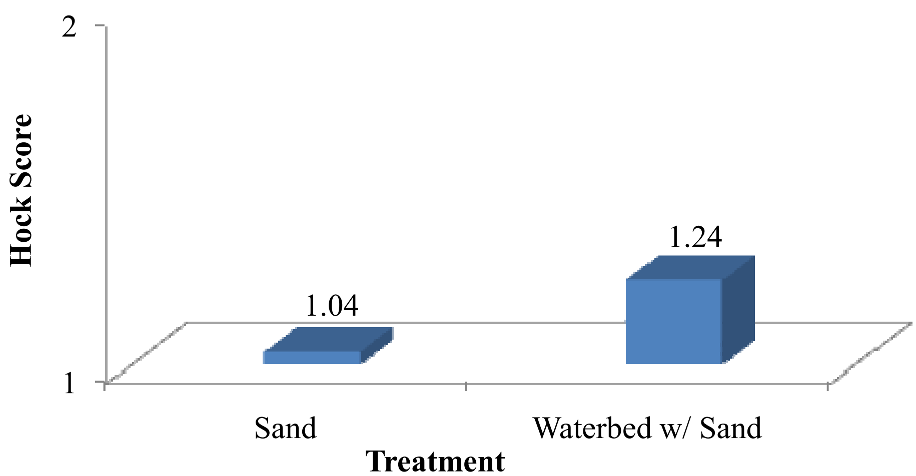


Figure 4-15. Trial 2 treatment main effect least square means for hock scores (1-No swelling or hair missing, 2-No swelling, but hair missing, 3-Swelling and/or lesions)

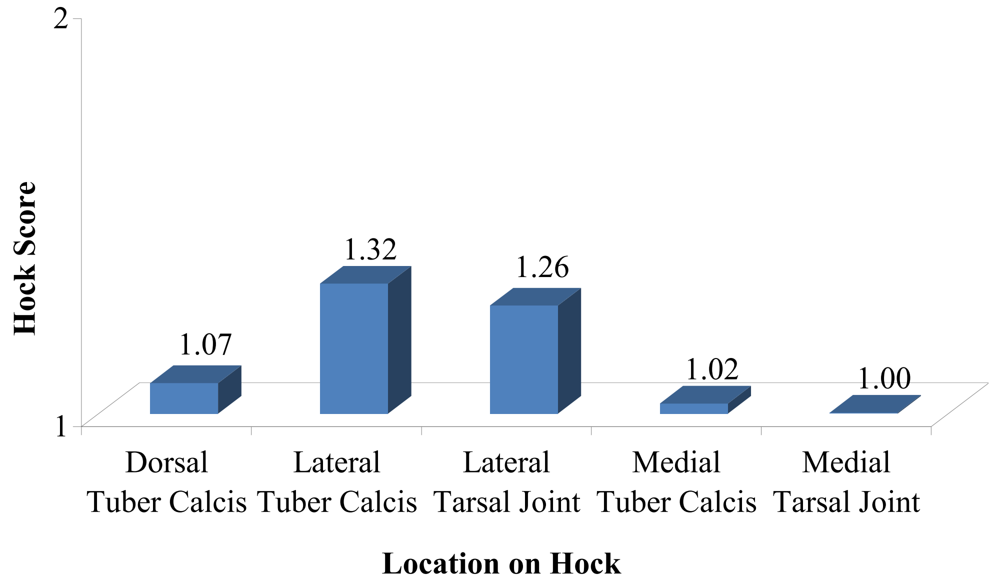


Figure 4-16. Trial 2 location on hock main effect least square means for both treatments combined

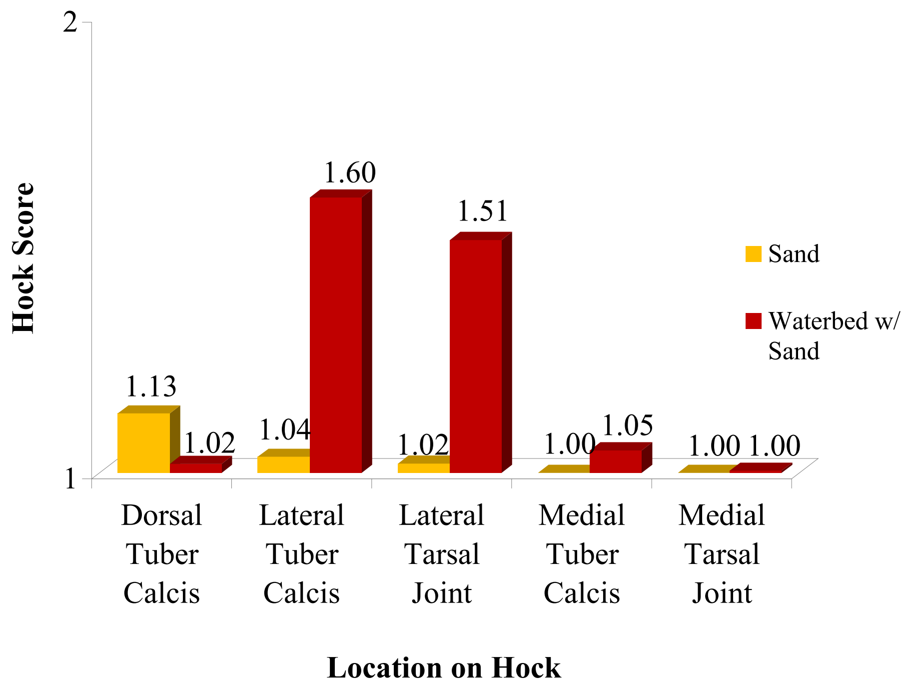


Figure 4-17. Trial 2 treatment*location (trmt*location) interaction

Hygiene Scores

Trial One

The hygiene scores were evaluated for the sand bedded verses the waterbed freestalls and the analysis was performed using SAS® V 9.1 programs, PROC GLM and PROC MIXED. This analysis showed the bedding material, the treatment (trmt), had a statistically significant effect on the overall hygiene score of the herds. The ANOVA table for this model is seen in Table 4-9. The Type III SS shows that the treatment was significant with $p<0.0001$ (Table 4-10). As with the orientation and hock scores analysis the hygiene scores 1, 2, 3, and 4 were weighed evenly for the statistical analysis. As a result, the least square means represent intermediate values based on the four possible discrete scores. In future studies, the more severe score of 4, meaning the dirtiest cow, should be weighted more in the analysis in order to have more realistic results that would be more indicative of the cleanliness or dirtiness of the cows in a given herd.

Table 4-9. Trial 1 ANOVA table for hygiene scores

Effect	DF	F Value	Error Term
trmt	1	40.56	cow(trmt)
cow(trmt)	98	3.84	----
week	3	4.21	cow(trmt)*week
trmt*week	3	0.39	cow(trmt)*week
cow(trmt)*week	294	----	----

Table 4-10. Trial 1 type III SS for hygiene score

Source	DF	Type III SS	Mean Square	F Value	Pr > F
trmt	1	22.53352941	22.53352941	23.71	<0.0001
week	3	7.01506603	2.338355343	2.46	0.0623
trmt*week	3	0.65506603	0.218355343	0.23	0.8756

The sand bedded freestalls had substationally more hygiene scores of 1 (no manure on hind hocks) with a least square mean hygiene score of 2.14. While the waterbed freestalls had more hygiene scores of 3 (manure caked above the coronary band) as well as scores of 4 (manure caked on the entire lower part of the hind legs). That is indicative of a least square mean hygiene score of 2.62 (Figure 4-18). The bedding had a significant effect on the overall cleanliness of the cows.

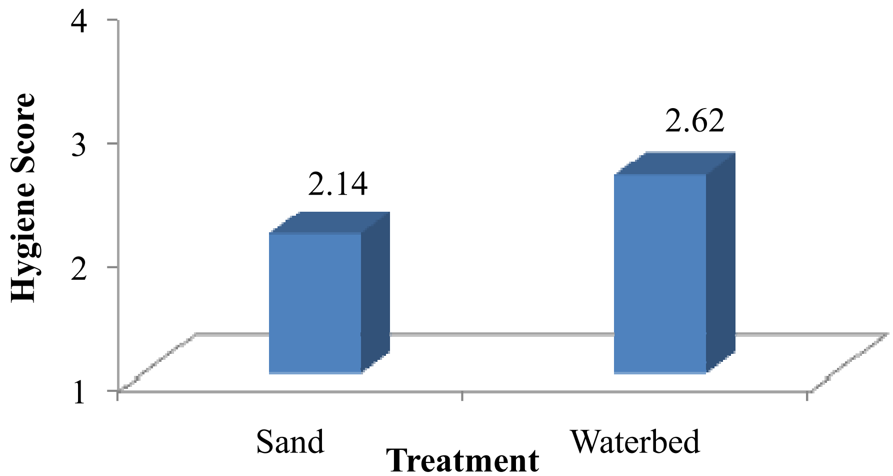


Figure 4-18. Trial 1 treatment main effect least square means for hygiene scores (1-No manure above coronary band, 2-Minor splashing above coronary band, 3-Plaques of manure above coronary band with visible hair, 4-Solid plaque of manure above coronary band and no visible hair)

Trial Two

As with trial one, the hygiene scores for trial two were evaluated for the sand bedded verses the waterbeds with sand on top and the analysis was performed using SAS® V 9.1 programs, PROC GLM and PROC MIXED. This analysis showed the bedding material, the treatment (trmt), had no significant effect on the overall hygiene score of the herd. The ANOVA table for this model is seen in Table 4-11. The Type III SS shows all fixed variables had no significant effect on the overall hygiene scores (Table 4-12). The waterbeds with sand on top had an overall lower least square mean hygiene score than did the sand bedded stalls from both trial one and trial two, even though it was not statistically significant (Figure 4-19). This indicated that cows on the waterbeds with sand on top tended to be the cleanest out of all three bedding material treatments.

Table 4-11. Trial 2 ANOVA table for hygiene scores

Effect	DF	F Value	Error Term
trmt	1	9.43	cow(trmt)
cow(trmt)	99	4.34	----
week	3	10.89	cow(trmt)*week
trmt*week	3	4.20	cow(trmt)*week
cow(trmt)*week	297	----	----

Table 4-12. Trial 2 type III SS for hygiene score

Source	DF	Type III SS	Mean Square	F Value	Pr > F
trmt	1	4.26036207	4.26036207	5.14	0.0239
week	3	14.76049214	4.920164047	5.94	0.0006
trmt*week	3	5.69118521	1.897061737	2.29	0.0780

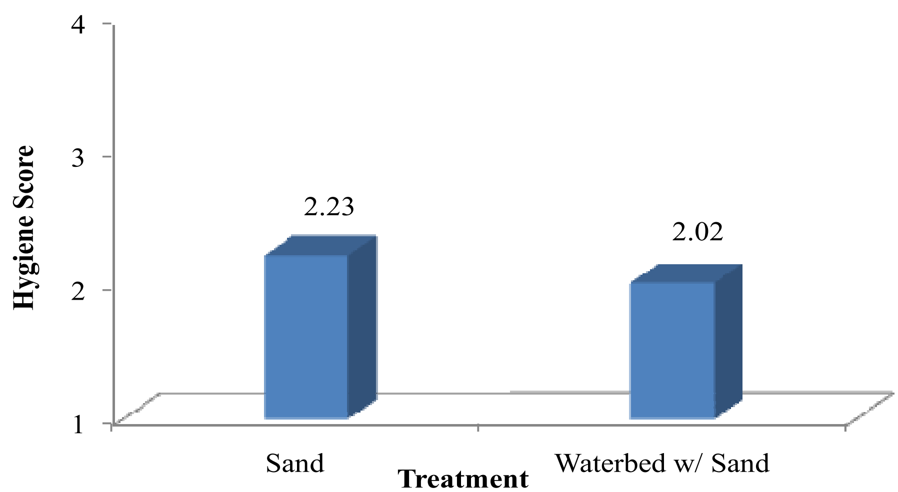


Figure 4-19. Trial 2 treatment main effect least square means for hygiene scores (1-No manure above coronary band, 2-Minor splashing above coronary band, 3-Plaques of manure above coronary band with visible hair, 4-Solid plaque of manure above coronary band and no visible hair)

The Effect of the Bedding Material on the Culling Rate

The most important reason for examining the surrounding environment of dairy cows is to increase cow comfort, which in turn improves performance and decreases cull rates. Reasons for being culled include, but are not limited to, low milk production, illness, mastitis, or lameness. There are many variables that can lead to increased culling rates or an increase in the number of cows being moved to the hospital herd; however, the bedding material in particular can have a dramatic effect on the instances of mastitis and lameness.

Trial One

For trial one, sand bedded verses waterbed freestalls, there was a total of 9 cows that were removed from the sand bedded milking herd and moved to the hospital herd. A total of 9 cows from the waterbed milking herd were moved to the hospital herd during the four week trial. For the sand bedded herd there were 8 cows that were treated for mastitis and 2 cows, one of which also had mastitis, were treated for foot rot (Table 4-13). There were 6 cows in the waterbed herd that were treated for mastitis and 1 leg injury during the first trial (Table 4-13). However, it must be noted that there was one cow that died due to severe fever during the first trial. There was no real difference between the sand bedded and waterbed freestalls on the overall culling rate and frequency of mastitis and leg/hoof problems
(Table 4-13).

Trial Two

For trial two, sand bedded verses waterbed freestalls with approximately 1.5 inches of sand on top, there were a total of 8 cows for both treatments that were moved to the hospital herd throughout the four week trial. The 8 cows in the sand herd consisted of 2 cows that were treated for foot problems and 6 cows that had mastitis. For the waterbed with sand herd, 5 cows had mastitis, 2 had low milk production and 1 was sick (Table 4-13). As seen with trial one, there was no real difference between the sand bedded verses the waterbeds with sand on top and their effect on the culling rate and frequency of mastitis and leg/hoof problems.

Table 4-13. Number of culled cows for both trial one and trial two

	Trial One		Trial Two	
	Sand Freestalls	Waterbed Freestalls	Sand Freestalls	Waterbed Freestalls with 1.5 inches of sand
Low Milk Production	0	1	0	2
Illness	0	1*	0	1
Mastitis	8	6	6	5
Hoof/Leg Injuries	2	1	2	0

* This illness led to the death of the cow.

Discussion

Sand bedded freestalls and Advanced Comfort Technology waterbeds with no sand on top and with 1.5 inches of sand on top were used to examine the effects of the freestall bedding material on the overall behavior and health of mature lactating Holstein cows for this study. This study was not a preference test; each herd was exposed to only one of the treatments per trial (Figure 3-2).

The overall behavior of the cows varied from trial one to trial two. The cow-freestall interaction for trial one varied significantly based on the bedding material. The behavior which had the highest percentage for trial one was cows lying within the freestalls with sand (52.95) and empty freestalls for the waterbed stalls (49.02) (Figure 4-3). The location of the cows that were not observed using the freestalls is a major concern. Even though the lying percentage was the highest orientation for the sand freestalls, if the two treatment percentages were added together, the highest percentage orientation was the empty stalls (Figure 4 -3). These results depict the fact that there are plenty of cows that were not using the freestalls. They were either eating/drinking, which was not taken into consideration for this study, or they were standing or lying within the alley ways. The first possibility, eating/drinking, is not a negative conclusion;

however, if more cows were standing or lying within the alleyways, that is not good for the cows or the farmers. At that point, the comfort of the freestalls must be examined. The best explanation of the high percentage of empty stalls for the waterbeds was due to the discomfort of the stalls, resulting in cows lying or standing within the alley ways. The explanation for the high percentage of empty sand bedded freestalls could be due to the number of cows that were eating/drinking or the effect of other environmental conditions.

There was no statistical difference for trial two between sand and waterbeds with sand on top (Figure 4-8). As explained in the results section, the high instance of empty stalls for both bedding materials was due to the greater number of cows eating once they returned from morning milking due to a change in the daily milking and feeding schedule. When the sand bedded freestalls were compared to the waterbed freestalls, the bedding had a significant effect on the behavior of the cows; the cows used the sand bedded freestalls more often. Adding sand on top of the waterbeds improved the use of the freestalls. There was no significant difference on the overall cow behavior between the sand bedded and waterbeds with sand on top freestalls.

As seen from trial one, most of the waterbeds were empty; however, in trial two, once sand was added to the waterbeds, the instance of cows lying within the freestalls increased significantly. A conclusion for this drastic increase can be the sand on top. However, the fact that the majority of the cows used for trial two were also used to the waterbeds from trial one (40 out of the 51 cows) can not be ignored. It has been proven in previous research that it takes time for cows to become acclimated to a new surrounding and a week for both trial one and trial two for acclimation may not have been long enough. No matter what, it is clear that adding sand on top of the waterbeds did have a significant effect on the overall cow-freestall interaction when compared to waterbeds alone.

Regardless of bedding material, data in Figures 4-5 and 4-10 indicate that the time of day for observing the cow behavior should not be ignored. As Overton et al. (2003) concluded, the best time to observe the lying behavior of the cows was approximately one hour before milking. This time was chosen in order to depict the most number of cows lying, resulting in the best cow comfort index. This study had similar results with the second highest frequency of lying cows for both trials corresponding to observation 1, one hour before morning milking. However, the highest frequency of lying cows for both trials corresponded to observation 3, 2 hours after morning feeding.

As seen in Figures 4-1 and 4-2 observation 3 corresponded, to on average, the hottest time of the day. These results are contrary to previous researchers on the effect of temperature on the behavior of lactating dairy cows. Wagner-Storch et al. (2003) concluded that for all stall bedding types, the stall use decreased with increasing temperatures. They found cows tended to stand up more within the stalls, as opposed to lying. However, Thoreson et al. (2000) concluded that during a summer trial the sand bedded freestalls had the overall highest lying frequency as compared to rubber mats or waterbeds. They also concluded that sand bedded freestalls were used less during the winter months as compared to the summer months. It can be concluded from this study that the sand bedded freestalls did indeed have the overall highest lying frequency and the lying behavior increased with increasing ambient temperature for all bedding materials. From Figures 4-1, 4-2, 4-6, and 4-10 it can be concluded that the ambient temperatures did not vary significantly between the two trials and the temperature, on average, had similar traits for each observation day throughout the two trials. Since all bedding materials had similar traits for all five observations of each day for both trials, it can be concluded that as the ambient air temperature increased, the lying frequency for all bedding materials increased.

The ambient temperature is one issue which can be measured and compared to the cow orientations recorded in this study; however, there are many other aspects that were not taken into consideration. Such variables include, but are not limited to, air movement, temperature of the floor and bedding materials (conductivity and thermal capacity of the bedding), as well as all modes of heat loading; radiation, convection, and conduction. This study only looked at the effect of the ambient temperature on the overall behavior of the cows and found that the lying frequency was increased with increasing temperatures. Cows will do whatever they can to transfer as much heat to the environment as possible within the Southeastern United States. For instance, it has been proven that cows will stand up more either within freestalls or within the alleys to capitalize on convective cooling. There are many aspects of the environmental that must be taken into consideration when trying to analyze the overall behavior of the cows. Even though the temperatures during this study were not ideal for the cows, there were no signs of heat stress. Such signs include panting and open mouth breathing.

Using the cow comfort index as used by Overton et al. (2003), the overall comfort of the herds for both trials was approximated with a target value of 0.85 in mind. The cow comfort index did not take into consideration cows eating or standing or lying within the alley ways, only the number of cows using the freestalls (lying, perching, and standing). The sand bedded freestalls for both trials resulted in the highest comfort index throughout the five observations per day. The waterbed freestalls resulted in the overall lowest comfort index throughout the five observations per day. The waterbeds with sand on top did not vary much from the sand bedded freestalls. For the sand bedded stall for trial one, all but two observation times resulted in a cow comfort index above the target value. This indicated, based on what the cow comfort index depicts, the overall comfort of the sand herd was ideal for the given conditions; most of the cows were lying within the freestalls. The waterbeds from trial one resulted in all of the indexes below the target value for each observation. This indicated that the overall comfort of the herd was not ideal, meaning not enough cows were lying within the freestalls for the given conditions. For trial two, the sand bedded and waterbeds with sand on top, had very similar results. For observation 2, both indexes were lower than the target value. This was due to the increased number of cows eating at this time. However, for the rest of the observations per day, the results were very close to the target value of 0.85. As a result, it can be concluded that the overall comfort of the cows in the sand bedded and waterbed stalls with sand on top were near to ideal for the given conditions.

In agreement with Fulwider et al. (2007) and Weary et al. (2000), the bedding material had significant effects on the overall hock injuries for both trials and the severity of injuries varied depending on the location on the hock. There was no difference between the waterbeds from trial one and the waterbeds with sand on top from trial two on the overall hock scores. The waterbed freestalls and the waterbeds with sand on top had the highest instance of hock scores, indicating a higher presence of hock injuries consisting of scores of 2 or 3 (LSM = 1.24). A score of two had no swelling with a bald area on the hock. A score of three had evident swelling and/or had lesions through the hide. The sand bedded freestalls from trial one had an overall least square mean score of 1.05 for trial one and 1.04 for trial two, indicating little to no hock injuries to the cows.

The two locations on the hocks for both the sand bedded and waterbed stalls with the lowest overall hock scores, indicating very little damage, were the medial tuber calcis and the medial tarsal joint. The dorsal tuber calcis resulted in the most damage for the sand bedded freestalls for both trials with an overall least square mean score of 1.18 and 1.13 for trial one and trial two respectively. This result is as expected, as this conclusion has been seen in previous research. Previous researchers stated the rear concrete curbs of the freestalls might be the cause of these increased instances of the damage to the dorsal tuber calcis. The location for the highest instance of hock injuries for the waterbed and waterbeds with sand freestalls was the lateral tuber calcis with a least square mean score of 1.60. This result was also similar to previous research for geotextile mattresses. The presence of increased frictional build up between the cow and the rubber of the waterbed has been used as an explanation for this increased damage to this location on the hock. However, this explanation does not explain why adding sand on top made no difference. Adding 1.5 inches of sand on top may not be enough sand to prevent the cows' skin from being exposed to the rubber of the waterbeds. This little amount of sand could possibly explain why there was no difference between the waterbeds alone and the ones with sand on top.

When examining the effects of freestall bedding materials on the overall leg hygiene, there are many factors which can not be ignored. Most importantly, the freestall maintenance must be considered. For both of the trials, each freestall was cleaned on a daily basis. The sand bedded freestalls were racked off and the waterbeds were cleaned during each morning milking. Sand was reapplied to the sand bedded freestalls each Monday of each week and sand was reapplied for the waterbeds with sand on top half way through the second trial. From previous research, the results of the hind leg hygiene based on various freestall bedding materials have been examined and there have been mixed results. Fulwider et al. (2007) concluded that rubber filled mattresses and waterbeds resulted in the cleanest cows, the lowest hygiene scores. However, Bewley et al (2001) concluded that the sand bedded freestalls resulted in the cleanest cows. The results from this study were just as mixed. From trial one, the waterbeds had the highest overall least square mean hygiene score of 2.62, indicating more hygiene scores of 3 or 4, dirtier cows. A score of three had distinct plaques of manure above the coronary band, but leg hair was visible. A score of four had a solid plaque of manure extending high up the leg. The sand bedded freestalls had a least square mean of 2.14, indicating more scores of 1 or 2. A score of one had little or no manure above the coronary band. A score of two had minor splashing above the coronary band.

In contrast to the first trial hygiene results, the sand bedded verses waterbed with 1.5 inches of sand on top had no significant difference on the overall cleanliness of the cows. Granted, the waterbeds with sand on top had a slightly lower least square mean score of 2.02 as compared to the sand bedded freestalls with a score of 2.23. This indicated that the waterbeds with sand on top had overall cleaner cows, however, not statistically significant. These results might be more indicative of the results concluded by Fulwider et al. (2007).

Advanced Comfort Technology Inc., the developers of the waterbeds, advertize that waterbeds should result in the cleanest cows by causing the urine, manure, and milk to run off the back of the freestalls into the alley, resulting in a cleaner lying surface, as compared to the typical sand bedded freestalls. This might be the case; however, the behavior of the cows must be taken into consideration when trying to determine why this study resulted in waterbed freestalls being the dirtiest. As seen in Figure 4-3, it was concluded that most of the waterbed freestalls were empty. This meant that most of the cows in this herd were standing in the alley, eating/drinking, or more likely lying in the alleys. This behavior would indeed explain why the waterbed herd resulted in the highest instance of dirtier cows. In order to better understand these results, further research should be performed that would make sure all cow activity can be seen; including the number of cows eating/drinking, lying, or standing in the alleys. This would result in a better idea of the daily activity of all cows. Having this additional knowledge might result in the explanation of why the cows from certain bedding materials are cleaner than others. If cows are not using the bedding material, such as seen in the waterbed herd, it is not a good conclusion to say the cows are dirtier due solely to the waterbed material. As seen in this research project, the reason why the cows are dirtier for the waterbed herd was because they disliked the freestall bedding material so much that they chose to lie in the alleys, resulting in much dirtier cows than if they used the freestalls, as seen via periodic walk-through observations.

Overall, trial two should be seen as better indication of various bedding materials' effect on overall herd health because, as seen in Figure 4-8, there was no significant effect of the bedding material on the overall herd behavior. As a result, the cows from the sand bedded and waterbeds with sand on top herds had no significant difference between the amounts of time spent within the freestalls. It can be concluded, since the cows spent almost equal amounts of time in the freestalls regardless of the bedding material, the hygiene scores are more indicative of the interaction between the bedding material and the cows. From this conclusion, it can be said that the sand bedded freestalls and the waterbeds with sand on top had no real difference on the overall hygiene of the cows.

The effects of the bedding material on the overall culling rate of the three treatments were not significant throughout the two four week trials. All three treatments had similar results of the number of mastitis outbreaks and hoof/leg injuries that required the cows to be removed from the milking herd and into the hospital herd (Table 4-13). Even though hock scores and hygiene scores are important, the overall culling rate of the herd should be seen as another aspect that the farmer would need to look at when trying to determine which bedding material will be more productive, and as a result, a better investment overall. From these results, there were no significant differences between the three bedding materials on the overall instances of mastitis and hoof/leg injuries.

CHAPTER 5
CONCLUSION

The objective of this study was to evaluate the effects of various freestall bedding materials on the overall health and behavior of lactating Holstein cows. The results from this research will be used for farmers to determine which bedding material would be more beneficial by focusing on the overall lying frequency of the cattle in the herd (cow comfort), hock health, and leg cleanliness.

This study tended to reinforce the fact why so many dairy farmers are still using sand bedded freestalls, regardless of the ongoing increasing cost as well as the waste management issues; however, it also raised the idea of using waterbeds with a layer of sand on top. Sand bedded freestalls had the overall highest frequency of lying cows for both trial one and trial two with least square means of 2.71 and 2.51 respectively. The waterbeds alone had the lowest frequency of lying cows, in actuality, they had the highest frequency of empty stalls, meaning more cows were either standing or lying in the alleys, as observed a few times during the first trial (LSM of 2.20). However, putting sand on top of the waterbeds did have an effect on the overall behavior of the cows as compared to the waterbeds alone. The lying frequency of the cows was not significantly different from the sand bedded stalls (LSM of 2.43).

It can be concluded from these results that the waterbeds alone are not appealing to the cow, possibly due to the appearance or the initial impact. Adding sand on top of the waterbeds changed the appearance of the waterbeds as well as the comfort level of the freestalls. It can be concluded that cows must prefer the feeling of sand on their skin as opposed to the rubber from the waterbeds when they lay down. At this point there is not much research examining the effect of the bedding material properties on the behavior of the cows. However, if there was, then those results might create some understanding of why the cows used the waterbeds with sand on top more as compared to the waterbeds alone.

Further research should be performed looking at the effects of the location of the freestalls within the barn to determine if certain freestalls are used more often than others. Also, most importantly, this project should be performed during both the winter and summer months of Florida. This experiment was performed dealing with the given conditions, which consisted of very hot temperatures, which could have affected the overall behavior of the cows. If this project was conducted during the cooler months, the behavior of the cows might change depending on the bedding material, which has been suggested by previous research. Also, if this project was repeated, all activities of the cows should be observed, as opposed to just the interaction between the freestalls and the cows, as well be able to record the actual time spent lying within the freestalls for a given 24 hour period. This added data would lead to a better understanding of what the cows are doing when they are not in contact with the freestalls.

From this study, it can be concluded that the decision to use a particular type of bedding material will ultimately be left up the farmer who will decide what will be better for the overall production. Hock injuries were evidently higher and more severe in the waterbed and waterbeds with sand on top. However, adding sand on top of the waterbeds resulted in no difference from the sand bedded stalls with regard to freestall usage and continued to the maintain the cleanest cows and the lowest instance of mastitis. This might be the needed evidence for farmers to make the economical investment into waterbeds. However, since hock injuries are generally not ignored in the dairy industry, it can be concluded from this study that there are clear benefits to using sand bedding for freestalls.

LIST OF REFERENCES

Albright, J. L., and C. W. Arave. 1997. The Behavior of Dairy Cattle. *CAB International*, Oxen, UK and New York, NY. 1:37-39.

Anderson, N. G. 2007. Free Stall Dimensions. *Livestock Technology*. Ontario, Canada.: Ministry of Agriculture, Food and Rural Affairs.

Anderson, N. G. 2003. Observations on Dairy Cow Comfort: Diagonal Lunging, Resting, Standing and Perching in Free Stalls. In *Proc. Fifth International Dairy Housing Conference,* 26-35. Fort Worth, TX.: ed. K. A. Janni. ASABE.

ASAE Standard EP444.1. 2001. Terminology and Recommendations for Freestall Dairy Housing, Freestalls, Feed Bunks, and Feeding Fences. *ASAE Standards 2001, 48th Edition*, St. Joseph. MI.

ASTM Standard D 5874-02. 2007. Standard Test Method for Determination of the Impact Value (IV) of a Soil. ASTM International, West Conshohocken, PA.

ASTM Standard F 1702-96. 2002. Standard Test Method for Measuring Shock-Attenuation Characteristics of Natural Playing Surface Systems Using Lightweight Portable Apparatus. ASTM International, West Conshohocken, PA.

Bardolph, M. 1996. Changing Environmental Regulations for Dairy Waste Management. In *Proc. 33rd Florida Dairy Production Conference*, 106-108. Gainesville, FL.: University of Florida.

Bethard, G., and J. G. Martin III. 2003. Facility Management Considerations That Impact Profit. Gainesville, FL.: University of Florida, Institute of Food and Agricultural Sciences.

Bewley, J., R. W. Plamer, and D. B. Jackson-Smith. 2001. A Comparison of Free-Stall Barns used by Modernized Wisconsin Dairies. *Journal of Dairy Science* 84:528-541.

Bramley, A. J. 1985. The Control of Coliform Mastitis. In *Proc. National Mastitis Council,* 4. Las Vegas, NV. National Mastitis Council, Inc., Madison, WI.

Bucklin, R. A., D. R. Bray, J. G. Martin III, L. Carlos, and V. Cavalho. 2009. Environmental Temperatures in Florida Dairy Housing. *Applied Engineering in Agriculture.*

Clark, J.A. 1981. *Environmental Aspects of Housing for Animal Production.* England: University of Nottingham.

Clegg, B. 1983 Application of an Impact Test to Field Evaluation of Marginal Base Course Materials. In *Proc .3rd Low - Volume Roads International Conference,* Washington, D.C.

Clegg, B., and J. Crandell. 1980. An Impact Soil Test as Alternative to California Bearing Ratio. In *Proc. 3rd ANZ Geomechanics Conference,* Wellington, NZ. ed. J. Crandell.

Cook, N. B., D. J. Reinemann. 2007. A Tool Box for Assessing Cow, Udder and Teat Hygiene. Madison, Wisconsin: University of Wisconsin-Madison.

Cook, N. B., K. Nordlund. 2004. An Update on Dairy Cow Freestall Design. In *Proc. American Association of Bovine Practitioners 37th Annual Conference.* Fort Worth, TX.

Cook, N. B., T. B. Bennett, and K.V. Nordlund. 2004. Effect of Free Stall Surface on Daily Activity Patterns in Dairy Cows with Relevance to Lameness Prevalence. *Journal of Dairy Science,* 87:2912-2922.

Cornell Cooperative Extension. Hock Assessment Chart for Cattle. Adapted from James Nocek.

Curtis, S.E. 1983. *Environmental Management in Animal Agriculture*. Ames, Iowa: Iowa State University Press.

Drissler, M., M. Gaworski, C. B. Tucker, and D. M. Weary. 2005. Freestall Maintenance: Effects on Lying Behavior of Dairy Cattle. *Journal of Dairy Science.* 88:2381-2387.

Fulwider W. K., T. Grandin, D. J. Garrick, T. E. Engle, W. D. Lamm, N. L. Dalsted, and B. E. Rollin. 2007. Influence of Free-Stall Base on Tarsal Joint Lesions and Hygiene in Dairy Cows. *Journal of Dairy Science.* 90:3559–3566.

Fulwider, W. K., and R. W. Palmer. 2004. Use of Impact Testing to Predict Softness, Cow Preference, and Hardening Over Time of Stall Bases. *Journal of Dairy Science.* 87:3080-3088.

Gaworski, M. A., C. B. Tucker, D. M. Weary, and M. L. Swift. 2003. Effects of Stall Design on Dairy Cattle Behaviour. In *Proc. Fifth International Dairy Housing Conference,* 139-146. Fort Worth, TX.: ed. K. A. Janni. ASABE.

Gebremedhin, K. G., Cramer, C. O., Larsen, H. J. 1985. Preference of Dairy Cattle for Stall Options in Free Stall Housing. *Transactions of the ASAE*. 28: 1637-1640.

Greenough, P. R. 2007. *Bovine Laminitis and Lameness.* Toronto, Canada: Saunders Elsevier.

Harris, B., and D. W. Webb. 1992. The Florida Dairy Industry and Situation. Gainesville, FL.: University of Florida, Institute of Food and Agricultural Sciences DS82.

Henderson, S. M., R. L. Perry, and J. H. Young. 1997. *Principles of Process Engineering*. 4th ed. St. Joseph, Minnesota: American Society of Agricultural Engineers.

Herlin, A. H. 1997. Comparison of Lying Area Surfaces for Dairy Cows by Preference, Hygiene, and Lying Down Behaviour. *Swedish Journal of Agricultural Research.* 27: 189-196.

Hogan, J. S., K. L. Smith, K. H. Hoblet, D. A. Todhunter, P. S. Schoenberger, W. D. Hueston, D. E. Pritchard, G. L. Bowman, L. E. Heider, B. L. Brockett, and H. R. Conrad. 1989. Bacterial Counts in Bedding Materials used on Nine Commercial Dairies. *Journal of Dairy Science.* 72:250–258.

Jensen, P., Recén, B., Ekesbo, I. 1988. Preference of Loose Housed Dairy Cows for Two Different Cubicle Floor Coverings. *Swedish Journal of Agricultural Research.* 18: 141-146.

Jones, G. M., and C. C. Stallings. 1999. Reducing Heat Stress for Dairy Cattle. Blacksburg, VA.: Department of Dairy Science, Virginia Tech.

Lindley, J. A., and J. H. Whitaker. 1996. *Agricultural Buildings and Structures.* St. Joseph, MI: American Society of Agricultural Engineers.

McFarland, D. F. 2003. Freestall Design: Cow Recommended Refinements. In *Proc. Fifth International Dairy Housing Conference,* 131-138. Fort Worth, TX.: ed. K. A. Janni. ASABE.

McFarland, D. F., and M. J. Gamroth. 1994. Freestall Designs with Cow Comfort in Mind. In *Proc. Third International Dairy Housing Conference,* 145-157. Orlando, FL.: ASAE.

McFarland, D. F., and R. E. Graves. 2003. Designing and Building Dairy Cattle Freestalls. University Park, PA.: Penn State University, College of Agricultural Sciences.

McNitt, A. S., and P. J. Landschoot. 2003. Effects of Soil Reinforcing Materials on the Surface Hardness, Soil Bulk Density, and Water Content of a Sand Root Zone. *Crop Science.* 43:957-966.

MidWest Plan Service (MWPS). 2000. Dairy Freestall and Housing Equipment. 7th ed. MWPS-7. Ames, Iowa: MWPS.

Mitlohner, F. M., J. L. Morrow-Tesch, S. C. Wilson, J. W. Dailey and J. J. McGlone. 2001. Behavioral Sampling Techniques for Feedlot Cattle. *Journal of Animal Science.* 79:1189-1193.

Mowbray, L., T. Vittie, and D. M. Weary. 2003. Hock Lesions and Free-stall Design: Effects of Stall Surface. In *Proc. Fifth International Dairy Housing Conference,* 288-295. Fort Worth, TX.: ed. K. A. Janni. ASABE.

Nordlund, K., and N. B. Cook. 2003 A Flowchart for Evaluating Cow Freestalls. *Bovine Practitioner.* 37:89-96.

O'Connell, J. M., Meaney, W. J. 1997. Comparison of Shredded Newspaper and Sawdust as Bedding for Dairy Cows: Behavioural, Clinical and Economic Parameters. *Irish Veterinary Journal.* 50: 167-170.

Overton, M. W., D. A. Moore, and W. M. Sischo· 2003. Comparison of Commonly Used Indices to Evaluate Dairy Cattle Lying Behavior. In *Proc. Fifth International Dairy Housing Conference,* 125-130. Fort Worth, TX.: ed. Kevin Janni. ASABE.

Overton, M. W., W. M. Sischo, G. D. Temple, and D. A. Moore. 2002. Using Time-Lapse Video Photography to Assess Dairy Cattle Lying Behavior in a Free-Stall Barn. *Journal of Dairy Science.* 85:2407–2413.

Phillips, C. 2002. *Cattle Behavior and Welfare*. 2nd ed. Malden, MA. : Blackwell Publishing.

Rodenburg, J. 1996. Mastitis Prevention for Dairy Cattle: Environmental Control. Ontario, Canada.: Dairy Cattle Specialist/OMAFRA

SAS. 2003. *Statistical Analysis System*. Ver. 9.1. Cary, N.C.: SAS Institute, Inc.

Spencer, H. 1998. Free Stall and Corral Management as Related to Mastitis Control. In *Proc. 1998 Mastitis Council Regional Meeting,* 60. Bellvue, WA.: National Mastitis Council

Thoreson, D. R., D. C. Lay, and L. L. Timms. 2000. Dairy Free Stall Preference Field Study. *2000 Dairy Report – Iowa State University.*

Tucker, C. B., and D. M. Weary. 2001. Stall Design: Enhancing Cow Comfort. *Advances in Dairy Technology* 13:155-166.

Van Horn, H. H., and C. J. Wilcox. 1992. *Large Dairy Herd Management*. Champaign, IL: American Dairy Science Association.

Vokey, F. J., C. L. Guard, H. N. Erb, and D. M. Galton. Observations on Flooring and Stall Surfaces for Dairy Cattle Housed in a Free-Stall Barn. 2003 In *Proc. Fifth International Dairy Housing Conference,* 165-170. Fort Worth, TX. ed. K. A. Janni. ASABE.

Vokey, F. J., C. L. Guard, H. N. Erb, and D. M. Galton. 2001. Effects of Alley and Stall Surfaces on Indices of Claw and Leg Health in Dairy Cattle Housed in a Free-Stall Barn. *Journal of Dairy Science.* 84:2686-2699.

Wagner-Storch, A. M., R. W. Palmer, and D. W. Kammel. 2003. Factors Affecting Stall Use for Different Freestall Bases. *Journal of Dairy Science.* 86:2253–2266.

Weary, D. M., and I. Taszkun. 2000. Physiology and Management of Hock Lesions and Free-Stall Design. *Journal of Dairy Science.* 83:697–702.

BIOGRAPHICAL SKETCH

Rachael Boone was raised in a rural area outside of Jacksonville, Florida where she, her sister, and mom had 12 acres and six horses. Rachael always had an interest in designing structures, in particular, animal housing facilities. She spent her freshman year at the University of Alabama–Tuscaloosa, with all intentions of majoring in civil engineering, with a focus on structural design. However, it was there that she learned of agricultural engineering. From the end of the fall semester at Alabama she began applying to other schools. She began her academic career in biological and agricultural engineering as a sophomore at North Carolina State University. With the great support of her family, friends, and great professors, she received a Bachelor of Science degree in biological and agricultural engineering in the spring of 2007. She then moved back to the state of Florida where she began her work toward a Master of Engineering in agricultural and biological engineering at the University of Florida. It was in the Department of Agricultural and Biological Engineering where she began her focus on animal housing structures. She successfully defended her thesis in January 2009 and received her Master of Engineering degree in May of 2009.