TRAILER MICRO-CLIMATE DURING LONG-DISTANCE TRANSPORT OF FINISHED BEEF CATTLE FOR THE SUMMER MONTHS IN NORTH AMERICA

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ABSTRACT

Transporting cattle from southern Alberta into the United States (US) plays a substantial economic role in the western Canadian beef industry. Thermal environments within cattle transport trailers are dependent on ambient conditions, and if inadequately managed, can be a welfare concern. To effectively manage cattle transport, the environmental conditions throughout the livestock trailer must be understood. The objective of the present study was to investigate the trailer micro-climate and welfare during 5-paired commercial long-haul transports of slaughter cattle from Alberta, Canada to Washington State, US during summer months. In addition, the effect of compartment location and trailer porosity (8.7% vs 9.6%) on trailer micro-climate, shrink and core body temperature were also investigated during the warmest in-transit hour and stationary events. The compartment location had an effect on micro-climate variables where the upper compartment had greater ($P < 0.05$) temperature than the bottom deck compartments and relative humidity variables had the opposite effect for both the warmest in-transit hour and stationary events. There was also an effect of trailer porosity on micro-climate variables where it was generally warmer in the trailer with the higher porosity in the stationary event. Differences between trailers included 2 additional roof hatches on the trailer with lower side-wall porosity and lower internal temperatures, which could suggest the location of the trailer porosity, could be important for heat and moisture exchange during transit. The nose of the trailer with higher porosity had generally warmer internal conditions (larger $T_{(trailer)}$ $^{\circ}$C and $THI_{(trailer)}$) than the trailer with lower porosity. This study also found that the temperatures inside the trailer can be 10.5°C greater than ambient temperatures during stationary events and 9°C greater than ambient levels during the warmest in-transit hour. The average amount of per-animal weight loss was 4.3 $\pm$ 0.3 % and was affected by trailer porosity and compartment, which followed the trends in thermal environment variables. The transit status (stationary or in-transit) and trailer porosity affected the vaginal core body temperature of the heifers in transit. The core body temperature was greater during stationary events for animals transported in the trailer with lower porosity. It is suggested that the lower side-wall porosity and/or the shape of perforation pattern could impair the movement of fresh air to the respiratory tract of heifers, thus impacting the main mechanism for dissipating heat. The difference in temperature from the trailer ceiling to the animal level was 3.38°C in the trailer with lower porosity (cooler at the ceiling) and 2.23°C in the trailer with the

higher porosity. This relationship also had a compartment location effect that followed the micro-climate compartmental differences. This could suggest that excess heat in the trailer with the lower porosity, that also had lower overall temperatures, exited through roof hatches, while in the trailer with the higher porosity, the heat escaped through the side-wall perforations. This theory also supports the idea that the location of where the porosity is located on the trailer may be important to alleviating heat stress in summer months during transport. The results of this study also indicated that there was no difference in the location of the data logger plane (driver, middle passenger) and within the compartments (front, middle, back), suggesting that compartment location effect is substantial when considering micro-climate but temperatures within a compartment are mostly homogenous. The trip that had average ambient temperatures of $25.9 \pm 6.06^{\circ}C$ for the entire journey, had a temperature Humidity Index that was considered in the danger or emergency category according to the Livestock Weather Heat Index during 95% of the warmest in-transit hour. This suggests that during ambient temperatures of $25.9^{\circ}C$, both trailers used in this study did not have sufficient heat exchange to mitigate the risk of heat stress for cattle.

Keywords: Cattle transport, micro-climate, welfare, compartment porosity, shrink, core body temperature

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LIST OF ABBREVIATIONS

AAFC	Agriculture and Agri-Food Canada
AB	Alberta
AV	Average
BC	British Columbia
CARC	Canadian Agri-food Research Council
CBT	Core body temperature; ^{o}C
CFIA	Canadian Food Inspection Agency
$^{\circ}$C	Celsius
cm	centimeter
d	day
in	inch
EU	European Union
ft	foot
g	gram
h	hour
kg	kilogram
kg/m^2	kilograms per square meter (stocking density)
km	kilometer
lb	pound
LWSI	Livestock Weather Safety Index
MB	Manitoba
m	meter
m^2	meters squared
m^3	meters cubed
min	minute
n	number
NA	North America
OIE	World Health Organization for Animal Health
P	porosity

RH	relative humidity
$RH_{ambient}$, %	ambient relative humidity
$RH_{Trailer,}$%	internal trailer relative humidity
SAS	Statistical Analysis Software
SD	standard deviation
SE	standard error
SCAHAW	Scientific Committee on Animal Health and Animal Welfare
SK	Saskatchewan
T	temperature
THI	temperature humidity index
$T_{ambient}\,^{\circ}C$	ambient temperature
$THI_{ambient\,,}$	ambient temperature humidity index
$T_{Trailer}\,^{\circ}C$	internal trailer temperature
$THI_{Trailer,}$	internal trailer temperature humidity index
US	United States of America
USDA	United States Department of Agriculture
Vs	versus
$\Delta T\,^{\circ}C$	change in temperature (internal trailer – ambient)
ΔRH%	change in relative humidity (internal trailer – ambient)
ΔTHI	change in temperature humidity index (internal trailer – ambient)
>	greater than
<	less than
%	percent

LIST OF EQUATIONS

1.0 INTRODUCTION

Less than 70 years ago, cattle were gathered from the Rocky Mountains and foothills of Alberta and trailed by horseback for hundreds of kilometers to assembly stations and then transported by railway to various destinations. The relocation of cattle to a central point was one of the major contributors to settlements of ranches, homesteads and eventually towns. Transport of live cattle by railway was replaced in the 1940's with trucks (Bill Dunn, Alberta historian, personal communication). Cattle drives are a rare sight today, and few cattle are driven on horseback for long distances. Today, farmers and ranchers transport their own cattle by truck and stock trailer that can hold around 10 cows or contract to commercial livestock hauling companies. A new commercial transportation unit comprised of a semi-truck and trailer can cost approximately $230,000. With large input costs for transportation units, ranches and feedlots with large volumes of cattle use the services of commercial fleets that are more economical and efficient.

Often, each cattle sale transaction results in a transit event for cattle. In Alberta (AB), cattle are typically transported between 3 and 7 times in their life and can include transportation to and from pastures, assembly yards, auctions, feedlots and a final journey to an abattoir (Figure 1.1). Large volumes of Canadian cattle are relocated annually. In 2011, 2.5 million (Canfax, 2012) head were transported for slaughter in western Canada. As much as 60% of the annual Canadian cattle inventory can be exported by land transportation to the United States (US) and can range from 500,000 to 1,600,000 head per annum (Canfax, 2012). Despite the large volumes of cattle transported within and outside of AB, there are few studies regarding the environmental conditions that cattle in North America (NA) are exposed to during the transport process, or the impact the transportation event has on their health and well-being.

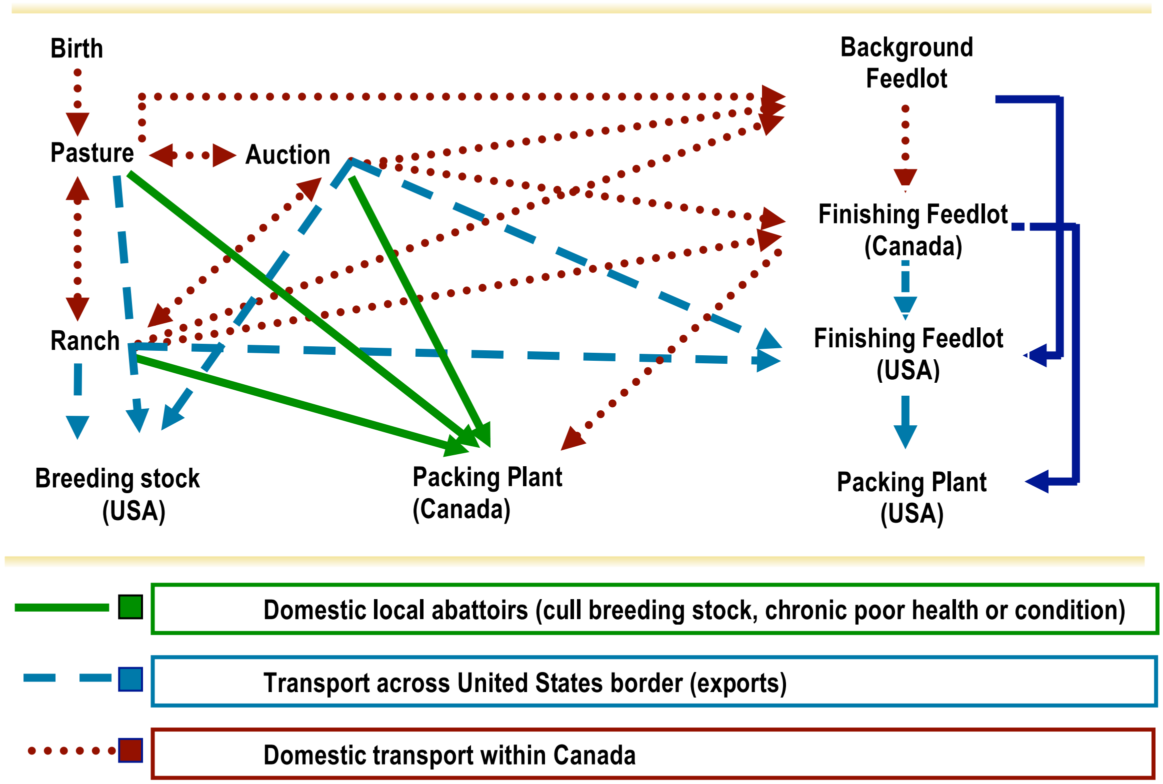


Figure 1.1 Logistics of cattle transport in Canada with domestic and international destinations.

Consumers in developed countries are increasing pressure on the livestock industry to demonstrate that production systems are humane and that standards to achieve safe humane transport are supported by sound science. Many meat-processing companies in NA also recognize these concerns and now require that their suppliers adhere to a set of standard auditable welfare practices. These factors have made animal welfare a priority area for the Canadian public and the beef industry. The outcome of transportation should be to achieve equilibrium between profitability and animal welfare during transport (European Commission, 2001b).

Public scrutiny of live animal transport has steadily increased over the past five years (OIE 2004; Broom, 2008). This is due to the fact that each relocation event has the potential to pose a risk of injury and distress to the animal thereby raising issues of animal welfare. Welfare is a broad term that incorporates the physical and mental well-being of the animal. Efforts should be made to handle animals in a humane and respectful manner because failure to cope can lead to disease, injury and lower production performance (European Commission, 2001a).

Typically, spring-born calves are received at the feedlot in the fall and are ready for market in the summer months the following year. During summer months, the highest volumes of finished cattle are transported to slaughter, which can pose many logistical challenges for the beef and livestock transportation industry. Long-distance transport across international borders can increase the risk of exposure to extreme summertime conditions. In addition, the international transport of live animals can result in increased transit durations due to border and veterinary inspection related delays (González *et al.,* 2012a). Finally, regulatory restrictions regarding driving time can also increase transit length while hauling cattle. Delays and stationary periods are inevitable during transportation practices and heat stress is the most detrimental challenge to health and well-being during cattle transit during summer months (Kettlewell *et al*., 2001). Delays and stationary periods were recently quantified by González *et al.* (2012a), in a benchmark study of current transport practices in the Alberta beef industry. They reported that 89% of all trips experienced a delay during long-haul transport. A total of 77% of all loads transported across the Canada/US border experienced a delay that on average lasted 1.3 ± 1.9 h with a maximum of 15 h (González *et al.,* 2012a). Furthermore, the average time that an animal remained on a truck was 15.9 ± 6.3 h with a maximum of 45 h (González *et al.,* 2012a). When the time on truck increased, it also increased the risk and amount of time that animals are exposed to environmental conditions such as excess heat and humidity. While cattle are more tolerant to colder temperatures than warmer temperatures (EFSA, 2004; European Commission, 1999), currently there are no recommendations for cattle in NA being transported during intense summer month conditions. To date, there have been no studies that have investigated the micro-climate conditions in NA for slaughter cattle transported during summer months. In addition, no studies have assessed the effect of trailer porosity on trailer micro-climate.

Still, there has been a considerable number of transport studies completed worldwide. Several European studies assessed the effects of cattle transport on meat quality (Maria, 2008), loading density (Tarrant *et al.,* 1988) and temperature and fasting (Fischer, 1981). Australian studies conducted by Eldridge *et al.* (1986; 1988) looked at the effects of handling, space allowance and road conditions during transport. In New Zealand, Fisher *et al.* (1999) looked at the effect of long-haul transport on pregnant cows.

However, practices in Europe, Australia, and New Zealand differ substantially in many aspects, including transport vehicle design, weather, distances, production practices, and road conditions when compared to Canada. For this reason, much of the European, Australian and New Zealand research are not applicable to the transportation of cattle in Canada. Collecting micro-climate information in cattle transport trailers in NA has practical implications for meat quality and welfare of cattle in transit (Schwartzkopf-Genswein *et al.,* 2012).

2.0 LITERATURE REVIEW

The objective of this literature review is to provide an overview of current research findings related to the effects of road transportation on beef cattle under NA conditions. Where possible, emphasis will be placed on the specific effects of trailer porosity and compartment location on trailer micro-climate factors such as temperature, relative humidity and temperature humidity index. Each of the transport factors listed above will be discussed with regard to their effect on animal welfare, including heat stress, shrink and core body temperature.

2.1 CATTLE TRANSPORTATION

2.1.1 Transport of finished cattle

The typical live weight of a finished steer is approximately 627 kg (1400 lbs) and a heifer is 605 kg (1350 lbs), yielding hot carcass weights of 386 kg (867 lbs) and 369 kg (824 lbs), respectively (Canfax, 2012). Southern AB finishes a large volume of fed cattle destined for slaughter. In 2011, 75.3% of all Canadian-fed cattle were finished in AB (Canfax, 2011). As Canadian feedlot production and slaughter procurement systems become geographically consolidated in southern AB, cattle from British Columbia (BC), Manitoba (MB) and Saskatchewan (SK) are being transported for longer distances to AB. Western Canadian (AB, BC, MB, SK,) domestic cattle procurement volumes were 2,515,450 head in 2010 and 2,208,202 in 2011 (Canfax, 2012). Transportation is a necessary part of the industry process as cattle are relocated to finishing feedlots or commercial slaughter facilities. Feedlot operations in southern AB have access to two large domestic packing plants located within 200 km, including large commercial processing plants located in High River and Brooks, AB. However, profitability dictates whether cattle will be sold on the domestic or US market. Faced with tight profit margins, feedlots often seek marketing strategies in the US where risk management options, Canadian dollar basis, option to feed a beta agonist, and age verification premiums are attractive. Exporting slaughter and feeder cattle to the US is a frequent practise for AB cattle-based enterprises, resulting in increased transit durations, as well as increases in the length and frequency of stationary periods the cattle may experience. This is of particular concern during the summer months when the potential for the risk of heat stress is high, potentially reducing the quality of animal welfare. The ability to quantify the cost of reduced animal welfare during long-distance transport in summer months would be beneficial and should be considered for economic models in profitability projection for cattle market analyses. Without an economic cost or financial loss corresponding to reduced welfare, there is little initiative to improve or change current practices.

2.1.2 Commercial Transport Trailers

Cattle are transported in 16.2-m (53-ft) long and 2.54-m (8.33-ft) wide, double-decked aluminum trailers that have a live weight capacity of 29,148 kg (65,000 lbs) in NA. Aluminum is used for transport trailers because it is a lightweight material and resistant to the corrosive elements of manure (Rick Sincennes, personal communication).

The livestock trailer has five-compartments, which include: nose, deck, belly, doghouse and rear as shown in Figure 2.1. The nose is the front compartment directly behind the tractor-trailer unit. The deck and belly are equally sized and are located in the middle of the trailer with the deck located above the belly. The doghouse compartment is directly above the rear compartment and therefore both can have the same floor space. However, ½ and ¾ doghouse configurations exist, where the area of the doghouse compartment is 50% or 75% of the space of the rear compartment, respectively (Rick Sincennes, personal communication).

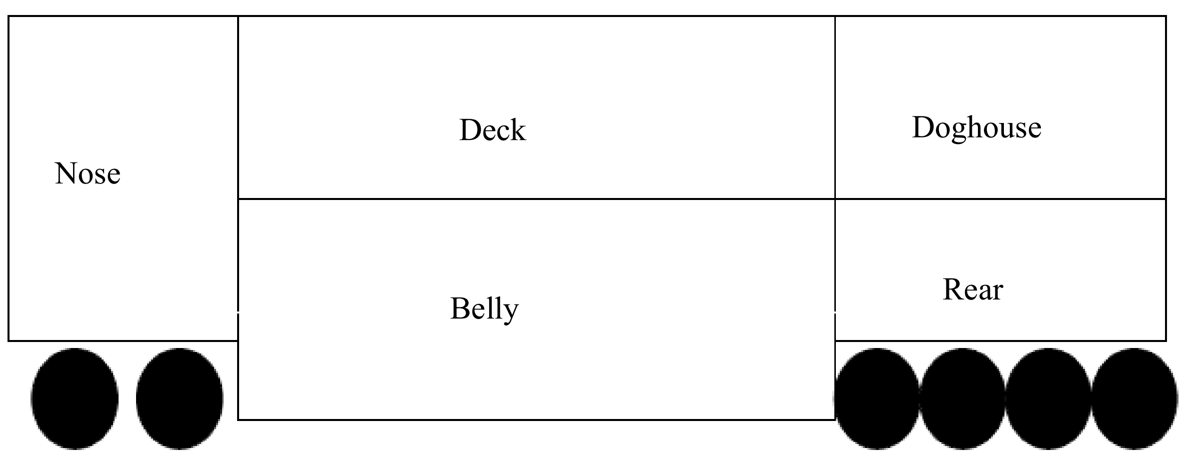


Figure 2.1 Schematic of a quad-axle cattle trailer with five compartments; nose, deck, belly, doghouse and rear.

Gates are used to separate animals in the deck, belly and doghouse compartments. These gates also protect handlers working in a confined space when moving cattle into specific trailer compartments. Nose decking is utilized to maximize space allowance by creating an additional compartment in the nose and only used for light feeders and calves. There are three ramps inside the trailer; the deck ramp that allows animals to reach the top level of the trailer, the counterbalance ramp or trap door that provides downward entry into the nose from the deck, and the belly ramp facilitating access to the bottom compartment (Rick Sincennes, personal communication).

The roof of the trailer can be equipped with up to 4 roof vents or hatches that slide open to allow an escape route for handlers in addition to increasing air exchange inside the trailer. Another feature of livestock transport trailers is the diamond corrugated flooring essential for proper footing and traction during transport. Each trailer is equipped with floor drains that aid drivers in cleaning manure out of the trailer. Additionally, some trailers can accommodate both hogs and cattle and are equipped with nose vents intended to increase airflow. Generally, the front and back of cattle trailers are solid with the exception of a gap at the top of the rear sliding door (Rick Sincennes, personal communication).

There is a variety of trailer models including feeder, hog, fat and specialized trailers to accommodate tall cattle. The feeder trailer is considered a standard trailer that has additional floor decking in the nose. Hog trailers can have three levels of pigs in the nose and two levels in the belly, requiring additional railing in these compartments. The trailer that was designed to haul slaughter or fat cattle has the nose compartment joined with the deck compartment and utilizes a double back door that is the width of the trailer that serves to increase the area for cattle while exiting. This trailer's design is to reduce bruising on fat cattle going to slaughter but poses a safety risk to handlers loading cattle onto the upper compartments and for this reason this model has lost popularity. Finally, the most recent trailer design was manufactured to accommodate the transport of slaughter Holsteins or large-framed beef cattle. This trailer provides equal height distances in the rear and doghouse that is achieved by using low profile tires, thus increasing the height of the two compartments but not the overall height of the trailer (Rick Sincennes, personal communication).

Commercial trailers can be a tri-axle (3 axles) or quad-axle (4 axles) design and are pulled by a tractor truck with tandem (2 axles) or tandem push axles (3 axles). As fuel prices increase, the industry preference (71.3%) has shifted to quad-axle trailers as reported by González *et al*. (2012a) to maximize efficiencies by hauling maximum allowable weight. The additional axles allow more weight per load and the weight is distributed more evenly throughout the tractor trailer unit on steering, drive and trailer axles to meet legal weight regulations. Weight allowance regulations vary from province to province as well as by the state in the US. Truck drivers with additional axles can be required to redistribute cattle at border crossings to meet these road allowance regulations for different states. (Rick Sincennes, personal communication).

2.2 STRESS ASSOCIATED WITH CATTLE TRANSPORTATION

2.2.1 Animal welfare

It is difficult to have one definition of animal welfare as there are many comprehensive approaches including biological and technical, regulatory, philosophical and human-animal interactions (Bock and Van Leeuwen, 2005; Dockès and Kling-Eveillard, 2006). Additionally there are also ethical, economic and political definitions of welfare that need to be considered (Lund and Olsson, 2006). However, definition of animal welfare I feel is the most appropriate for this thesis is "as an animal's ability to cope, both physically and mentally with its surrounding environment" (Broom, 2008). A summary of the biological, behavioural and environmental requirements of livestock are found in the five freedoms that were recommendations of the Brambell Report (1965), and revised by FAWC (1993) that include:

1) freedom from thirst, hunger and mal-nutrition – by ready access to fresh water and diet to maintain full health and vigour,

2) freedom from discomfort– by providing a suitable environment including shelter and a comfortable resting area,

3) freedom from pain, injury and disease – by prevention or rapid diagnosis and treatment,

4) freedom to express normal behaviour – by providing sufficient space, proper facilities and company of the animal's own kind and

5) freedom from fear and distress – by ensuring conditions which avoid mental suffering.

Transportation of live animals has been identified as one of the most controversially discussed topics in food-animal production as loading and unloading, poor handling, insufficient ventilation, poor driving performance, road conditions and insufficient supply of feed and water all reduce animal welfare (European Commission 1999; 2001a). Animal welfare is reduced when an animal has difficulties coping with environmental stressors (Broom and Johnson, 1993; Silanikove, 2000). A discussion about animal welfare and stressors is appropriate in this thesis because the motivation to assess the effect of micro-climate on cattle outcomes was initiated by the transportation industry and scientific community's welfare concerns. Humane transport advocates believe that first, industry needs to understand and quantify trailer micro-climate environment through sound science before solutions for animal welfare concerns can be addressed.

2.2.2 Measuring stress

Stress can be quantified by measuring biological indicators using a scientific approach (Ewing *et al*., 1997; Carenzi and Verga, 2007). Stress is a type of response or outcome which can be a result of negative animal welfare situations. Stress can be measured by comparing baseline measurements when the animal is not subjected to a stressor, to those measured when the animal is experiencing a stressful event (Broom, 1991). In addition, stress can be measured by clinical, physiological (heart rate, body temperature and respiration rate) behavioural, and biochemical (cortisol, catechaloamines, lactate, creatine kinase; European Commission, 2001a; Broom, 2003) methods, as well as health manifestations (shipping fever, lameness, chronicity; Duff and Galyean, 2007) and carcass parameters (shrink, bruising and dark cutters; Kreikemeier *et al*., 1998; Scanga *et al*., 1998). These measures provide an indication on whether the animal is coping with its environment (Broom, 1991).

2.2.3 Transportation related stressors

Safe and humane transportation of livestock is an important factor when it comes to the public perception of food animals. Negative outcomes during or due to transport can impact economics from international trade, food quality and consumer purchases (Harris, 2005). Animal welfare during transportation is significant as relocation of livestock is a known physical and psychological stressor (Tarrant, 1990; Ljungberg *et al.,* 2007). Stressors include disruption of daily patterns, mixing of unfamiliar animals, confinement and standing for long periods of time (Knowles *et al*., 1999; Warriss, 2004). Additional stressors include loud noises, unfamiliar sounds, smells, vibrations (Stevens and Camp, 1979) and lack of drainage and bedding within the transport trailer (CARC, 2001). Numerous stressors associated with transport have previously been identified and include rough animal handling (Grandin, 2001), poor driving techniques (González *et al*., 2012a), low or high loading density (Broom, 2003; OIE, 2004; González *et al*., 2012d), and feed and water withdrawal (Cole and Hutcheson, 1986; Aiken and Tabler, 2004; González *et al*., 2012b). Each of these unfavorable transport conditions will be elaborated on in the section below and feed and water withdrawal will be discussed in the shrink section.

Each transportation event requires handling of cattle that includes the assembly of cattle, sorting and loading onto the transport trailer and unloading at their final destination. The handling experience for cattle can be stressful due to factors such as unfamiliar smells, loud noises (Waynert *et al.,* 1999), confined areas, and inexperienced or insensitive handlers (Fisher *et al*, 1999; Grandin, 2001; Wikner *et al*., 2003; Hartung and Springorum, 2009). Signs of stress during handling include reluctance to move forward, freezing, running away, and vocalizations (European Commission, 2001a). Penetration of the cattle's flight zone can cause the animals to perceive humans as a threat, which may elicit a flight response. Poor and rough handling increases stress that can cause bruising, fragmented bones and reduced immunity (Hartung and Springorum, 2009). Additionally, a distressed animal can take up to 30 minutes for its heart rate to return to normal (Grandin, 1997). Studies have shown that the handling event for cattle can be more stressful than painful events such as branding (Schwartzkopf-Genswein, 1997) or the transit event itself (Booth-McLean *et al*., 2007). Good handling experiences during loading and unloading events are vital to ensure minimal stress during the transit (Grandin, 1997).

Driving quality can have a large impact on the well-being of animals during transit (Grandin, 1997; Wikner *et al*., 2003; Schwartzkopf-Genswein *et al.,* 2008). For example, poor driving performance can have a negative impact, including increased slips and falls caused by sudden jerks or abrupt stops during transit (Hartung and Springorum, 2009). Also, González *et al*. (2012c) reported that cattle transported by drivers with less than 6 years of livestock hauling experience had higher shrink than those cattle transported by drivers who had greater than 6 years of experience hauling livestock. Furthermore, drivers with less than 5 years experience were more likely to have a non-ambulatory or compromised animal during a transport event than those drivers who had greater than 5 years of experience (González *et al*., 2012c). Experienced livestock transport drivers tend to have smoother driving techniques and avoid hard braking and tight corners that increase the strain and fatigue cattle experience while maintaining their balance during transit (Knowles *et al*., 1999; Tarrant and Grandin 2000). Additionally, experienced drivers are often aware that minimizing stationary periods (Ellis and Ritter, 2006), parking in orientations that maximize airflow and seeking shade when possible provides greater cattle comfort during trips (Kettlewell *et al.*, 2005). Livestock transport drivers also have an important role in determining loading density.

Loading density is a multifaceted issue of importance when transporting livestock. Loading density is critical to maintaining good animal welfare during transportation (OIE, 2004; Broom and Fraser, 2007). Loading density refers to the space animals have available when placed in a compartment of a transport trailer and is measured as kg of body weight per m^2 or m^2 per animal (CARC, 2001). A beef animal weighing 583 kg (1300lbs) has a recommended maximum loading density of 425 kg/m^2 (87lbs/ft^2) and a minimum area per animal of 1.3 m^2 (15 ft^2) (CARC, 2001). Densities that are too low or too high can cause an increase in falling, injuries, bruising, mortality, cortisol levels and incidence of dark cutters (Tarrant *et al*., 1988; 1992; González *et al*., 2012c). Beatty (2005) reported that loading density on ships transporting cattle during summer months had a direct negative effect on heat stress in cattle. Loading densities above the maximum recommendations during hot and humid weather has the potential to have a substantial negative impact on the micro-climate within the trailer (Hartung and Springorum, 2009). When cattle are loaded past the maximum loading density recommendation additional metabolic heat is produced by cattle. The animals' physical body can block inlets and outlets for airflow. These factors contribute to heat accumulation inside the trailer, reduce the volume of air available for air exchange and require more air turnover to provide fresh air to animals (Purswell *et al*., 2006) and increase internal trailer temperatures. During hot weather, loading densities should be reduced (European Commission, 1999; EFSA, 2004). To prevent dangerous heat accumulation in livestock trailers, CARC (2001) recommends that loading densities should be reduced by 10% for cattle, 25% for hogs, 10-15% for horses and 15% for sheep during hot and humid conditions (CARC, 2001).

The cost of cattle transport is calculated as dollars per hundred weight for every kilometer ($/100 lbs/km) and therefore there is economic motivation to load animals as densely as possible (Schwartzkopf-Genswein *et al*., 2012). The role of balancing loading density and weight regulations while maximizing pay weight for cattle owners is often the responsibility of livestock transport drivers. The area of the compartment, the type, size and weight of the cattle, prevailing environmental conditions and the distance that cattle will be transported are important aspects of loading density (González *et al*., 2012c). Finally, drivers of commercial livestock transport vehicles need to ensure that cattle are equally distributed throughout the trailer to comply with government axle weight regulations. Monetary penalties, re-distribution of load or reducing number of animals can be a result of non-compliance (Government of Alberta Ministry of Transportation, 2012). González *et al*., (2012c) reported results from an industry benchmark survey indicating that finished cattle in AB were being transported within weight regulations and overall trailer loading density recommendations.

2.3 HEAT STRESS AND TRANSPORT

The thermal conditions that the animals are exposed to during transport are considered the greatest stressor to animals (Kettlewell *et al.,* 2005). The temperature of the environment can escalate the degree of stress animals are experiencing during the transport process. High temperatures in combination with high humidity are a special concern as it can be fatal (Hahn, 1999; Brown-Brandl *et al*., 2005a). When faced with environmental challenges, animals respond by eliciting a behavioural or physiological response to maintain homeostasis (Curtis, 1983). Behavioural responses to heat stress by cattle include moving away from their herd mates, seeking shade and consuming water (Curtis, 1983; Mader *et al.*, 2007). However, during transport, cattle are unable to respond to heat stress because they are confined on the trailer and water is not available during transit.

Heat stress is a complex biological process and environmental conditions, acclimation, and physiological response and capability all contribute to the thermal load experienced by animals. To gain understanding about heat stress and thermal load it is important to consider the quantification and environmental reference parameters for thermal load and the thermoregulatory responses of cattle and modes of heat flow that are the main principles of heat stress for cattle.

2.3.1 Quantification of thermal load

The thermal environment is a combination of many factors that play an important role in determining the environmental heat demand. Humidity plays a key role in heat transfer, which must be considered when characterizing a thermal environment. Relative humidity is the measure "of water vapour in moist but unsaturated air" (Albright 1990). Relative humidity is an important factor when considering heat stress for livestock and humans and can be experienced as mugginess or sauna-like conditions during summer months. Cattle are more susceptible to heat stress when high temperatures are paired with high relative humidity (Kettlewell and Moran, 1992). Psychrometric principles indicate that the air inside a livestock trailer can hold different amounts of moisture depending on the trailer temperature. When considering micro-climate for livestock during transport, relative humidity cannot be assessed independently from temperature. For this reason, the concept of a temperature humidity index has been widely used.

The temperature humidity index (THI) (Thom, 1959) was developed as an indicator of thermal stress in livestock (Hahn and Mader, 1997;). The THI is calculated using temperature (°C) and RH (%) (Thom, 1959). The Livestock Weather Hazard Index was adapted from the THI by categorizing ambient conditions as safe (THI < 74), alert (THI = 75 - 78), danger (THI = 79 - 83), and emergency stress (THI >84) (Whitter, 1993) as an indicator of discomfort cattle may experience from heat stress. Other researchers (Hahn, 1999; Gaughan *et al.*, 2008) have developed a modern THI equation to include the effects of black globe temperature, wind speed, night cooling, and hide colour as well as animal responses such as panting and respiration rate (Hahn *et al.*, 1997; Brown-Brandl *et al.,* 2006; Gaughan *et al.*, 2000b). However, the mentioned modern THI factors require expensive instruments and software to utilize and were out of scope for this research project. Therefore a simple THI was used as the indicator of heat stress.

2.3.2 Thermoregulatory responses of cattle

Bos Taurus cattle, like all mammals, are homeothermic, regulating body temperature to remain at a relatively constant level independent of environmental temperature. Homeothermic animals require a relatively constant body temperature over long periods but there are slight fluctuations on smaller scales of time as the animal makes adjustments to changes in ambient temperature (Curtis, 1983). Change in the heat content occurs in the body shell, which importantly serves as a thermal buffer for body temperature regulation by protecting the core from large changes in temperature. To maintain heat balance, cattle will physiologically, anatomically and behaviourally alter rates of production, gain or lose heat and storage of heat (Curtis, 1983). To maintain thermostasis, feedlot cattle will increase their respiratory rate by panting and through open-mouthed breathing, sweating and other behavioural responses including shade seeking, reduced feed intake, and increased water consumption (Curtis, 1983). As temperatures rise into the upper critical temperature range, the animal must use active heat-dissipating mechanisms (i.e. panting) that require considerable amounts of energy, which adds to the metabolic heat load (Curtis, 1983). At the stage where body temperature is slightly elevated, in an effort to maintain homeothermy, the animal may voluntarily reduce body activity to reduce heat production in response to heat stress. When temperatures rise above the upper critical temperature, the animals are at risk of death. At this stage core body temperature (CBT) rises uncontrollably in response to an increased metabolic rate and therefore an increase in heat production. This positive feedback sequence is referred to as spiralling hyperthermy which can lead to heat death by tissue hypoxia (Curtis, 1983).

The thermal neutral zone is the effective environmental temperature in which an animal can maintain homeothermy without using mechanisms to dissipate or conserve heat (EFSA, 2004). When an animal is experiencing one or more thermoregulatory processes necessary to dissipate heat it can be defined to be undergoing heat stress (Curtis, 1983). Cattle are exposed to extreme temperature fluctuations throughout the year. Heat stress vulnerability also depends on the acclimation of climatic conditions as well as individual coping mechanisms (Curtis, 1983). Cattle are more tolerant to cold temperatures than warm temperatures (European Commission, 1999) as they can tolerate (maintain homeothermy without using physiological mechanisms) ambient temperatures 60°C below their core body temperature ([38.6 - 60] = - 21.4°C) but can only withstand ambient temperatures 5°C above core body temperature (CBT) (Curtis, 1983). In Canada, it is not uncommon to have -45°C (80°C below CBT) in the winter however, there has not been research under controlled environmental conditions to assess the effects on CBT in beef cattle. Core body temperature can be used as an indicator of the status of the thermal neutral zone. If the core body temperature is above or below the normal temperature this could mean the animal is eliciting a homoeothermic response to environment. An increase of 1.5°C in CBT is referred to as hyperthermia while a decrease of 1.5°C CBT is referred to as hypothermia. When

CBT increases are greater than 4 - 5°C it is fatal, however, a drop of 5°C is not usually fatal but is a considerable physiological stressor (Kettlewell *et al*, 2005).

There are currently no quantifiable guidelines or recommendations for internal trailer micro-climate in Canada. According to the Health of Animals Regulation (SOR/95-85 section 143), it states that animals must be protected from exposure to the weather (Health of Animals Regulation, (C.R.C., c.296) but climatic ranges are not specified for trailer micro-climate or animal housing. In contrast, the EU has recommendations for animal housing and transport vehicles, declaring the lower critical temperatures to be -40°C and the upper critical temperature as 28°C for cattle (Wathes *et al*., 1983). The EU has also recommended that cattle should not be transported when the ambient temperature falls below 5°C, or rises above 30°C. When the ambient RH is above 80%, the maximum temperature to which cattle are to be exposed during transportation is reduced to 27°C (EFSA, 2004). It should be noted that these recommendations are for European transport trailers (See Appendix B2), which are significantly different from those in NA.

2.3.3 Modes of heat flow

Cattle have an internal thermal gradient; metabolic heat rises from the body core and flows outward to the cooler body surface, using conduction and circulatory convection (Curtis, 1983). Animals lose heat to and gain heat from the environment and energy transfers via radiation, convection and conduction. Heat can be lost by evaporation of water from the respiratory tract and skin surfaces (Curtis, 1983). In addition, some heat can be gained when water condenses on the hide. There are five means of heat flow: sensible, latent, radiation, conduction and convection that are important factors when considering heat load (Curtis, 1983).

Sensible forms of heat flow include radiation, convection and conduction. Furthermore, sensible forms of heat transfer are caused by temperature gradients. Solar radiation is the only form of heat flow that does not require a material medium to transfer energy. The absorptivity of solar radiation depends on sunlight angle and characteristics of the animal and environmental surfaces (Curtis, 1983). During conduction, heat is transferred through solids and fluids when a molecule with high vibrational and rotational motion transfers kinetic energy to a cooler molecule via collision. Animals lose heat by natural convection which is dependent on the animal surface area ratio (animal's surface geometry), air temperature gradient as well as air speed, air vapour pressure, posture and orientation to airflow (Curtis, 1983).

Latent forms of heat flow do not occur on a thermal gradient but occur along a vapour pressure gradient where the heat absorbed changes water from a liquid to vapour without causing the medium to change temperature. The heat does not disappear, but it is hidden or latent. Evaporation and condensation are latent forms of heat transfer (Curtis, 1983).

Heat is lost through evaporation of water from the skin surface and the respiratory tract and evaporative heat loss is correlated with air temperature, humidity and air movement. Heat exchanged from the respiratory tract or moist skin to the atmosphere moves across a pressure gradient when adjacent air contains less moisture (Beatty, 2005). Humid weather limits losses by evaporation as the vapour gradient of the atmosphere and the animal tissue is minimal. As temperature rises, cattle tend to pant and sweat as well as increase their respiratory rate to reduce heat load (Guaghan, *et al*., 2000). Cattle facing severe heat loads will pant with their tongue extended and are often seen with foam or drool expelled from their mouths (Mader *et al.,* 2007).

When an animal's micro-climate is cooler than its body surface, sensible heat is lost to the environment and the animal must generate more heat or gain heat to reach equilibrium (Curtis, 1983). As ambient temperatures rise, gradients become narrower and the rate of sensible heat loss declines. Under warm or hot ambient conditions, when the ability to lose sensible heat is diminished by a reduced temperature gradient, the animal must increasingly depend on evaporative heat loss, a process that depends on a vapour-pressure gradient and is relatively independent of temperature (Curtis, 1983). Animals have more control over evaporative heat loss than sensible heat exchange as animals have evolved mechanisms by which they can dissipate heat from their skin. This involves adjusting the rate of evaporation from their skin and upper respiratory tract by increasing breathing frequency and depth, and increasing the amount of water on the external surface by sweating (Curtis, 1983).

2.3.4 Environmental stressors during transport

Many stressors have been documented (Jarvis e*t al*., 1996; Hall and Bradshaw, 1998; Knowles, 1999; McGlone *et al.,* 1993) to compromise animal welfare during transit, but it is the thermal micro-climate within the trailer that poses the greatest risk to animal welfare (EFSA, 2004; Hartung and Springorum, 2009). Under extreme conditions, thermal effects can result in mortality (Kettlewell *et al*., 2005). Stressors that livestock face during transportation can lead to reduced health and welfare. These stressors include inadequate micro-climate from poor air velocity, air quality and ventilation (Hartung and Springorum, 2009). In addition, these stressors can be exacerbated by environmental conditions during transport (Hartung and Springorum, 2009) and include the accumulation of heat resulting from lack of airflow during stationary periods (Kettlewell *et al*., 2005), high ambient temperatures and humidity (Mader *et al*., 2006; Hahn, 1999) and direct and indirect solar radiation (Silanikove, 2000).

The greatest heat load experienced by cattle is during the summer months of July and August (Dewell, 2010). This period is also the time when the highest volumes of cattle are transported for slaughter (González *et al.*, 2009). Heat stress is quantifiable by thermal or heat load, for which there are several contributing risk factors. Cattle do not sweat effectively and rely primarily on respiration to cool themselves (Dewell, 2010). Climatic factors including solar radiation, dry bulb temperature, and humidity and wind speed (Gaughan *et al.,* 2008; Mader *et al.,* 2002; 2006) also contribute to heat load. Finished cattle tend to be more prone to heat stress disorders than lighter cattle because they have greater fat cover preventing them from regulating heat effectively because the fat cover acts as insulation (Dewell, 2010). Finished cattle are also fed high-energy diets that result in high rates of metabolic heat production (Brown-Brandl *et al*., 2006) that can increase the temperatures inside the trailer. Cattle also have the added effect of the rumen fermentation process, which generates additional heat that the cattle need to dissipate in order to maintain homeothermy during hot summer days (Dewell, 2010). Numerous hot days without sufficient night cooling can push cattle beyond their physiological ability to cope (Gaughan *et al.,* 2008) as it takes at least 6 hours to dissipate daily heat load (Dewell, 2010). This is of special concern, because it can be fatal to beef and dairy cattle (Mader *et al.,* 2006; Brown-Brandl *et al.,* 2006; Hahn, 1999). In an effort to reduce heat stress in feedlots, management practices include moving cattle away from wind breaks, increasing air flow in pens, providing shade and water misters and ensuring ample water supply (Mader *et al.*, 2007)

2.4 TRANSPORTATION INDUSTRY PRACTICES

2.4.1 Microclimate conditions within road transportation vehicles

A significant stressor during transport is the micro-climate the cattle are exposed to for the duration of the journey (European Commission, 1999). The environmental conditions that cattle are exposed to within the trailer during transport is called the micro-climate which is the cumulative effect of factors such as the temperature and humidity of the air, air velocity, air quality, ventilation and insulating properties of trailers' walls, floor and roof (EFSA, 2004). Methods used to describe micro-climate include THI (Mader *et al.,* 2006; Brown-Brandl *et al*., 2005b; West, 2003), ammonia (NH_3) concentrations, carbon dioxide (CO_2) concentrations (European Commission, 2001a) and carbon monoxide (CO) (Randall, 1993) concentrations. Micro-climate at the compartment level has not been characterized in cattle trailers in NA, but it has been characterized in trailers used to transport swine (Brown *et al*., 2011; Hayne *et al*., 2009) and poultry (Burlinguette *et al*., 2012; Knezacek *et al*., 2010) in Canada

2.4.2 Micro-climate: Ambient temperatures

During long-distance hauling a wide range of geographical terrain can be encountered including mountain ranges, desert, forests and water bodies all of which can affect the ambient temperature, humidity and climatic variation. Exposure to large temperature ranges over short transport durations does not allow enough time for livestock to acclimate, creating an environmental challenge for the animal. Acclimation to heat stress is a process that takes several days or even weeks as it requires a hormonal signal to affect target tissue in response to environmental stimuli (Johnson and VanJonack, 1976; Horowitz, 2001).

High ambient temperatures are an environmental stressor for cattle and are directly related to temperatures inside livestock trailers (Silanikove, 2000). Fluctuating and extreme temperatures can affect production, welfare and carcass quality, including the incidence of dark cutting beef (Warriss, 1990; Scanga *et al.,* 1998). Ambient temperatures in the north western US during the summer months were reported to be as high as 45°C (González *et al.,* 2012a). A recent cattle transport study found that one third of all journeys assessed occurred at temperatures greater than 30°C, and 68% of those journeys occurred between July and November (González *et al.,* 2012a). González *et al.* (2012c) reported cattle were more likely to become lame and/or non-ambulatory when the average ambient temperature was above 20°C and the incidence of mortality outcomes was greater when average ambient temperature was 35°C. Currently, there is no information on the effect of extreme ambient temperatures on the micro-climate inside NA livestock transport trailers. High ambient temperature during transportation can be speculated to exacerbate the impact of heat stress and thus reduce animal welfare (EFSA, 2004).

2.4.3 Transport duration

Transit duration directly influences the stress cattle are exposed to during transport. As transit duration increases, so does the potential risk of animals being unable to cope with multiple stressors such as fatigue, feed and water withdrawal and environmental conditions (Swanson and Morrow-Tesch, 2001). Positive animal welfare outcomes occur when transport durations are minimized during periods of time when temperatures exceed the upper critical temperature threshold. González *et al.* (2012c) also reported that the longer time cattle spent on a trailer the more likely they are to become lame and non-ambulatory and there is a sharp increase in the incidence of mortality when cattle were on the trailer for more than 30 h. The Health of Animals Act (S.O.R./91-525, s 148) states maximum allowable transport duration in Canada is 48 h but can be up to 52 h if they can reach their final destination during that time (Health of Animals Act, 2012). In contrast, the US regulation for maximum transport duration is 28 h (USDA Bureau of Animal Industry, 1873). Finally, in Europe, cattle being transported on a trailer without feed, water or environmental control can be transported for 14 h before stopping for a required 1-h resting period after which they can be transported for an additional 14 h (EFSA, 2004). Cattle transported in Europe on road with on-board feed and water stations have different regulations depending on the distance travelled, temperature and number of drivers (EFSA, 2004). In a recent Canadian study, González *et al.* (2012a) reported the average long-haul transport duration within and outside of AB was 16 h with a maximum of 45 h. The same study also found that only 4.7% of all cattle loads assessed were in transit for more than 30 h and that slaughter-weight cattle were able to cope with longer transport durations and greater ambient temperatures than feeders, calves and cull cows (González *et al.,* 2012a). In a similar study conducted in Ontario, it was found that 68% of transit durations were under 8 h, 15% were between 40 and 48 h, 11% were greater than 48 h and 3% of all loads were greater than 72 h (Thrower, 2009). Another transportation audit for slaughter cattle that was also conducted in Ontario indicated that 86% of transit durations were under 8 h; 9% were 8 - 16 h and only 0.2% of loads were over 48 h with average transit duration of 12 h (Warren *et al.,* 2010). Summaries of transport duration studies indicate that the majority of journeys are well under the 48-h transport time regulation.

2.4.4 Stationary periods

Long-distance transport (Knowles, 1995) and the amount of time cattle are on board a truck (González *et al.,* 2012a) have the potential to negatively impact animal welfare. The amount of time that cattle are confined on a trailer can be increased due to delays such as stopping for border crossings, mechanical breakdowns, adjustment of driving speed due to weather conditions, rest stops, and waiting to unload cattle at their final destination.

Thrower (2009) reported that in-transit delays for cattle transported in Ontario were on average 4 h long but also reached a maximum of 58 h. González *et al.* (2012a) reported that 89% of all long-haul journeys for cattle transported to and from AB experienced a delay. One delay that could have an important impact on well-being of the cattle during transportation is the border crossing delay. This delay was experienced in 77% of all loads assessed with an average delay length of 1.32 h, and with a maximum delay length of 15 h. In addition, rest-stop delays occurred in 28.2% of loads with an average of 2.9 h delay, and had a maximum of 15 h. Finally, unloading delays occurred in 48% of all loads with an average of 1.03 h delay, and a maximum of 12 h (González *et al.,* 2012a). In response to lengthy wait times at slaughter facilities, the American Meat Institute (AMI) indicated that arrival management processes to minimize wait times and unloading delays is critical for animal welfare. Waiting times can be due to lack of staff available, plant breakdowns, and emergencies. Efficient truck scheduling should have a steady flow of trucks to unload with minimal waiting and stationary periods (AMI, 2012). In summary, most long-distance journeys had more than one delay each trip. These delays may not be avoided and result in stationary periods.

All reported delays are inevitable and not only increase the amount of time on truck, but can also be one of the most dangerous periods during transit. When the tractor-trailer unit is stationary, there is accumulation of heat and noxious gases such as; ammonia, methane, carbon dioxide and monoxide (EFSA, 2004). When upper critical thresholds are reached for temperature, humidity and gaseous materials the incidence of animal mortality and reduced well-being is greater (Curtis, 1983; EFSA, 2004;). Dangerous gas levels and extreme micro-climate parameters can be prevented by air exchange through adequate ventilation (Albright, 1990).

During stationary events, heat and humidity can accumulate due to poor ventilation. There is a positive relationship between outside ambient temperature and the inside temperature of the trailer (Wikner *et al.,* 2003) meaning that the temperature is generally warmer inside a loaded trailer. In addition, temperatures are greater during stationary events than when the trailer is moving (Kettlewell, 2001; Wikner *et al.,* 2003). Goldhawk *et al.* (2010) reported that during an 11-minute stationary period, the trailer temperature was 2.4°C warmer than ambient temperature in AB. A Swedish study by Wikner *et al.* (2003) reported temperatures up to 6°C warmer inside the trailer than outside. According to the Livestock trucking guide extreme temperatures during transport can be detrimental and can cause death (Grandin, 2001). These extreme temperatures can result in hyperthermia and deaths if the animals cannot dissipate heat fast enough (Curtis, 1983; Hahn, 1999). Heat and gas accumulation can result from insufficient ventilation (Muirhead, 1983).

2.5 ANIMAL RESPONSES AND OUTCOMES RELATED TO TRANSPORT STRESS

There are many indicators of animal welfare and stress, which can be quantified as previously described. For research, it is beneficial that measurements are practical and economical. In addition, method and procedures used to collect animal data should be non-invasive, and stress to livestock should be minimized. Animal outcomes used in this study were shrink and CBT, which will be discussed in further detail below.

2.5.1 Shrink

Shrink is a practical measurement for industry and researchers that provides valuable information related to animal welfare and stress endured during commercial transit. Shrink is derived from the amount of live body weight lost during a transportation event and is regularly measured and recorded in the cattle industry. Shrink can be measured in one of two ways; a truck load of cattle are weighed pre and post transport over a ground scale in small groups, or over a truck scale where the unit is weighed empty (tare) and weighed with a full load (gross). Shrink can be calculated as the difference between animal weight at the beginning of the trip and the animal weight at the end of the trip, expressed as a percentage of the beginning animal weight. Shrink is an important economic factor in the sale of cattle (Camp *et al*., 1981; Coffey *et al*., 2001) and the range of shrink in the beef industry has been reported from < 1% to as high as 14% of the total body weight (Warris, 1990; Tarrant and Grandin, 2000; González *et al.,* 2012b). The AB beef industry generally uses an average "pencil" shrink of 4% and 4.5% for cattle shipped in the morning and afternoon, respectively. Greer *et al*. (2011) documented shrink by compartment during the summer transportation of finished beef cattle to be the greatest in the nose compartment, the lowest in the rear, with the remaining compartments being similar in shrinkage. Shrink and mean trailer THI were found to be positively correlated (Goldhawk *et al*., 2011). There is evidence that greater shrink is related to reduced performance and greater morbidity (Camp *et al.,* 1981; 1983) in addition to having a negative impact on animal welfare and profitability.

Shrink can vary by cattle type and condition. For example, feeder and cull cattle have been shown to lose more body weight than calves, while fat cattle tend to lose less than feeders

(González *et al.,* 2012d). Factors that affect shrink include transport duration, mean ambient temperature (González *et al.,* 2012d) and water and feed withdrawal (Cole and Hutcheson, 1986; Aiken and Tabler, 2004) as well as stress, physical exertion, and rough handling (Warris, 1990).

A common physiological effect of high heat load is increased shrink during transit (Cole and Hutcheson, 1986; Harman *et al.,* 1989). Water is a major component of body mass (75-81%), and shrink is the result of loss of gut fill (from defecation and urination) and respiratory exchange causing the evaporation of water (Yousef, 1983; Curtis, 1983). Electrolytes are lost by sweat, losing fluids and deprivation of water over long periods of time and these losses can contribute to tissue shrink, which in turn has negative effects on meat quality (Schaefer *et al*., 1997). Typically, finished beef cattle in ambient temperatures ranging from 26 to 32°C can consume between 55 L to 78 L of water daily (Cowbytes, Beef Ration Balancer, Version 4, 1999). The balance of water gain to loss is critical because water is required to maintain consistent body temperature (Warriss, 1990; Coffey, 2001; Beatty *et al.,* 2006). As ambient temperature increases, more body water is lost lending to the importance of hydration in times of high heat load (Yousef, 1983). High ambient temperatures paired with no access to water during transit can lead to dehydration and reduced welfare.

2.5.2 Core body temperature

Beef cattle are homeotherms and have relatively stable CBT that can range between 37.8°C and 39.2°C with an average temperature of 38.6°C (Merck's Veterinary Manual, 2008). During extreme ambient conditions beef cattle also have the ability to regulate and stabilize their CBT (Silanikove, 2000). Core body temperature fluctuations occur throughout the day and are related to activities such as eating and drinking, physical activity and status of estrus (Kyle *et al.,* 1998) Additionally, there are diurnal rhythms for internal body temperature that respond to changes in the thermal environment (Sparke *et al.,* 2001) and can vary from 1°C (Zhang *et al*., 1994) to 3°C (Silanikove, 2000) during temperature challenges. Core body temperature in cattle peaks 2 h after the peak ambient temperature peaks and it can take at least 6 h to dissipate daily heat load (Dewell, 2010).

Core body temperature is commonly used in commercial feedyards for detecting febrile animals needing medical intervention. Core body temperature has been used as an indicator of cattle comfort and health status and CBT has been measured to indicate the degree of stress and thermal loads that cattle are experiencing (Gaughan *et al*., 2000a; Mader *et al.,* 2002). Methods to measure CBT include rectal (Gaughan *et al*., 2000b) and tympanic temperature probes (Mader *et al*., 2007); implants within the peritoneal cavity (Beatty, 2006); and abdomen (Kamerman *et al*., 2001) and vaginal temperature monitoring implants for females (Bergen and Kennedy, 2000; Kyle *et al.*, 1998). Measurement of vaginal temperatures is a non-invasive technique used to measure CBT and has a high correlation to tympanic membrane temperature ($r = 0.77$) (Bergen and Kennedy, 2000). Vickers *et al*. (2010) also found that vaginal temperature was closely associated with rectal temperature and could capture diurnal changes in body temperature. Additionally, studies have shown a strong positive correlation between vaginal temperature and respiration rate, demonstrating a stress response to increased body temperature (Vickers *et al*., 2010). Vaginal temperature in beef and dairy cattle is a practical evaluation tool for heat-abatement treatment as Brouk *et al.* (2005) used vaginal temperature to determine the effectiveness of supplemental cooling fans during warm weather.

Several studies have investigated the response of CBT in controlled thermal environments (Mader *et al.,* 1999; Zhang *et al*., 1994); onboard transport ships (Beatty *et al*., 2006) and in natural environments (Robertshaw, 1985) for beef cattle. During commercial transport in Canada, CBT has been studied in poultry (Knezacek, 2010) and swine (Tamminga *et al.,* 2009). However, there are currently no published studies assessing the CBT of beef cattle during transit. There has been research conducted measuring CBT in preparation for transport. Booth-McLean *et al.* (2007) measured CBT pre-loading and at off-loading and reported CBT was 0.2°C higher at off-loading than at pre-loading. Tamminga *et al*. (2009) reported that when pigs were transported in pot belly trailers, their CBT was higher during stationary events than compared to in-transit and in-lairage events. Furthermore, during stationary events, the pigs transported in the top deck compartments were found to have higher CBT than the rest of the trailer (Tamminga *et al.,* 2009). Animal responses such as CBT are sensitive to the micro-climate within the compartment that the animal is loaded in during transit (Tamminga *et al.,* 2009; Knezacek, 2010)

2.6 TRAILER MICRO-CLIMATE CONTROL

Micro-climate control for agricultural buildings is a major field of study in engineering. It focuses on finding economical means to achieve animal comfort through heating, ventilation and air conditioning. However, environmental control for micro-climate in transport vehicles is not as common because designing environmental control systems is complex, as it involves interactions between biological systems and the thermal environment. The main goal of environmental control is to provide environmental balance for growth, production and the well-being of animals. In order to create a favorable balance, an understanding of physics, thermodynamics, mathematics through calculus, fluid mechanics, heat transfer, psychometrics, refrigeration, weather phenomena, control theory, and environmental biology is required (Albright, 1990). Ventilation has become a vital component for the building design process. There are many factors that influence internal trailer micro-climate as seen in Figure 2.2 and ventilation may play a key role in controlling trailer temperatures (Wikner *et al*., 2003).

Ventilation of livestock transport trailers in NA is natural and air flows in and out of livestock trailers through the openings along the sides and roof of the trailer. Forces that move air in a natural ventilation system work as a pressure differential from an area of high to low pressure (Turnbull and Huffman, 1987). When livestock trailers are stationary, any pressure variations around the trailer are minimized, and there is greatly reduced air exchange, leading to elevated concentrations of noxious gases, temperature and humidity (EFSA, 2004).

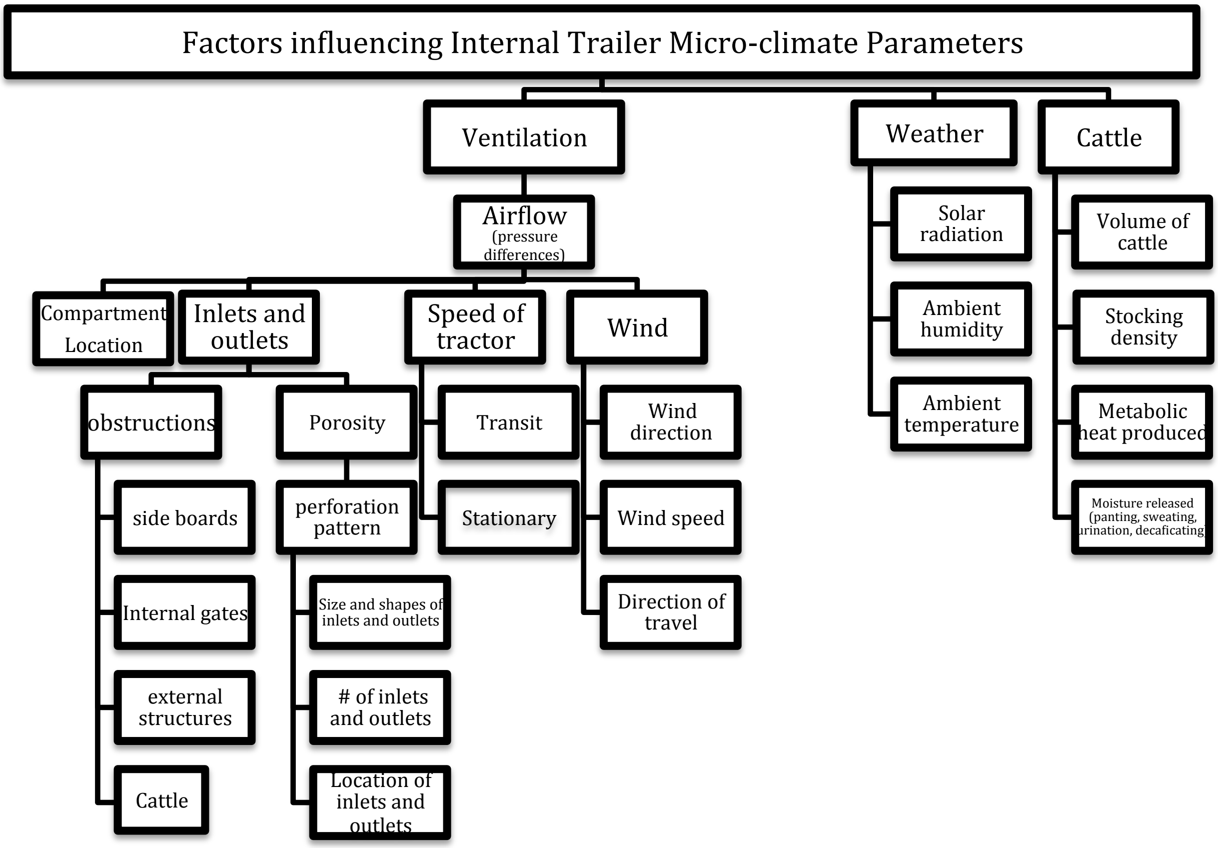


Figure 2.2 Factors influencing internal trailer micro-climate.

Currently, there are no mechanical ventilation designs for cattle trailers in NA, while Europe has many mechanical ventilation designs that utilize electrical fans (EFSA, 2004). Natural and mechanical ventilation systems operate under different principles. Each has a set of contrasting advantages, disadvantages and applications (Awbi, 1991; Li, 2007).

2.6.1 Ventilation

Ventilation is the process where air is exchanged and circulated within an environment in structures such as buildings, barns (Albright, 1990) and transport trailers (Kettlewell *et al.,* 2001). Ventilation can be measured in numerous ways and most methods require expensive instruments and analytical software. Methods to measure ventilation generally include the volume of air entering and leaving the building, barn or other structures and the speed or flow of air, direction of air, and air pressure. Measurement of air distribution and ventilation are difficult to study because air is invisible. Kettlewell *et al.* (2001) have reported that airflow is difficult to control during transport because of the turbulent flow and erratic movement of air. To understand air mixing patterns the placement of inlets, air infiltration, the effect of wind and static pressure, and placement of exhaust fans need to be considered. Air mixing should distribute fresh air uniformly, prevent drafts, and control airflow direction within animal housing (Albright, 1990).

2.6.2 Mechanical ventilation

Mechanical or forced ventilation uses fans and strategically placed inlets and outlets to meet required environmental conditions and can be achieved by negative, positive and neutral pressure methods (Albright, 1990). A properly designed ventilation system should meet the biological requirements of the animal by balancing sensible heat, moisture content and contaminant concentration. One of the major dangers of inadequate ventilation is the stress and disease that arises by high levels of humidity, noxious gases, aerosols and excessively high temperatures during warm weather conditions. Today, mechanical ventilation systems are designed with innovative sensors for temperature, moisture and CO_2 using controls that automatically readjust when needed by negative feedback systems. These highly developed mechanical ventilation systems provide a steady environmental state, but come at a greater cost (Albright, 1990).

2.6.3 Natural ventilation

Natural ventilation is also known as passive ventilation and is the airflow without the use of mechanical systems such as fans. Natural ventilation uses wind and temperature differences called thermal buoyancy (Heiselberg, 2004). Wind ventilation supplies air through openings in the trailer with a greater positive pressure on the windward side (side exposed to wind) and exhausts air on the leeward side (side not exposed to wind). Wind ventilation depends on wind speed and direction as well as size of the openings. Natural ventilation by thermal buoyancy uses air exchange with two or more zones with different air densities. This effect uses the difference in temperature and moisture content creating a pressure difference (Awbi, 1991; Li, 2007). Advantages of natural ventilation systems are that they are low capital and energy cost, non-polluting, easy to maintain and does not rely on a power source. Disadvantages of natural ventilation are poor air distribution, imprecise temperature control and wide temperature and RH fluctuations due to changing weather patterns (Albright, 1990). The effectiveness of natural ventilation is determined by prevailing weather conditions, micro-climate, building design and building use (Awbi, 1991; Li, 2007). Significant factors contributing to naturally ventilated trailers include: inlets and outlets, ground speed of the tractor and prevailing wind speed.

2.6.4 Ventilation in transportation trailers

Ventilation is a key element for good animal welfare practices during transit and facilitates air exchange (Wikner *et al*, 2003). Ventilation is essential for diluting and removing air contaminates and providing fresh air for livestock. Animals add moisture to the trailer environment through urination and defecation as well as sweating and panting and therefore the trailer environment is typically more humid than the ambient humidity (Kettlewell *et al.,* 2001). Ventilation and air exchange within the trailer are imperative to remove heat and moisture that can accumulate during transport (Kettlewell *et al.,* 2001). If heat and moisture build up and are not removed, the temperature will become greater inside the trailer than outside the trailer (Kettlewell *et al.*, 2005).

Muirhead (1983) conducted one of the few studies on airflow in NA livestock trailers using wind tunnel tests, and the tests indicated that there was limited, or no airflow inside tandem trailers. Purswell *et al.* (2006) also found little air exchange in horse trailers when horses were absent or when horses were present. The aerodynamics of livestock vehicles illustrates airflow moves from the back of the trailer to the front (Kettlewell, 2001). High temperatures and humidity have been found directly behind the cabin of the truck as a result of decreased airflow from a neutral pressure system behind the truck (Kettlewell, 2001). Poultry are often transported in two adjoining trailers in Canada known as B-trains. Burlinguette *et al*. (2011) concluded that air entered from the back (of the trailer closest to the tractor) of a poultry transport B-trailer and moved to the front, however, they reported the opposite temperature distributions in the rear trailer and proposed that air entered through the front and exited through the back. This phenomenon was also supported by Hoxey *et al*. (1996) and Baker *et al*. (1996). Such trends in direction of airflow during transit were suggested to be due to the differential air pressures surrounding commercial transport vehicles as the pressure envelope around moving vehicles was affected by vehicle length and shape (Götz, 1987). Further research is needed to determine rate and direction of airflow in commercial transport trailers in NA. Although measuring airflow was out of the scope for this research project the direct relationship to micro-climate parameters is directly influenced by airflow inside trailer.

2.6.5 Compartment effect on trailer micro-climate

It has been recognized that there is a relationship between compartment location and trailer micro-climate. European transportation studies (Christensen and Barton-Gade, 1999; Kettlewell *et al*., 2001; Fiore *et al.,* 2009) and Canadian studies (Hayne *et al.,* 2009; Brown *et al*., 2011; Correa *et al*., 2013; Fox, 2013) with pigs reported that there was a clear effect of compartment location on micro-climate and welfare parameters such as core body temperature. Regardless of the species, the front compartment (nose) that is located behind the cab of the tractor tends to have greater temperatures (Kettlewell *et al.,* 2001; Brown *et al.,* 2011) and THI (Stanford *et al*., 2011;Fox, 2013) which can result in greater heat load for livestock during transit. In addition, Stanford *et al*. (2011) found that the nose compartment had the greatest THI value followed by the upper compartments, where deck/doghouse and belly/rear had lower values which, is also in agreement with Christensen and Barton-Gade (1996) and Fiore *et al.* (2009).

2.6.6 Trailer porosity effect on trailer micro-climate

Ventilation in NA livestock trailers is supplied by inlets and outlets on the sides of the trailer. There are various sizes and shapes of openings throughout the trailer. Merritt and Wilson trailers are the most common type of commercial livestock trailers in AB and are designed with different air inlets or perforation patterns (Figure 2.3). Merritt trailers have a punch hole perforation pattern consisting of one large oval (11.2 X 15.2 cm) and multiple rows of 3 circular holes (radius -3.8 cm). Wilson trailers have a Duffy perforation pattern consisting of one large oval (11.2 X 15.2 cm) and multiple rows of two small ovals (5.1 X 7.6 cm). Perforation patterns on trailers can differ by compartment, trucking company and type of trailer. The portion of the trailer wall that is open for ventilation is quantified as the porosity. Trailer porosity is calculated by dividing the area of the ventilation openings by the total area of the trailer surface.

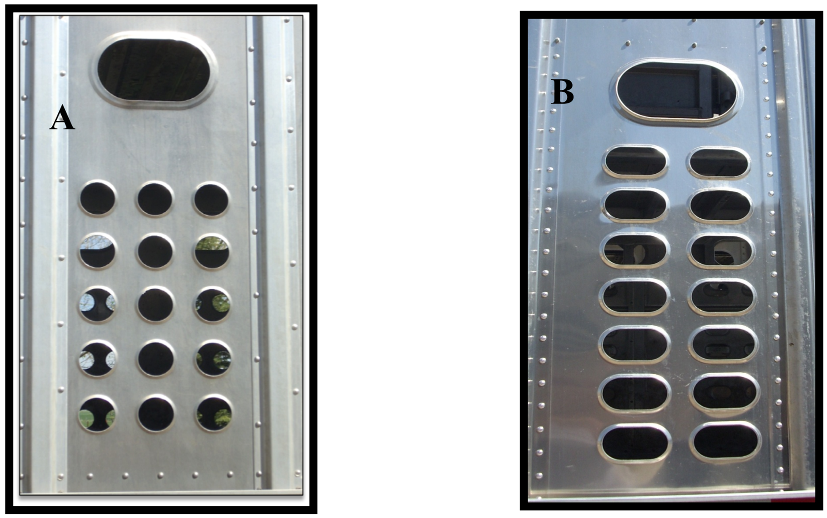


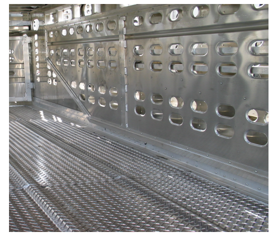
Figure 2.3 Examples of Punch Hole (A) and Duffy (B) perforation patterns on cattle transport trailers

The porosity of trailer walls can differ depending upon the species being transported and company that manufactures the trailer. In swine transport, there can be two layers of pigs in the nose and three layers in the middle portion of the trailer and there is generally more porosity in hog trailers. Trailers can be manufactured according to a customer's request and can include rear vents, nose vents or roof hatches. Most hog trailers have vents in the front of the nose compartment and the back of the rear compartment. These vents are absent from trailers manufactured specifically for cattle. The back of the trailer in cattle trailers can have porosity ranging from 0 to 4%. Additional holes in the back of the trailer can increase the porosity of the rear compartment by 9%. The front of the nose compartment in cattle trailers is usually solid (0% porosity) and adding nose vents can increase nose compartment porosity by 15%. Roof hatches provide additional ventilation however; many livestock trailers do not have this option. Each roof hatch can add up to 1% porosity to the compartment, and some trailers have a maximum of 4 roof hatches.

2.6.7 Inlet and outlet obstructions

The porosity of the trailer is important for ventilation and airflow. Obstructions to the openings in the trailer can hamper airflow by creating an impenetrable barrier; these include parking next to buildings and other cattle liners during stationary events and by internal gates laying flat against the sidewall of the trailer (Table 2.1).

Table 2.1 Internal trailer obstructions of airflow in cattle liners

Compartment	
Rear Loading ramp blocks the passenger side perforations	 
Doghouse Floor of doghouse blocks perforations from drivers side Entrance gate can be also solid	 
Belly and deck Internal gates when not in use obstruct side perforations	
Nose The internal gate from the nose to the deck compartment	
Back door of trailer Some trailers have few perforations at the rear. Right: Outside view Left: Inside view (note: trailer does not have doghouse compartment)	 

There are some management practices that also obstruct airflow by blocking the inlets and outlets. For example, hog trailers use side boarding or panels on trailers for cool weather to protect the hogs during transit. Side boarding can reduce porosity for each compartment and is effective for climate control for pigs when used properly.

Sideboards are not a general practice for cattle and González *et al.* (2012a) reported no use of sideboards for cattle transported in western Canada. However, Thrower (2009) reported that during the winter, 258 loads were transported with 0% sideboards; 32 loads with 1 to 25% sideboards; 67 loads with 26-50% sideboards and 2 loads with 51-75% boards and only 1 load with 1-25% sideboards during the summer months in Ontario. Further, an audit of transport conditions for slaughter cattle in Ontario found that during summer months 79% of trailers did not have side boarding yet 14% had 76 -100% blocked. During spring, 66% of trailers did not have sideboards but 16 % were 76-100% blocked indicating no or little ventilation (Warren *et al.*, 2011).

Because most hog trailers are also suitable for hauling cattle, it can be common to haul one species one direction and haul another species back to the original location. On occasion, large feedlots receive cattle in hog trailers with sideboards present at ambient temperatures of 10°C (Figure 2.4). Some feedlots in southern AB have policies stating that cattle will not be accepted in trailers with side boarding. Hogs and cattle are acclimated to different environments where hogs are housed in climate-controlled buildings and cattle are housed outdoors with exposure to all climatic conditions. These practices of cross species hauling without adjusting porosity for species has the potential to reduce airflow inside the trailer and could result in negative health and welfare outcomes.

Figure 2.4 Livestock trailer transporting cattle to a feedlot in Alberta with winter boards (weather conditions were +10°C). Side porosity 8.53% (Nose 8.8%; Deck 8.9%; Belly 5.8%; Doghouse 12.8%; Rear 8.23%).

Management practices that restrict airflow through side-wall perforations can easily be altered by removing side boarding or parking to maximize airflow, however, when trailers are manufactured with low porosity they cannot be easily altered to accommodate more holes after market. There are some companies that order trailers with low porosity or obstruct holes to prevent manure from soiling the sides of the trailer or road (Figure 2.5). The compartment porosity on these trailers can be as low as 1.9%. The belief is that trailers with low porosity would have restricted airflow compared with high-porosity trailers potentially leading to the accumulation of heat and moisture inside the trailer which could have negative effects on animal health and welfare particularly during the summer months.

Figure 2.5 Cattle Livestock trailer with an overall porosity of 4.7%. (Nose 2.4%; Deck 3.6%; Belly 8.0%; Doghouse 1.9%; Rear 3.4%)

3.0 OBJECTIVES

The main objective of this thesis was to determine the effect of livestock trailer porosity on the micro-climate within the trailer during summer long-haul transport. It is hypothesized that the compartment and trailer porosity will have an effect on trailer temperature and moisture conditions. This objective was investigated in further detail by examining a stationary event and warmest in-transit hour.

The second objective of this thesis was to determine the effects of trailer compartment location and trailer porosity on live weight loss (shrink) in slaughter weight beef cattle during summer long-haul transport. It is hypothesized that cattle within compartments with a warmer/more humid micro-climate would have greater shrink than those transported in cooler/less humid compartments.

The third objective was to determine if the transportation status (stationary or in-transit) had an effect on CBT. It is hypothesized that if the cattle are exposed to a transportation event where cattle are experiencing heat stress and can no longer balance their homeostatic state, this may result in an increase of CBT.

The fourth objective of this research was to compare temperature values at animal and ceiling level within an in-transit trailer. It is hypothesized that temperatures at animal level will be greater than at the trailer ceiling. Another objective was to determine if the trailer micro-climate readings were affected by data logger position within the trailer.

The final objective of this thesis was to characterize the thermal environment that cattle can be exposed to during transport in North America during summer months.

4.0 MATERIALS AND METHODS

The experimental procedures of this study were approved by the Animal Research Ethics Board of the University Committee on Animal Care and Supply at the University of Saskatchewan and the Agriculture and Agri- Food Canada (Lethbridge Research Centre) Animal Care and Use Committee according to animal care protocol ACC#0826 (Canadian Council on Animal Care, 1993).

4.1 Animals

Four hundred fifty-two mixed breed heifers (BW= 619 ± 22 kg) were transported from a feedlot (50º11'N, 112º25'W elevation 700 m) located in southern Alberta to a commercial slaughter plant. Heifers were under 20 mo. of age and originated from various ranch sources in western Canada and were housed and fed in the same commercial feedlot for 9 mo. prior to the start of the study. All cattle were fed a diet to meet or exceed NRC (2000) nutrient requirements. All cattle had *ad libitum* access to feed and water until the time they were removed from their home pen for loading.

Seven days prior to departure (D-7), heifers were handled through a chute to prepare veterinary export documents required to transport the cattle across the Canada/US border. A subset of focal heifers (8 to 11 per load) were randomly selected and handled one additional time, one day prior to transport (D-1) to fit the heifers with temperature data collection devices (Table 4.1). Core body temperature was measured continually in all focal heifers using a temperature logger (model DS1922, Dallas Semiconductor Corp., Dallas, Texas, USA 75244; dimension: 1.63 × 0.63 cm) affixed to an intra-vaginal device. Another temperature logger was attached to an ear tag to allow determination of temperature gradients between the ceiling of the trailer and animal level, as illustrated in Figure 4.1. Core body temperature monitoring devices were inserted into the vagina of each focal heifer by an experienced veterinarian 24 h prior to departing for transport (Figure 4.2). Focal heifers were kept separate from non-focal animals until the day of transport to reduce handling stress. On the day of transport, focal heifers were randomly assigned to a compartment in the trailer and mixed with non-focal animals. Both intra-vaginal and ear tag temperature loggers were set to record at 2-min intervals. The vaginal loggers were set to record for 24 h prior to transport to capture baseline CBT data on all focal heifers.

All temperature (T) and relative humidity (RH) data loggers were retrieved from the heifers after exsanguination. A summary of transportation events is presented in Table 4.2. On arrival at the slaughter plant, each compartment of cattle was weighed separately and each load of cattle remained in a single lairage pen for an average of 12 h prior to processing.

Figure 4.1 Temperature and relative humidity data logger (I-button) attached to the ear tag of a focal animal

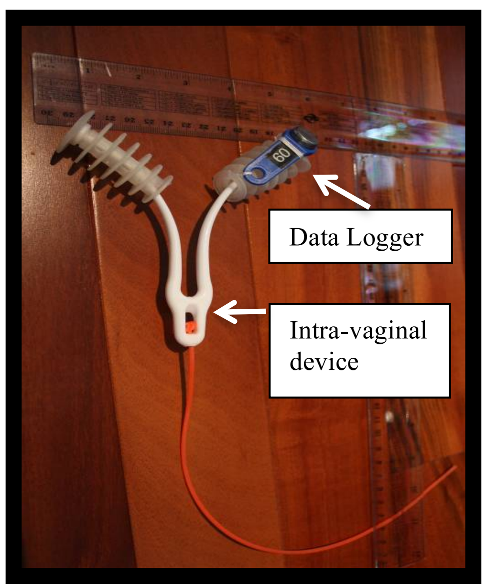


Figure 4.2 Intra-vaginal device with temperature data logger (I-button) used to collect core body temperature on focal animals.

Table 4.1 Distribution of focal animals by trip, trailer and compartment

Trip	Overall Trailer Porosity (%)	Number of head	Rear	Belly	Deck	Doghouse	Nose	Total Number of Focal animals
1	A (8.7P)	46	3	3	3	1	1	11
1	B (9.6P)	46	3	3	3	1	1	11
2	A (8.7P)	45	3	3	3	1	1	11
2	B (9.6P)	45	3	3	3	1	1	11
3	A (8.7P)	46	3	2	2	1	1	11
3	B (9.6P)	46	3	2	2	1	1	11
4	A (8.7P)	45	3	2	2	1	1	9
4	B (9.6P)	45	2	2	2	1	1	8
5	A (8.7P)	44	3	3	3	1	1	11
5	B (9.6P)	44	3	3	3	1	1	11

Table 4.2 Animal handling and data collection timelines relative to transportation events.

Time relative to Departure	Timeline and events
D-7 d	All heifers to be transported were handled through a processing chute in preparation for export. Focal heifers (11 per load) were randomly selected and penned separately from the larger group.
D-2 d	Insertion of intra-vaginal core body temperature data loggers into focal animals.
D-1.5 h	All heifers were randomly allocated to 1 of 2 trailer porosity treatments.
D- 1 h	Heifers were handled and loaded on to trucks.
D-0.5 h	Body weight was captured by compartment over legal truck scale.
0 (D)	Transportation starts.
D + 0 to 5 h	Morning transit event.
D +5 to 5.5 h	United States / Canada border crossing. Stationary event.
D + 6 to 10 h	Afternoon transit event.
D + 11 to 12 h	Warmest in-transit event.
D + 12.5 to 14 h	Heifers unloaded at destination slaughter plant. Body weight was collected by compartment over ground scale and heifers were penned at the slaughter plant by truckload.
D + 14 to 24 h	Lairage event. Heifers were penned by truckload and water was available.
D + 24 to 26 h	Exsanguination of heifers and collection of data logger.

4.2 Cattle and transportation procedures

There were 5-paired loads for each trailer treatment, which resulted in 10 trips in total. The same two truck drivers carried out all cattle loading procedures throughout the study with the same truck and trailer combination. Drivers were selected for their careful driving style and experience (>11 yr) to minimize the effects of driving style and handling on animal outcomes. Cattle loading at the feedlot took place between 0830 and 0900 h with unloading of cattle at the plant taking place between 19:00 and 21:00 h depending on delays (border inspection and construction). Cattle were transported 1 or 2 d per week for 5 wk (Trip 1, August 14; Trip 2; August 21; Trip 3, August 26; Trip 4, and August 28; Trip 5 September 3) depending on cattle availability. The standardized handling procedure consisted of moving compartment herd mates in groups onto the trailers using low-stress handling. Heifers were loaded at an industry standard density of 224 – 476 kg/m^2. Heifers were sorted into loads containing 44 to 46 head. Each compartment was loaded according to the loading schedule (Table 4.3) and loading density (Table 4.4). At the time when the tractor-trailer unit arrived at the Canada/US border crossing, the fourth axel of the quad trailer (at the back of trailer) was engaged. This event coincides with a redistribution of the animal weight in the trailer being redistributed to the rear of the trailer. This was achieved by moving 1 to 3 head of cattle from the deck to the doghouse as seen in Tables 4.3 and 4.4.

Cattle were transported a distance of approximately 940 km to a commercial plant, a journey that took approximately 12.5 to 14 h. Each load of cattle transported originated from the same feedlot with their final destination being the same packing plant. The transport route included travel on primary highways through prairie, mountain ranges and desert. All 10 trailer loads of cattle were unloaded using low stress handling without electric prods. No bedding was used in any of the trailers. Cattle did not have access to feed and water during transport. Cattle were unloaded and weighed by compartment before moving to lairage pens at the packing plant which contained water troughs.

Table 4.3 Number of cattle per trailer compartment before and after crossing the Canada/US border.

Trip	Overall Trailer Porosity (%)	# of head	Rear	Belly	Deck Canada	DH[1] Canada	# of head moved	Deck USA	DH[1] USA	Nose
1	A (8.7P)	46	10	13	14	4	2	12	6	5
1	B (9.6P)	46	10	13	14	4	0	14	4	5
2	A (8.7P)	45	10	12	14	4	3	11	7	5
2	B (9.6P)	45	10	12	14	4	3	11	7	5
3	A (8.7P)	46	10	13	14	4	3	11	7	5
3	B (9.6P)	46	10	13	14	4	2	12	6	5
4	A (8.7P)	45	10	13	13	4	3	10	7	5
4	B (9.6P)	45	10	13	13	4	2	11	6	5
5	A (8.7P)	44	10	12	13	4	3	10	7	5
5	B (9.6P)	44	10	12	13	4	2	11	6	5

[1]*Doghouse*

Table 4.4 Loading density by compartment before and after crossing the Canada/US border.

Trip	Overall Trailer Porosity (%)	# of head	Rear kg/m^2	Belly kg/m^2	Deck Canada kg/m^2	DH[1] Canada kg/m^2	# of head moved	Deck USA kg/m^2	DH[1] USA kg/m^2	Nose kg/m^2
1	A (8.7P)	46	404.8	422.7	466.2	239.6	2	377.0	333.0	353.1
1	B (9.7P)	46	407.7	418.5	457.4	224.6	0	457.4	224.6	381.2
2	A (8.7P)	45	415.4	425.3	444.0	295.8	3	332.9	393.1	399.9
2	B (9.6P)	45	432.6	439.9	476.9	283.2	3	390.9	330.0	403.2
3	A (8.7P)	46	415.4	425.3	444.0	236.1	3	332.9	393.1	391.7
3	B (9.6P)	46	432.6	439.9	476.9	240.1	2	390.9	330.0	399.8
4	A (8.7P)	45	418.5	420.3	441.5	245.6	3	323.8	407.8	435.0
4	B (9.6P)	45	128.0	442.3	452.1	225.4	2	371.5	323.1	407.9
5	A (8.7P)	44	.	430.2	464.4	243.0	3	347.2	403.0	411.4
5	B (9.6P)	44	415.1	417.5	457.0	247.4	2	373.7	344.3	425.3

[1]*Doghouse*

4.3 Description of trailer types

A Merritt quad axle trailer (2008, Cattledrive quad, Merritt Equipment Co., Henderson, CO, United States 80640) pulled by a 2004 Western Star 4950 tractor (Figure 4.3) and a Wilson quad axle trailer (2008, Silver Star, Wilson trailer company, Sioux City, Iowa 51116) pulled by a 2004 International, 9400 tractor (Figure 4.4) were used in the study. Tractor – trailer specifications are found in Table 4.5. Both trailers were constructed of aluminium with punched perforation patterns on their sides varying in size and configuration and resulting in different porosities. The Merritt trailer had an estimated overall porosity of 8.7% while the Wilson trailer had an estimated porosity of 9.6%, however, there were also differences in porosity amongst compartments within each trailer (Table 4.6). Trailer B had slightly greater porosity (difference of 0.07 and 0.05 %) in the nose and belly compartments when compared to Trailer A. Trailer A also had 5.8% less porosity in the rear compartment. Trailer A had 0.5% greater porosity in the doghouse and 2% more in the deck. Porosity calculations are presented in Appendix A. The basic design and construction of the two trailer types were similar with approximately the same floor space (Table 4.7). Trailer B had 2 roof hatches in the deck compartment (0.71×0.61 m) and Trailer A had 3 roof hatches in the deck and 1 in the doghouse (0.73×0.61 m) yielding 4 roof hatches. The air volumes for each compartment for Trailers A and B are presented in Table 4.8.

Figure 4.3 Trailer Type A used in the study with a perforation pattern yielding 8.7% porosity.

Figure 4.4 Trailer Type B used in the study with a perforation pattern yielding 9.6 % porosity.

Table 4.5 Tractor-trailer specifications[1]

Trailer	A	B
Axel	Quad	Quad
Year	2008	2008
Tractor	Western star	International
Tare weight	16330-17690 kg	17011-17690 kg
Gross (max) Canada	46500 kg	46500 kg
Gross (max) USA	44900kg	44900 kg
Flooring	aluminium	aluminium
Number of Decks	2	2
Ventilation	Natural	Natural
Perforation Pattern	Punch hole	Duffy
Number of compartments	5	5
Trailer Width	2.55 m	2.53 m
Trailer Length	16.2 m	16.2 m
Roof Hatches	4	2
Size of roof hatch	0.61x0.73m	0.61x0.71m

[1]Additional trailer dimensions found in Appendix B

Table 4.6 Comparison of compartment porosity between Trailers A and B (side porosity + front + rear + roof)

	Compartment					
Trailer	Overall (%)	Rear (%)	Belly (%)	Deck[1] (%)	Doghouse[2] (%)	Nose[3] (%)
A	8.7	9.70	10.67	8.51	7.43	4.47
B	9.6	15.50	10.82	6.48	6.97	4.55
Difference	0.9	-5.80	-0.05	+2.02	+0.46	-0.07

[1] Deck= sides + roof

[2]Doghouse = sides + roof + rear of trailer

[3]Nose = front + sides + roof

Table 4.7 Comparison of floor space between Trailers A and B

	Compartment			
Trailer	Rear (m^2)	Belly/Deck (m^2)	¾ Doghouse (m^2)	Nose (m^2)
A	14.40	18.20	11.37	7.67
B	14.41	18.41	11.02	7.74
Difference	0.01	.21	0.65	0.07

Table 4.8 Air volume by number of animals per compartment for Trailers A and B

Compartment[1]	# of Head	Air volume per animal (m^3/animal)
Doghouse	7	2.13
Deck	14	2.21
Rear	11	2.27
Belly	13	2.31
Deck	13	2.38
Doghouse	6	2.50
Belly	12	2.50
Deck	12	2.58
Deck	11	2.82
Doghouse	4	3.74
Nose	5	4.00

[1]Trailers A and B had the same air volume space when values were rounded to 2 decimal places

4.4 Micro-climate data

Internal trailer temperature ($T_{trailer}$ °C) and relative humidity ($RH_{trailer}$%) were recorded using 43 data loggers (model DS1923, Dallas Semiconductor Corp., Dallas, Texas, USA 75244) having a temperature range of -20 to +85°C, with an accuracy of ± 0.5°C and an RH range of 0 to 100% with a sensitivity of ± 0.6%. In each compartment, loggers were affixed to a piece of wood (0.02 × 0.02 m) that was fastened to the I-beams located on the ceiling of each trailer compartment. Data loggers were situated so that they would not come into contact with the animals or ceiling and were hung 6 cm from the ceiling. The nose was fitted with loggers to replicate the same ceiling height as the deck and belly compartments. The number of data loggers per compartment was kept constant within and between all trailers. Consequently, 5 data loggers were placed in the nose, 11 in each of the belly and deck, and 8 in each of the rear and doghouse (Table 4.9). Data loggers were positioned in three parallel planes; driver (left-hand side when viewed from the rear), middle and passenger (right-hand side when viewed from the rear) which are shown in Table 4.10. The locations of data loggers remained constant for each journey and were not removed for the duration of the study. An additional 2 data loggers (enclosed within plastic mesh cylinders to allow air flow but covered sufficiently to control for the effects of solar radiation) were affixed to the outside of the cabin of the truck on both side mirrors to monitor ambient temperature ($T_{ambient}$ °C) and ambient relative humidity ($RH_{ambient}$%) during each journey (Figure 4.5). When the trailer was cleaned, data loggers were avoided by only washing floors or the exterior of the truck to prevent data logger exposure to moisture. Each logger was set to record micro-climate parameters at 1-min intervals for each journey. Data were downloaded (Thermodata 3 version 3.1.4, Embedded Data Systems, Lawrenceburg, Kentucky, USA 40342) immediately after the journey and exported to an Excel spreadsheet (Microsoft Office Excel, Microsoft Corporation, Redmond, WA). Throughout each journey, trailer location was recorded using a global positioning system device (GPS; Q- Starz BT- Q 1100 P Platinum, Qstarz International Co., Ltd, Ming Chuan, Taiwan) affixed to each tractor-trailer unit. Computers and temperature/RH loggers were synchronized after each journey to ensure precise time coordination. GPS data were used to categorize each transport event by a time stamp and then all logger data were matched to these times.

Figure 4.5 Data logger affixed to tractor mirrors to measure ambient conditions. The insert shows the protective plastic mesh case covering the data logger to reduce solar effects on micro-climate measures

Table 4.9 Number and location of loggers used per trailer compartment

	Compartment					
	Rear	Belly	Deck	Doghouse	Nose	Truck Mirrors
Floor space (m^2)	14.41	18.41	18.41	11.02	7.41	-
Number of data loggers	8	11	11	8	5	2
Area per sensor (m^2/data logger)	1.8	1.67	1.67	1.38	1.55	-

Table 4.10 Data logger location by compartment and by plane

Plane	Driver's (left-hand) side	Middle	Passenger's (right-hand) side
Distance horizontally from left-hand side wall (m)	0.15	1.26	2.36
Distance rearward from the front of trailer			
Nose (5 data loggers)	0.6m 2.4m	1.5m	0.6m 2.4m
Deck (11 data loggers) Belly (11 data Loggers) * same placement	3.7m 5.5m 7.0m 9.5m	4.6m 6.1m 7.6m	3.7m 5.5m 7.0m 9.5m
Rear (8 data Loggers) Doghouse (8 data loggers) *Same placement	11.7m 12.8m 15.6m	11.6m 13.7m	11.7m 12.8m 15.6m

4.5 Transportation events

Stationary Event: This event was defined as when the tractor-trailer unit was stopped at the Canada/US border for a minimum of 20 min between 1200 and 1400 h. Data used to identify a stationary event were obtained from the GPS unit on each truck. When the speed of the tractor-trailer unit was < 9 km/h it was considered "stationary". Concurrent stationary events that were less than 5 min apart were merged together as one event. The border crossing was the only stationary event used for analysis because it occurred consistently across all trips. Some trips had wait times to unload at the plant or rest stops while other trips did not. Each stationary event was not marked by a time factor because most events were less than an hour.

Warmest in-transit hour: This event was defined as a 1-h event when the trailer temperatures were the greatest when the tractor-trailer unit was in-transit. Greatest ambient temperature was determined to occur between 1700 and 1800 however, there were road construction delays that resulted in stationary periods during this hour during numerous trips. As a result the warmest in-transit hour was determined to be between 1800 and 1900 h.

The stationary event and warmest in-transit hour were analysed separately as the hour of the day was statistically significant ($P < 0.0001$). All event times were also confirmed with a driver's log.

4.6 STATISTICAL ANALYSIS

4.6.1 Micro-climate data

There were 6 micro-climate parameters (dependent variables) used in the analysis for each event using 1 min intervals:

1. $T_{(trailer)}$ °C: average internal trailer temperature,
2. $RH_{(trailer)}$%: average internal trailer relative humidity and
3. $THI_{(trailer)}$: average internal trailer THI, where

temperature humidity index (THI) was calculated according to (Thom, 1959). Specifically

$$THI= (1.8\times T+32) - ((0.55-0.0055\times RH) \times (1.8\times T-26)) \quad (4.1)$$

where: T = temperature(°C),

RH = relative humidity(%) and THI is unit less.

To investigate the relationship between the ambient conditions and the internal micro-climate, the difference (delta; Δ) between the two was used to describe the change between the external and internal parameters; variables including ΔT ºC, ΔRH%, ΔTHI were calculated as:

4. $\Delta T^{o}C$ = average internal T ($T_{(trailer)}{}^{\circ}C$) – lowest ambient T ($T_{(ambient)}{}^{\circ}C$),
5. $\Delta RH\%$ = average internal RH ($RH_{(trailer)}\%$) – lowest ambient RH ($RH_{(ambient)}\%$) and
6. ΔTHI = average internal THI ($THI_{(trailer)}$) – lowest THI ($THI_{(ambient)}$)

Positive (+) Δ values indicated that the internal variables ($T_{(trailer)}{}^{\circ}C$, $RH_{(trailer)}\%$, and $THI_{(trailer)}$) were greater than ambient conditions while a negative (-) Δ value indicated that the internal variables were lower than ambient conditions. Before analysis, all invalid data points were removed. Micro-climate $T_{(ambient)}{}^{\circ}C$ and $T_{(trailer)}{}^{\circ}C$ data were considered invalid if the recorded temperature ($T_{(trailer)}{}^{\circ}C$ and $T_{ambient}{}^{\circ}C$) was outside the $T^{\circ}C$ range of 0 to 55°C (Canadian National Climate Archives and National weather service, US).

$RH_{(ambient)}\%$ and $RH_{(trailer)}\%$ data were considered invalid when recorded data were greater than 100%, indicating that the data logger reached saturation and would most likely indicate a data logger malfunction. Because the THI was derived from T and RH values, there were no modifications to those data.

Micro-climate data were summarized by event and averaged by trip, trailer and compartment, using pivot tables in spread-sheet software Excel (Excel, Microsoft Office. Microsoft Corporation, Redmond, WA).

4.6.2 Shrink

Live weight was obtained for groups of heifers transported within the same compartment because there was not an individual animal scale available at the feedlot or packing plant. Heifers were weighed by compartment prior to loading at the feedlot and weighed again on a ground scale post-transport. Shrink was determined as:

[1- (compartment weight after transport/ compartment weight before transport) × 100]. (4.2)

Shrink was calculated by compartment for each journey. The weights of animals transported in the deck and doghouse compartments were combined because animals were moved at the Canada/ US border for quad axle weight requirements and it was therefore not possible to accurately assess the weight of the animal that was relocated.

4.6.3 Core body temperature

To account for individual variation in CBT, ΔCBT was used for analysis. CBT was recorded 2 days prior to transport and the results recorded 24 hours prior to transport were used as baseline data. The day of insertion of the vaginal device was not used in the analysis to ensure that the heifers had become accustomed to the device and did not skew CBT data. The baseline data were averaged to one data point for each animal. During the day of transport the CBT was recorded and matched to transportation events such as stationary and in-transit. For each transportation event the time was confirmed by driver logs and GPS and was averaged to one data point per animal. To calculate ΔCBT, the baseline temperature was subtracted by transportation event (baseline CBT – Stationary or in-transit event). For all the individual animal CBT data, each animal was matched with trip, trailer and compartment. Lethal critical minimum and maximum CBT for homeotherms ranges between 37°C and 43°C (Ivanov, 2006). Based on this information, any recorded CBT data below 37°C and above 43°C were considered invalid data and discarded.

4.6.4 Data logger location

To determine if data logger location (trailer ceiling vs. animal level) had an effect on the recorded temperatures, comparisons were made with data collected from a one-hour period between 1500 and 1600 h when the trailers were in-transit. Temperature data were summarized into a single value for each trip, trailer and compartment.

To determine if the trailer ceiling data logger placement had an effect on micro-climate data during the warmest in-transit hour, each data logger was categorized by plane (driver, middle and passenger) and location within the compartment (front, middle, back)

4.7 Experimental design and treatments

Five paired trailer loads of cattle were monitored to quantify the temperature and humidity parameters to assess the effects of each trailer porosity and compartment location on animal shrink and CBT. This study was carried out as a split-plot randomized block design with a 2 × 5 factorial arrangement of treatments:

1) Trailer porosity: Trailer A (8.7%P); Trailer B (9.6%P)

2) Compartment location: nose; deck; belly; doghouse; rear

Trailer was the main plot and the compartment location was the subplot with date of transport as the blocking factor.

4.8 Statistical analysis

Descriptive statistics were obtained using the MEANS procedure of SAS (v.9.1.3; SAS Institute, Cary, NC) for average, minimum, maximum and standard deviation of parametric data. Data were tested for normality using the PROC UNIVARIATE procedure (v.9.1.3; SAS Institute, Cary, NC). All extreme values were removed for all statistical analyses. The minimum, mean, and maximum values were obtained from the raw data and were used for each event to create a single value for each day, trailer and compartment. The effects of trailer porosity and compartment on all micro-climate parameters ($T_{(trailer)}{}^{\circ}C$, $RH_{(trailer)}\%$, $THI_{(trailer)}$, ΔT, ΔRH, and ΔTHI) were analysed using the MIXED procedure of SAS for a split-plot randomized block design.

Micro-climate data from the entire journey, warmest in-transit hour, and stationary event were used. Data were analysed using a MIXED model (v.9.1.3; SAS Institute, Cary, NC) including compartment, trailer, and their interactions as fixed effects. For the entire journey, time was considered a repeated factor and was subjected to trip, trailer and compartment and was used to define the warmest in-transit hour. For the warmest in-transit hour and stationary period, compartment was the repeated factor subjected to trip and trailer with trip as a random factor. Each analysed variable was subjected to 3 variance-covariance structures: compound symmetry, autoregressive order one and unstructured. The covariance structure that minimized the

Schwarz's Bayesian information criterion was considered the most desirable analysis. If interactions were not significant they were removed from the model.

Shrink data were transformed to log scale to achieve a normal distribution, and were analysed using the same model described above for micro-climate data for the warmest in-transit hour and stationary event, including trip as a random effect. The effect of loading density on live weight loss and CBT was investigated and there was no effect of loading density and therefore it was not included in the statistical model.

For CBT, data were analysed using a MIXED procedure of SAS (v.9.1.3; SAS Institute, Cary, NC) including compartment, trailer and status (in transit or stationary), and their interactions as fixed effects, and trip as a random effect. Compartment was considered a repeated effect subjected to trip, trailer and animal ID. As described above, each analysis was subjected to 3 variance-covariance structures.

The data logger location was analysed using the same model as shrink data, including data logger effect as a fixed effect and trailer and trip as random effects.

Least-squares means were generated by the LSMEANS statement within SAS and tested for least significant difference across all main effects and appropriate interactions for micro-climate parameters, shrink and ΔCBT. Least square means and standard errors were calculated for independent variables and interactions, and differences among means were compared by using the PDIFF option of the mixed model procedure. Tests of multiple comparisons of LSMEANS were considered significant at a level of $P < 0.05$; LSMEANS with P values between 0.05 and 0.10 were considered tendencies. Where interactions between compartment location and trailer porosity were significant ($P < 0.05$) the SLICE option within SAS was performed for trailer and compartment interactions.

5.0 RESULTS

5.1 DESCRIPTIVE STATISTICS

The ambient weather conditions varied by day and trip in this study. For example, there were 4 trips that had average ambient temperatures that ranged from 17.0 to 19.5°C. However, one trip had an average ambient temperature of 25.9 ± 6.06°C. To further examine the extreme temperatures in this study, the warmest trip of the warmest in-transit hour was described in further detail using data from both trailer types. Trailer micro-climate parameters were categorized for the warmest in-transit hour that included temperature ranges in 5°C increments and $THI_{(trailer)}$ was categorized using the Livestock Weather Hazard Indices for the warmest in-transit event. Extreme temperatures during the stationary event were assessed to determine the time when the maximum ΔT was reached after the tractor-trailer was stopped. Because there was a time effect for the entire journey, no additional descriptive statistics were performed and only focused on the warmest in-transit hour and stationary event.

5.1.2 Ambient micro-climate variables

Descriptive statistics for ambient conditions over the entire journey, stationary event and warmest in-transit hour are summarized in Table 5.1. The average $T_{(ambient)}$°C for all data (entirety of all trips) was 18.2 ± 4.94°C with a minimum of 7.1°C and maximum of 34.2°C. During the stationary event, $T_{(ambient)}$°C had an average value of 18.8 ± 4.00°C with a minimum and maximum of 10.6 and 33.1°C, respectively. Average $T_{(ambient)}$°C for the warmest in-transit hour was 24.7 ± 3.36°C with a minimum of 11.9°C and maximum of 34.2°C.

Ambient RH ranges were 11.3 – 100%, 20.8 - 89.8 % and 11.9 – 58.1% for the entire journey, stationary event and warmest in-transit hour, respectively.

Similar average ambient THI values where observed for the entire journey (62.2 ± 6.05) and stationary event (62.8 ± 4.69). However, the average ambient THI for the warmest in-transit hour (69.5 ± 4.03) was 10% greater when compared to the entire journey and stationary event (Table 5.1).

Table 5.1 Descriptive statistics of ambient temperature, relative humidity and temperature humidity index for 10 truckloads of cattle hauled from Southern Alberta to Southern Washington during the summer months.

Variable	Event	Mean[1]	Min	Max	Range[2]	N
$T_{(ambient)}$ °C	Entire	18.2 ± 4.94	7.1	34.2	27.1	3663
	Stationary	18.8 ± 4.00	10.6	33.1	17.4	398
	Warmest h	24.7 ± 3.36	11.9	34.2	22.3	586
$RH_{(ambient)}$%	Entire	47.4 ± 18.56	11.3	100	88.7	3487
	Stationary	47.9 ± 20.09	20.8	89.8	69.1	340
	Warmest h	29.8 ± 6.51	11.9	51.8	39.9	520
$THI_{(ambient)}$	Entire	62.2 ± 6.05	44.8	80.1	35.4	3487
	Stationary	62.8 ± 4.69	54.5	72.4	20.9	340
	Warmest h	69.5 ± 4.03	55.6	80.1	24.5	520

[1] Mean was calculated as the average value among trailers and compartment
[2] Maximum minus minimum during the journey

Table 5.2 Descriptive statistics of ambient and trailer temperatures by trip

Variable	Trip	Mean[1]	Min	Max	Range[2]	N
August 14	$T_{(trailer)}$ °C	30.0 ± 5.16	12.2	41.6	29.4	59521
	$T_{(ambient)}$ °C	25.9 ± 6.06	10.6	37.7	27.1	743
August 21	$T_{(trailer)}$ °C	21.9 ± 5.15	10.7	39.7	20.0	57677
	$T_{(ambient)}$ °C	17.4 ± 4.52	10.1	28.7	18.6	737
August 26	$T_{(trailer)}$ °C	18.7 ± 3.98	7.6	28.2	20.6	53054
	$T_{(ambient)}$ °C	17.0 ± 3.98	7.1	24.2	16.6	753
August 28	$T_{(trailer)}$ °C	19.3 ± 3.25	11.1	31.7	20.6	57971
	$T_{(ambient)}$ °C	19.5 ± 3.56	7.1	30.7	14.0	716
September 3	$T_{(trailer)}$ °C	21.1 ± 3.52	9.7	30.7	21.0	58104
	$T_{(ambient)}$ °C	18.5 ± 3.93	6.1	27.2	21.2	714

[1] Mean was calculated as the average value among trailers and compartment
[2] Maximum minus minimum during the journey

The descriptive statistics for $T_{(trailer)}$ °C by trip are shown in Table 5.2. The warmest trip, recorded on August 14th, had an average trailer temperature of 30.0 ± 5.16 °C, with a minimum and maximum temperature of 12.2 °C and 41.6 °C, respectively while the coolest trip had an average trailer temperature of 18.7 ± 3.98 °C, and a minimum and maximum of 7.6 °C and 28.2 °C, respectively.

5.1.3 Trailer micro-climate variables

Descriptive statistics for the trailer micro-climate parameters during the entire journey, stationary event and warmest in-transit hour are summarized in Table 5.3. The average $T_{(trailer)}$ °C for the entire journey was similar to the average $T_{(trailer)}$ °C for the stationary event (22.3 ± 5.97°C and 22.6 ± 5.59°C, respectively). However, average $T_{(trailer)}$ °C for the warmest in-transit hour (28.2 ± 4.75°C) was approximately 6°C greater than the average for both the entire journey and stationary event.

5.1.4 Delta values

Average values for ΔT, were similar for the entire journey (ΔT = 4.1 ± 4.38°C) and stationary event (ΔT = 3.8 ± 3.16°C). However, the ΔT, and ΔTHI for the warmest in-transit hour (ΔT = 1.4 ± 5.23°C and ΔTHI= 1.7 ± 1.54) were less than half the ΔT and ΔTHI values recorded for the entire journey and the stationary event as presented in Table 5.3.

Table 5.3 Descriptive statistics for micro-climate variables for 10 truckloads of cattle hauled from Southern Alberta to Southern Washington State during the summer months.

Variable	Event	Mean[1]	Min	Max	Range[2]	N
$T_{(trailer)}$ °C	Entire	22.3 ± 5.97	7.6	41.0	33.0	280220
	Stationary	22.6 ± 5.59	11.7	41.6	29.0	7920
	Warmest h	28.2 ± 4.75	16.1	40.7	24.6	21615
$RH_{(trailer)}$%	Entire	67.5 ± 16.80	12.6	100.0	75.4	280220
	Stationary	53.8 ± 16.89	19.6	100.0	80.4	7920
	Warmest h	34.8 ± 8.22	12.6	92.0	79.6	21615
$THI_{(trailer)}$	Entire	50.3 ± 6.58	36.0	88.1	51.9	280220
	Stationary	68.2 ± 6.26	53.4	88.1	34.7	7920
	Warmest h	73.8 ± 5.28	60.3	86.8	26.5	21615
Δ[3]T °C	Entire	4.1 ± 4.38	-11.5	10.5	22.5	280220
	Stationary	3.8 ± 3.16	-10.3	10.5	20.8	7920
	Warmest h	1.4 ± 5.23	-10.4	9	19.4	21615
Δ[3]RH %	Entire	2.9 ± 8.88	-36.5	76.2	112.7	280220
	Stationary	5.7 ± 9.13	-17.2	64.0	81.8	7920
	Warmest h	5.5 ± 5.64	-16.50	30	46.2	21615
Δ[3]THI	Entire	5.4 ± 4.65	-22.0	30.0	52.0	280220
	Stationary	5.4 ± 3.83	-9.5	14.10	32.7	7920
	Warmest h	1.7 ± 1.54	-14.6	10.8	37.7	21615

[1] Mean was calculated as the average value among trailers and compartment
[2] Maximum minus minimum during the journey
[3]Δ Internal trailer micro-climate minus ambient micro-climate (sensors on mirrors of truck)

5.1.5 Micro-climate during the warmest in-transit hour

When micro-climate data were observed for all 5 trips from both trailers during the warmest in-transit hour, the mean $T_{(trailer)}$ °C ranged between 35 and 39°C, for 18% of the hour (Figure 5.1). However, when the warmest trip was observed separately, the average $T_{(trailer)}$ °C ranged between 35 and 39°C for 81% of the hour with only 3% of the time below 29°C (Figure 5.2).

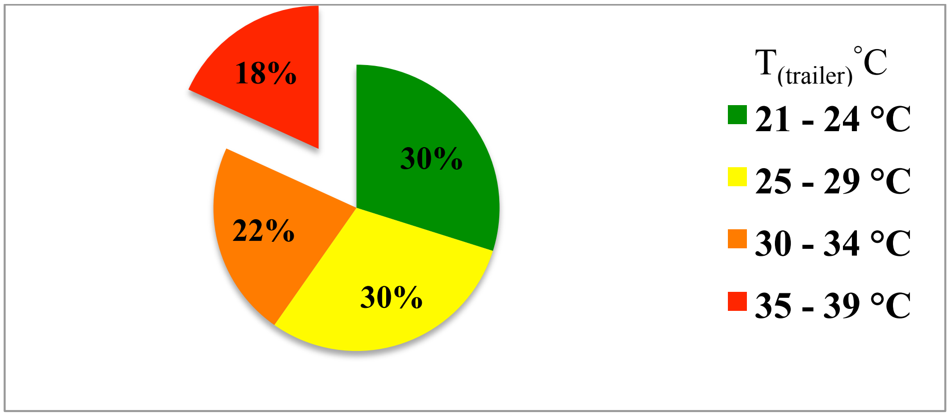


Figure 5.1 The distribution of $T_{(trailer)}$ °C ranges during the warmest in-transit hour for all 5 trips and both trailer porosities. Data were calculated from 86 data loggers collecting micro-climate data at one-minute intervals (n=21615).

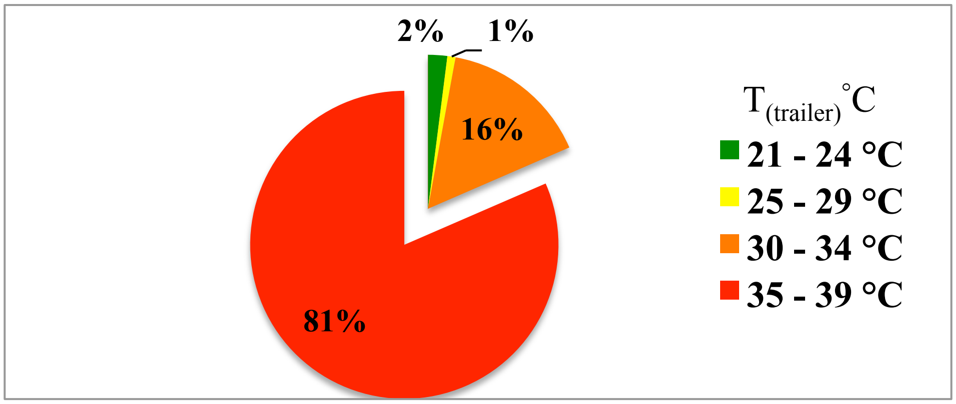


Figure 5.2 The distribution of $T_{(trailer)}$ °C ranges during warmest in-transit hour for the warmest trip and both trailer porosities. Data were calculated from 86 data loggers collecting micro-climate data at one-minute intervals (n=5400).

During the warmest in-transit hour for all trips and trailer porosities, the $THI_{(trailer)}$ was categorized according to the Livestock Weather Hazard Index (LWHI) as either safe (THI < 74), alert (THI = 75 - 78), danger (THI = 79 - 83) or emergency (THI > 84) 54%, 21%, 24% and 1%

of the time, respectively (Figure 5.3). To determine the extreme THI values that were observed in this study, the data from the warmest trip during the warmest hour were looked at in more detail. It was found that the percentage of time in the danger and emergency categories increased from 24 to 81% and from 1 to 14%, respectively when compared to all 5 of the journeys (Figure 5.4).

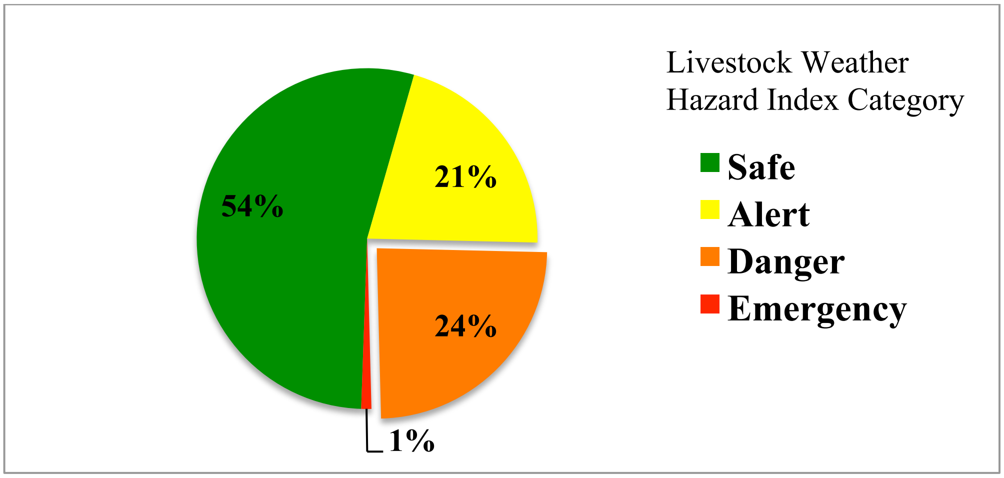


Figure 5.3 The Livestock Weather Hazard Index categories during the warmest in-transit hour for all 5 trips and both trailer porosities. Data were calculated from 86 data loggers collecting micro-climate data at one-minute intervals (n=21615).

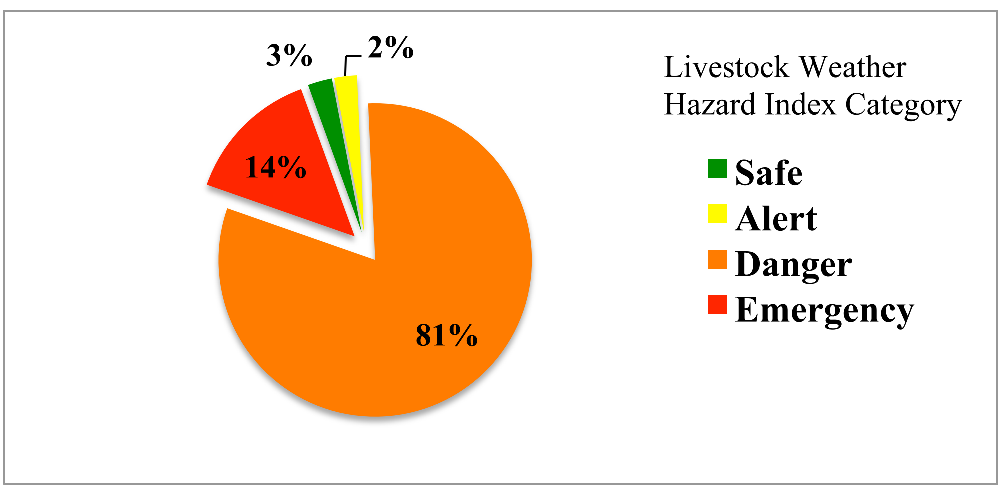


Figure 5.4 The Livestock Weather Hazard Index categories for the warmest trip during the warmest in-transit hour and both trailer porosities. Data were calculated from 86 data loggers collecting micro-climate data at one-minute intervals (n=5400).

5.1.6 Maximum temperatures during the stationary event

The transportation duration (time loaded to unloaded) ranged from 12.5 to 14 h and each trip had delays that resulted in stationary periods. The amount of time that the tractor-trailer unit was stationary per trip was on average 1.43 ± 0.6 h and ranged from 0.5 to 2.3 h. As expected the greatest temperatures were observed during the stationary event of the warmest trip. When the warmest trip was observed separately from the rest of the trips, descriptive statistics indicated that the maximum and average $T_{(trailer)}$ °C for Trailer A were located in the doghouse compartment (Table 5.4). However, in Trailer B, the deck compartment was the compartment with the greatest values for maximum and average $T_{(trailer)}$ °C.

When ΔT was observed by minute, the findings were similar to the maximum and average temperatures. The average maximum ΔT for the stationary event was used to determine the time when the internal temperatures reached peak values. The average maximum ΔT was reached between 19 and 29 min after the trailer stopped for Trailer A and 18 to 25 min after the trailer stopped for Trailer B. The maximum difference between trailer and ambient temperatures were 10.5°C degrees in Trailer A and 9°C in Trailer B. The greatest maximum ΔT values were observed in the doghouse followed by the nose compartment of Trailer A (Figure 5.5) while Trailer B had the greatest ΔT values in the deck and the doghouse (Figure 5.6). The belly compartments of both trailers had the lowest ΔT values.

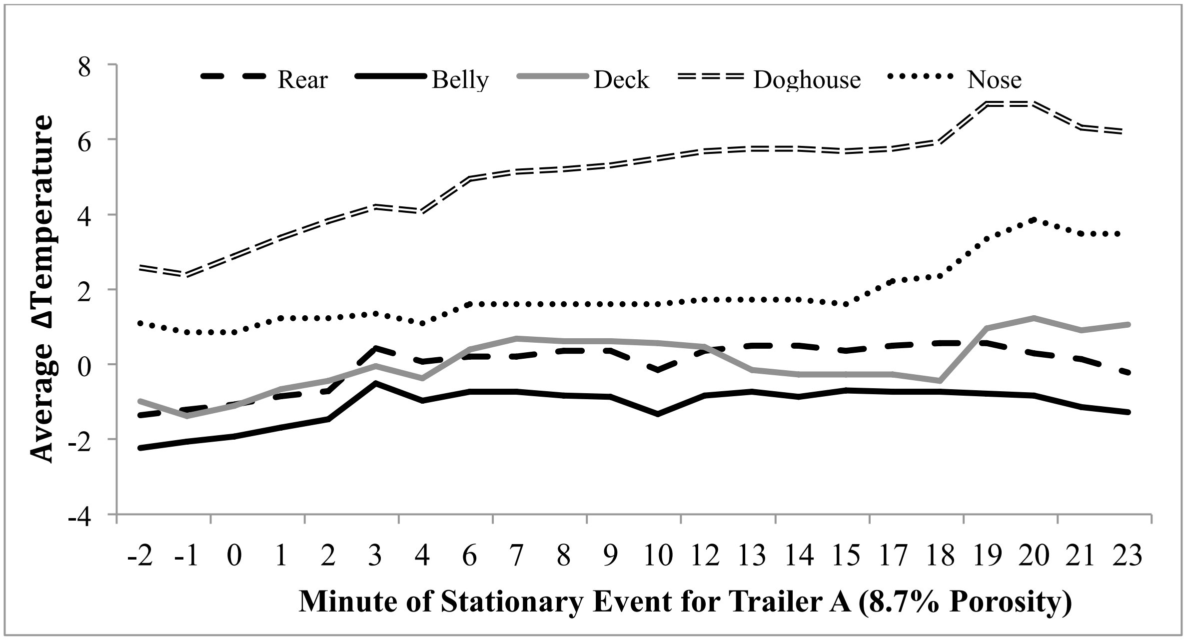


Figure 5.5. The average difference in trailer and ambient temperatures for Trailer A during the stationary event of the warmest trip. Data were calculated from 45 data loggers collecting micro-climate data at one-minute intervals (n=900).

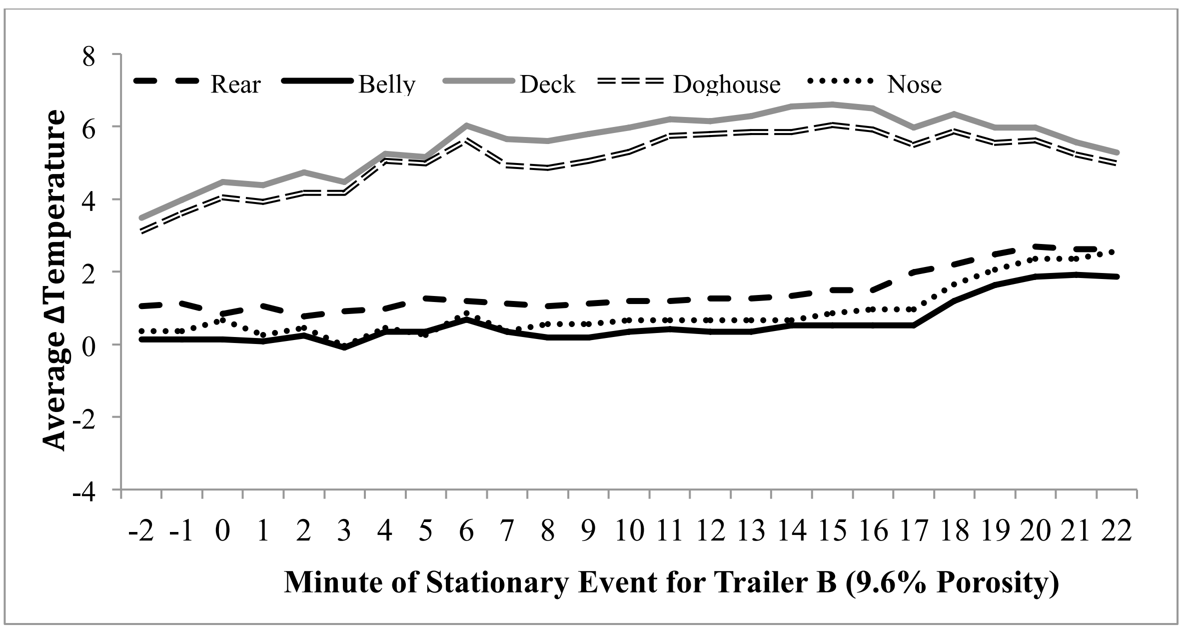


Figure 5.6. The average difference in trailer and ambient temperatures for Trailer B during the stationary event for the warmest trip. Data were calculated from 45 data loggers collecting micro-climate data at one-minute intervals (n=900).

Table 5.4 Maximum temperatures by compartment during a stationary event at the Canadian/US border crossing on the warmest trip.

Variable	Trailer Porosity (%)	Rear	Belly	Deck	Doghouse	Nose
Mean $T_{(trailer)}$ °C	A(8.7P)	31.6 ± 1.84	30.8 ± 2.51	31.3 ± 5.57	34.9 ± 2.21	32.8 ± 0.98
	B(9.6P)	31.9 ± 1.46	31.9 ± 1.37	34.8 ± 1.96	34.3 ± 1.71	31.5 ± 4.26
Max $T_{(trailer)}$ °C	A(8.7P)	37.7	38.2	39.7	41.6	40.6
	B(9.6P)	40.7	37.6	41.1	39.7	40.1
Mean Δ^1T	A(8.7P)	0.20 ± 1.922	-0.60 ± 2.601	0.00 ± 5.54	3.63 ±2.044	1.51 ± 1.270
	B(9.6P)	0.76 ± 1.41	0.06 ± 1.304	3.23 ± 1.74	2.85 ±1.58	2.06 ± 1.268
Max Δ^1T	A(8.7P)	5.1	2.6	7	10.5	4.6
	B(9.6P)	5.5	4.5	9	8	5.4
Minute[2]	A(8.7P)	29	29	20	19	20
Minute[2]	B(9.6P)	23	24	18	18	25

[1]Δ Internal trailer micro-climate minus ambient micro-climate (sensors on mirrors of truck)
[2] Time to reach maximum Δtemperature

5.1.7 Shrink

Descriptive statistics for shrink are presented in Table 5.5. Overall, shrink, regardless of trailer porosity or compartment, was 4.3% ± 0.34 with a minimum of 3.0% and maximum of 6.69%. The belly compartment had the lowest mean shrink of 4.1% ± 0.29. The nose compartment had the largest shrink range (3 to 6.69%) with a mean of 4.5% ± 0.44. Minimum shrink in Trailer A (3.13%) occurred in the rear compartment while and the maximum shrink (6.0%) occurred in the deck and doghouse. However, in Trailer B, both the minimum (3.0%) and maximum (6.69%) shrink occurred in the nose compartment. The deck and doghouse compartments were classified as one since cattle were redistributed at the Canada/US border to ensure compliance with axle weight allowances by country. These combined compartments (deck and doghouse) had a mean shrink of 4.4% ± 0.31.

Table 5.5 Descriptive statistics for shrink, expressed as percentage of starting weight.

Compartment	Mean[1]	Minimum	Maximum	Range[2]	N
Rear	4.2 ± 0.34	3.3	5.3	2.0	9
Belly	4.1 ± 0.29	3.3	5.2	1.9	10
Deck + Doghouse	4.4 ± 0.31	3.8	6.0	2.2	10
Nose	4.5 ± 0.44	3.0	6.7	3.7	10
Trailer A	4.3 ± 0.33	3.1	6.0	2.8	19
Trailer B	4.3 ± 0.37	3	6.7	3.7	20
Overall	4.3 ± 0.35	3.0	6.7	3.7	39

[1] Mean was calculated as the average value among trailers and compartment
[2] Maximum minus minimum during the journey

When the distribution of shrink values was observed, compartment shrink was categorized in ranges used by industry for the sale of cattle and ranged from 3 to 3.4%; 3.5 to 3.9%; 4.0 to 4.4%; 4.5 to 4.9%; 5.0 to 5.4%; 5.5 to 5.9% and shrink values greater than 6%. Compartment shrink was lower than 4% in 35.9% of all trips, shrink between 4 and 5% in 48.7% of all trips and shrink greater than 5% in 15.4% of the trips (Figure 5.7).

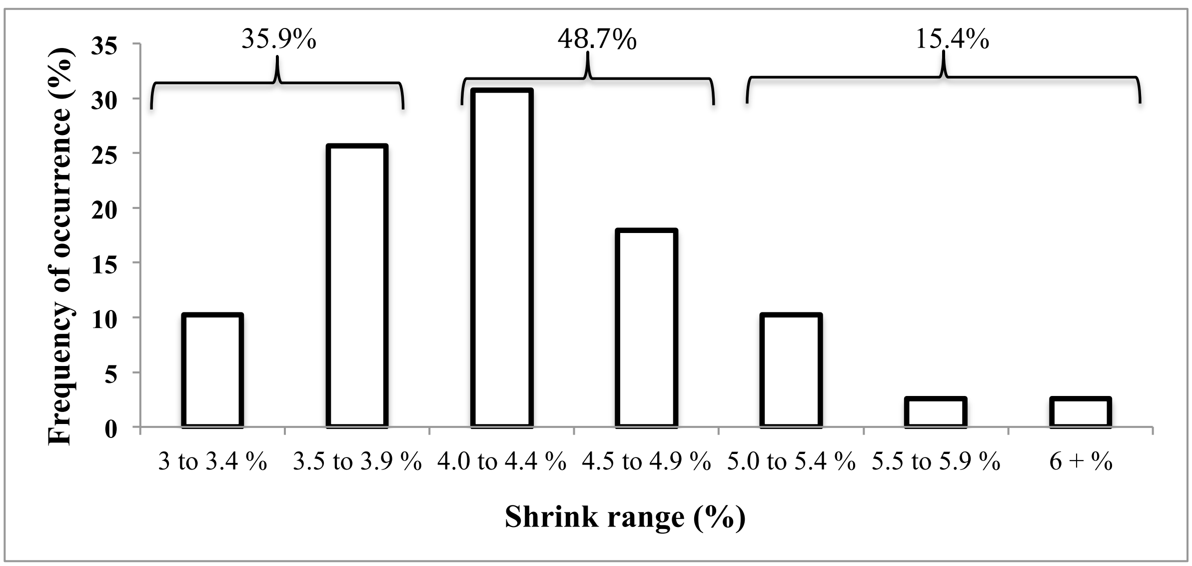


Figure 5.7. Distribution of compartment shrink (n=39)

5.1.8 Core body temperature

Descriptive statistics for ΔCBT are summarized in Table 5.6. Mean ΔCBT was 0.02 ± 0.2°C for all heifers. When the heifers were subject to handling (loading and unloading) their mean ΔCBT was 0.43 ± 0.0°C. In addition, when the tractor-trailer unit was in-transit the mean ΔCBT was 0.04 ± 0.3°C and when the tractor-trailer unit was stationary, the mean ΔCBT was 0.16 ± 0.3°C. Finally, when the heifers were unloaded at the slaughter plant and in lairage the ΔCBT was -0.36 ± 0.0°C. Although, ΔCBT for handling and lairage was collected for this study, ΔCBT during handling and lairage these events were not included in the analysis as it was not a primary objective in this thesis and may have masked the effect of stationary and transport events on ΔCBT.

Table 5.6 Descriptive statistics for ΔCore body temperature

Compartment	Mean[1]	Minimum	Maximum	Range[2]	N
Transport	0.04 ± 0.3	-0.69	0.59	1.28	101
Stationary	0.16 ± 0.3	-0.58	0.93	1.50	101
Handling	0.43 ± 0.3	-0.41	1.51	1.92	101
Lairage	-0.36 ± 0.0	-0.61	-0.22	0.39	101

[1] Mean was calculated as the average value among trailers and compartment
[2] Maximum minus minimum during the journey

5.2 Entire journey

There were no interactions observed between compartment location and trailer porosity for any of the micro-climate variables. However, a time effect ($P < 0.0001$) was observed for all micro-climate variables. The differences in trailer temperature by time were used to define the warmest in-transit hour. The warmest in-transit hour occurred between 1700 and 1800 h (Figure 5.8). However, due to the fact that several stationary periods occurred during that time frame as a result of highway construction, a one-hour period between 1800 and 1900 h was selected from which to compare the micro-climate variables during the warmest in-transit hour.

There were no differences ($P > 0.15$) by trailer porosity in any of the micro-climate variables assessed with the exception of ΔRH. Trailer A had ΔRH values 3 times greater ($P < 0.001$; Table 5.7) than Trailer B. In addition, no differences were observed between compartments within a trailer for any of the micro-climate variables with the exception of ΔRH. The ΔRH values were greater ($P < 0.001$) in the rear, belly and nose compartments compared to the deck and doghouse.

Table 5.7 The effect of time, trailer (Tr) and compartment (C) location on micro-climate parameters

	Compartment Location (C)						Trailer Porosity (%) (Tr)			P-Value				
Variable	Rear	Belly	Deck	DH[1]	Nose	SEM[1]	A(8.7)	B(9.6)	SEM[2]	C	Tr	C×Tr	C×Tr×T	Time[4]
$T_{(trailer)}$ °C	21.85	21.63	22.43	22.34	22.59	1.28	21.62	22.72	0.81	NS[3]	NS	NS	NS	<0.0001
$RH_{(trailer)}$%	53.34	54.47	50.38	49.11	54.04	2.91	53.39	51.15	1.84	NS	NS	NS	NS	<0.0001
$THI_{(trailer)}$	67.16	66.95	67.62	67.33	68.26	1.48	66.77	68.16	0.93	NS	NS	NS	NS	<0.0001
ΔT°C	3.80	3.57	4.37	4.29	4.52	0.97	3.7	4.5	0.61	NS	NS	NS	NS	<0.0001
ΔRH%	4.10^a	5.21^a	1.12^b	-0.16^b	4.82^a	0.94	4.72^A	1.31^B	0.59	0.0001	0.0005	NS	NS	<0.0001
ΔTHI	5.14	4.39	5.60	5.32	6.24	1.04	5.00	5.90	0.66	NS	NS	NS	NS	<0.0001

[1]Doghouse compartment
[2]Pooled SEM
[3]NS = Not significant
[4]Time is represented by hour of transport

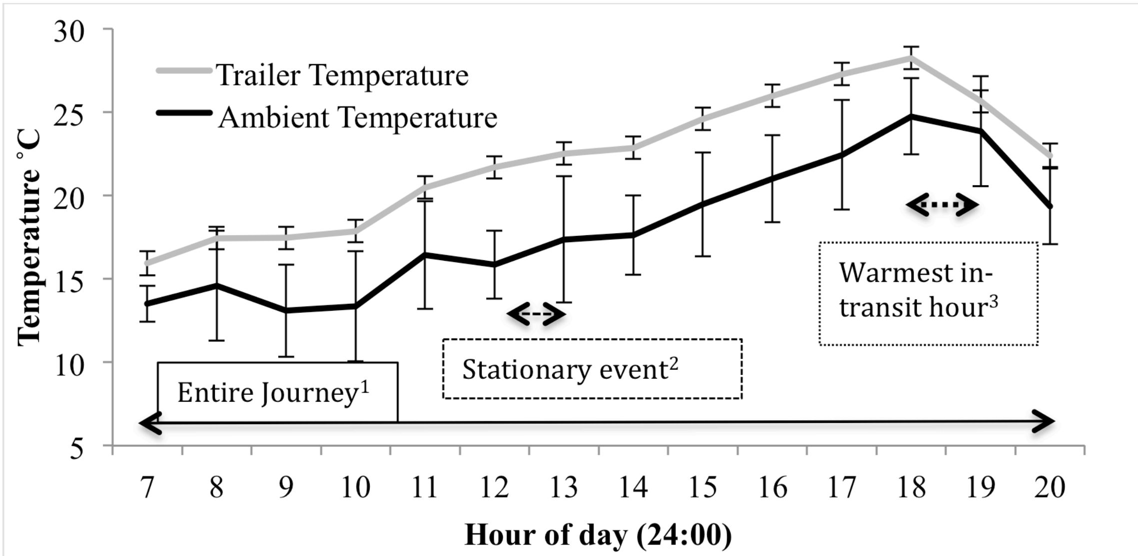


Figure 5.8. Trailer and ambient temperature by hour of day and transportation events
[1]Entire journey: the whole duration of transport event
[2]Stationary event: tractor-trailer unit was not moving and occurred at Canada/US border
[3]Warmest in-transit hour: tractor-trailer unit was in-transit during the warmest hour of day

5.3. Warmest in-transit hour

5.3.1 Trailer temperature

Least squares mean (±SEM) for micro-climate variables by compartment and trailer during the warmest in-transit hour are presented in Table 5.8. No interactions between compartment location and trailer porosity were observed for temperature during the warmest in-transit hour. However, there was an effect of compartment location for all $T_{(trailer)}{}^{\circ}C$ values with the exception of minimum $T_{(trailer)}{}^{\circ}C$.

Compartment location had an effect on mean $T_{(trailer)}{}^{\circ}C$ during the warmest in-transit hour. Mean $T_{(trailer)}{}^{\circ}C$ in the nose, deck and doghouse compartments did not differ from one another and the rear compartment was similar to the doghouse compartment. When the belly compartment was compared to the rear compartment there was no differences observed for mean $T_{(trailer)}{}^{\circ}C$, and both the belly and rear were less than the deck (belly: $P < 0.004$; rear: $P < 0.06$) and the nose (belly: $P < 0.03$; rear: $P < 0.06$). In addition, the belly compartment had lower mean $T_{(trailer)}{}^{\circ}C$ than ($P < 0.03$) the doghouse compartment.

There was an effect of compartment location and trailer porosity on maximum $T_{(trailer)}{}^{\circ}C$ ($P = 0.0001$). The belly compartment had the lowest maximum $T_{(trailer)}{}^{\circ}C$ compared to the nose ($P =$

differences ($P > 0.10$) observed between the rear compartment and the belly, deck, doghouse and nose. Differences in maximum $T_{(trailer)}$ °C were observed between the deck compartment, the nose ($P = 0.03$) and doghouse ($P = 0.01$) compartments. Maximum $T_{(trailer)}$ °C was greater ($P = 0.04$) for Trailer B than Trailer A.

Compartment location had an effect on minimum ΔT ($P = 0.03$), mean ΔT ($P = 0.001$) and maximum ΔT ($P = 0.08$). The belly and rear compartments had lower minimum ΔT values than the deck ($P < 0.002$) and doghouse ($P < 0.01$) compartments while the rear did not differ from the belly. Furthermore, minimum ΔT in the nose compartment was greater than the belly ($P < 0.04$) while the nose did not differ from the rear compartment. Finally, the nose, deck and doghouse compartments did not differ from one another ($P > 0.15$; Table 5.8).

There was a compartment location effect on Mean ΔT values during the warmest in-transit hour. The belly compartment had lower mean ΔT values when compared to the nose ($P = 0.0002$), doghouse, ($P = 0.001$) and deck ($P = 0.004$) compartments while the belly did not differ from the rear compartment. The mean ΔT in the rear compartment was also lower than in the nose ($P = 0.004$), and doghouse, ($P = 0.02$) and tended to differ from the deck ($P = 0.08$) compartment. Finally, the deck, doghouse and nose did not differ in mean ΔT when compared to one another.

Maximum ΔT also differed by compartment location. The maximum ΔT in the nose compartment was not different ($P > 0.15$) from the rear. However, the nose maximum ΔT was greater than the belly ($P = 0.007$) and tended to differ from the deck ($P < 0.06$) and doghouse ($P < 0.09$) compartments. The maximum ΔT for the remaining compartments did not differ from one another.

5.3.2 Relative humidity

There were no interactions ($P > 0.10$) observed between compartment location and trailer porosity for any of the RH parameters. However, there was an effect of compartment location for minimum and mean $RH_{(trailer)}$% and ΔRH.

Minimum RH was found to differ by compartment location and was greatest ($P = 0.0004$) in the nose compartment. The minimum $RH_{(trailer)}$% value did not differ between the rear and belly compartments or between the deck and the doghouse compartments. However, the rear and belly had greater minimum $RH_{(trailer)}$% values than the deck ($P < 0.0001$) and doghouse ($P <$

0.0001) and less than the nose ($P < 0.03$). Similar results were observed for minimum ΔRH with the exception that minimum ΔRH tended to differ ($P < 0.07$) between the nose and the rear compartments.

Mean $RH_{(trailer)}$% and ΔRH for the nose, rear and belly compartments were greater ($P < 0.03$; Figure 5.9) than for the deck and doghouse compartments. In addition, mean $RH_{(trailer)}$% in the deck compartment was greater ($P = 0.009$) than the doghouse compartment.

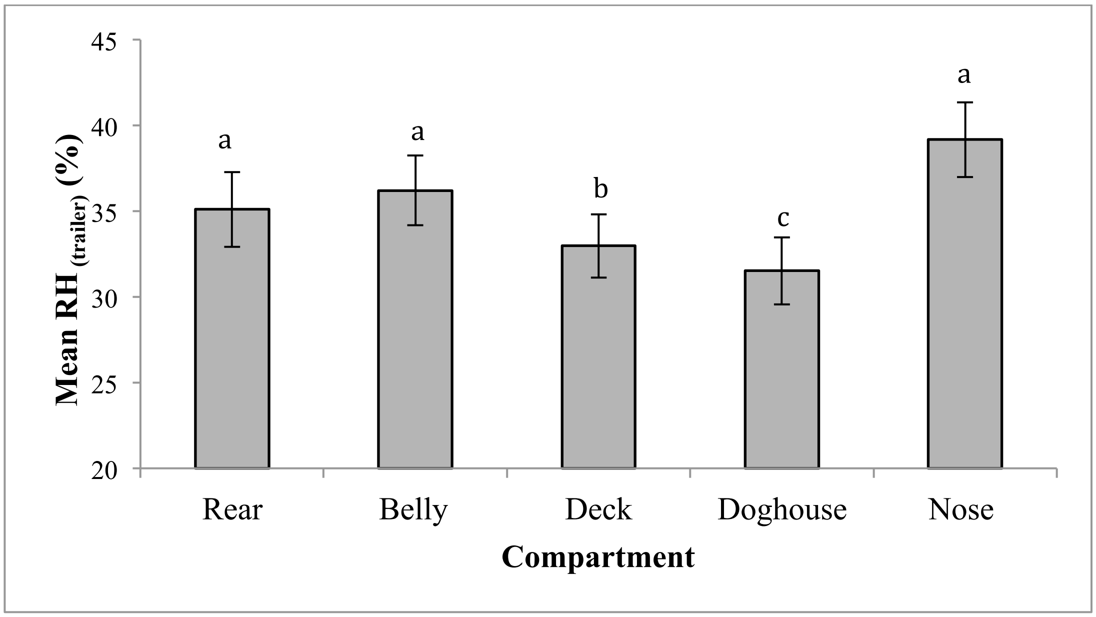


Figure 5.9 Least square means (±SEM) for $RH_{(trailer)}$(%) between compartments for Trailer A and B porosity types during the warmest in-transit hour ($P < 0.001$).
[abc] Bars with different superscripts differ between compartments ($P < 0.05$).

5.3.3 Temperature Humidity Index

An interaction between compartment and trailer (C×Tr) was observed for mean $THI_{(trailer)}$ ($P < 0.0001$). No differences were observed between the same compartments of the different trailers. However, there were differences between compartments within a trailer. The mean $THI_{(trailer)}$ in Trailer A did not differ by compartment location. The belly compartment in Trailer B had a lower mean $THI_{(trailer)}$ than the nose ($P < 0.07$) and deck ($P < 0.02$) compartments while the belly did not differ from the doghouse and rear compartments. There were also differences in mean $THI_{(trailer)}$ between the deck and doghouse compartments ($P < 0.04$) and between the rear and doghouse compartments ($P < 0.07$) in Trailer B (Figure 5.10).

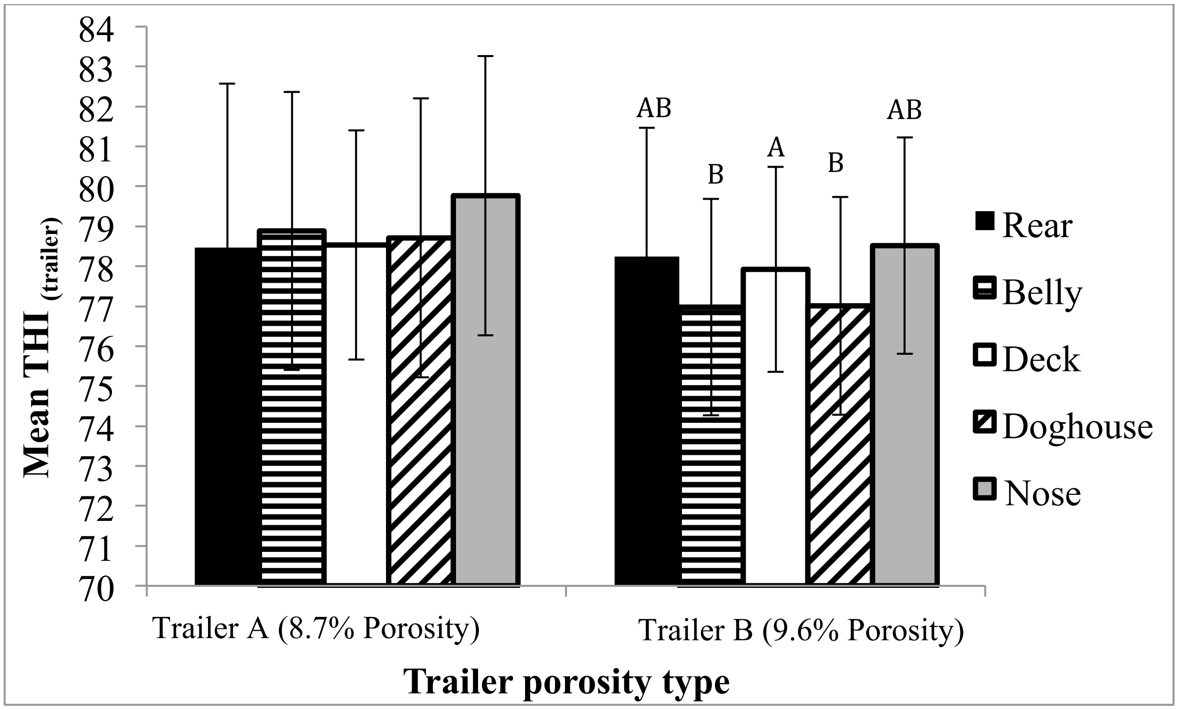


Figure 5.10 Least square means (±SEM) for mean THI within compartment during the warmest in-transit period ($P < 0.002$).
^{AB} Bars with different superscripts differ within trailer B ($P < 0.05$).

Maximum $THI_{(trailer)}$, mean ΔTHI and maximum ΔTHI were affected by compartment location. Maximum $THI_{(trailer)}$ was greater ($P < 0.05$) in the nose compared to the belly ($P < 0.03$), deck ($P < 0.05$) and doghouse ($P < 0.005$) however, the rear only tended to differ from the nose ($P < 0.09$). The maximum $THI_{(trailer)}$ tended ($P = 0.10$) to be greater in Trailer B than Trailer A. Mean and maximum ΔTHI were also greater in the nose compared to the rear ($P < 0.02$), belly ($P < 0.005$), deck ($P < 0.05$) and doghouse ($P < 0.04$) compartments while the rear, belly, deck and doghouse did not differ from one another. Maximum ΔTHI in Trailer B tended to be greater ($P = 0.07$), than Trailer A.

Table 5.8 The effect of compartment location and trailer porosity on trailer micro-climate during the warmest in-transit hour

		Compartment Location(C)						Trailer porosity (Tr)			*P-Value*		
Micro-climate Variable		Rear	Belly	Deck	Doghouse	Nose	SEM[1]	A(8.7%)	B(9.6%)	SEM[1]	C	Tr	C×Tr
$T_{(trailer)}$ °C	Min	24.7	23.00	24.2	26.4	25.5	1.49	25.7	23.8	1.80	NS[3]	NS	NS
	Mean	27.4^{ab}	27.3^{b}	27.8^{a}	27.7^{ab}	27.9^{a}	2.08	27.61	27.68	2.07	0.04	NS	NS
	Max	30.4^{abc}	29.5^{c}	30.2^{b}	30.0^{b}	31.2^{a}	2.53	29.65^{B}	30.83^{A}	2.51	0.0001	0.04	NS
$RH_{(trailer)}$%	Min	25.2^{b}	25.3^{b}	22.9^{c}	22.5^{c}	28.9^{a}	3.12	25.1	24.8	3.12	< 0.0001	NS	NS
	Mean	35.1^{a}	36.2^{a}	32.8^{b}	31.4^{c}	39.2^{a}	2.99	33.9	35.9	2.90	< 0.0001	NS	NS
	Max	50.8	57.9	49.9	50.1	48.19	7.16	50.0	60.0	4.77	NS	NS	NS
$THI_{(trailer)}$	Min	70.2	68.8	69.9	71.6	71.1	1.76	71.0	69.6	2.17	NS	NS	NS
	Mean	73.0	73.0	73.3	73.3	74.1	2.47	73.0	73.6	2.49	< 0.0001	NS	< 0.0001
	Max	78.4^{ab}	77.9^{b}	78.2^{b}	77.8^{b}	79.1^{a}	2.81	75.5^{B}	77.7^{A}	3.18	0.07	0.10	NS
Δ^{2}T°C	Min	-1.48^{ab}	-3.32^{b}	-2.07^{ab}	-0.07^{a}	-0.90^{ab}	1.252	-1.27	-1.87	1.486	0.03	NS	NS
	Mean	0.56^{bc}	0.28^{c}	1.05^{ab}	1.18^{a}	1.39^{a}	0.387	0.95	0.84	0.521	0.001	NS	NS
	Max	3.97^{ab}	3.28^{b}	3.72^{ab}	3.80^{ab}	4.60^{a}	0.305	3.51	4.24	0.315	0.08	NS	NS
Δ^{2}RH%	Min	-2.51^{ab}	-2.69^{b}	-4.95^{c}	-5.71^{c}	-0.78^{a}	1.603	-3.64	-3.02	1.567	< 0.0001	NS	NS
	Mean	5.57^{a}	6.59^{a}	3.24^{b}	1.79^{c}	9.44^{a}	1.266	5.11	5.54	1.328	<0.0001	NS	NS
	Max	25.81	34.45	21.17	21.81	21.94	5.13	19.64^{B}	33.24^{A}	3.830	NS	0.04	NS
Δ^{2}THI	Min	-0.50	-1.97	-1.27	0.68	0.16	1.475	-0.56	-0.59	1.465	NS	NS	NS
	Mean	1.36^{b}	1.33^{b}	1.72^{ab}	1.62^{b}	2.53^{a}	0.471	1.83	1.60	0.575	0.04	NS	NS
	Max	4.86^{b}	4.94^{b}	4.88^{b}	4.72^{b}	6.00^{a}	0.501	4.40^{B}	5.86^{A}	0.591	0.03	0.07	NS

[1]pooled SEM
[2]Δ Internal trailer micro-climate minus ambient micro-climate (sensors on mirrors of truck)
[3]NS = Not significant
^{abcd} differ between compartments ($P < 0.10$)
^{AB} differ between trailers ($P < 0.10$)

5.4 Stationary event

5.4.1 Temperature

Least squares means (±SEM) for micro-climate variables by compartment location and trailer porosity during the stationary event are presented in Table 5.9. Tendencies for a C×Tr interaction were observed for maximum $T_{(trailer)}{}^{\circ}C$ ($P < 0.07$) and maximum ΔT ($P < 0.10$). There were no differences observed between the same compartments between trailer porosities. However, differences were observed between compartments of the same trailer.

In Trailer A, the C×Tr interaction indicated that maximum $T_{(trailer)}{}^{\circ}C$ in the belly compartment was lower than the doghouse ($P < 0.10$) and rear ($P = 0.04$) compartments and maximum $T_{(trailer)}{}^{\circ}C$ in the belly did not differ from the deck and nose compartments. In addition, no differences were observed in Trailer A between the nose, deck and rear compartments when compared to one another.

In Trailer B, the C×Tr interaction indicated that the maximum $T_{(trailer)}{}^{\circ}C$ did not differ between the doghouse when compared to the nose, rear, belly and deck compartments. In addition, the belly and rear compartments had lower maximum $T_{(trailer)}{}^{\circ}C$ values than the deck ($P < 0.09$) and nose ($P < 0.04$; Figure 5.11) compartments.

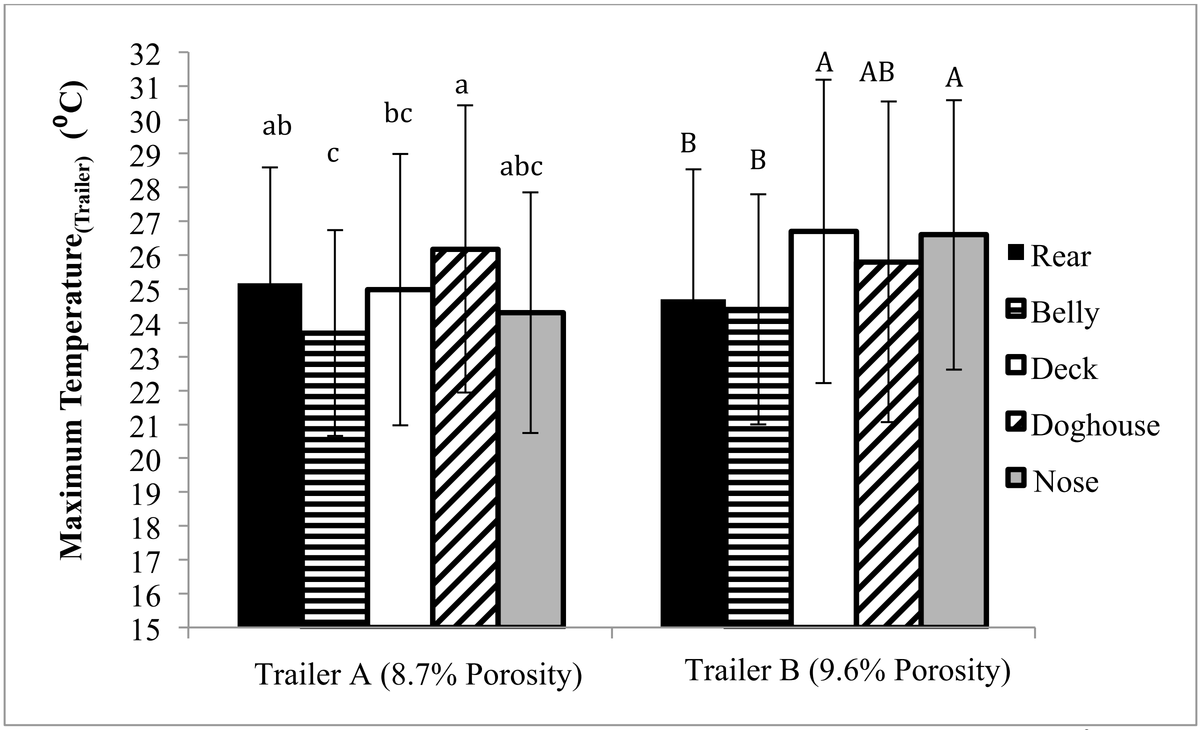


Figure 5.11. Least squares means (±SEM) for maximum trailer temperature ($T_{(trailer)}$ °C) within compartment during stationary events ($P < 0.07$).
[abc] Bars with different letter differ within Trailer A ($P < 0.10$).
[ABC] Bars with different letter differ within Trailer B ($P < 0.10$).

An interaction ($P < 0.10$; Figure 5.12) was observed between compartment location and trailer porosity for maximum ΔT. Maximum ΔT in the nose of Trailer B was 1.02°C greater ($P < 0.02$) than the nose of Trailer A. Furthermore, there were no differences in maximum ΔT observed between any of the compartments in Trailer A. However, there were differences observed in maximum ΔT for Trailer B. The maximum ΔT in the rear, deck, doghouse and nose compartments did not differ from one another. Finally, the belly had lower maximum ΔT than the nose ($P = 0.03$) and deck ($P < 0.10$) and the belly did not differ from the rear and the doghouse.

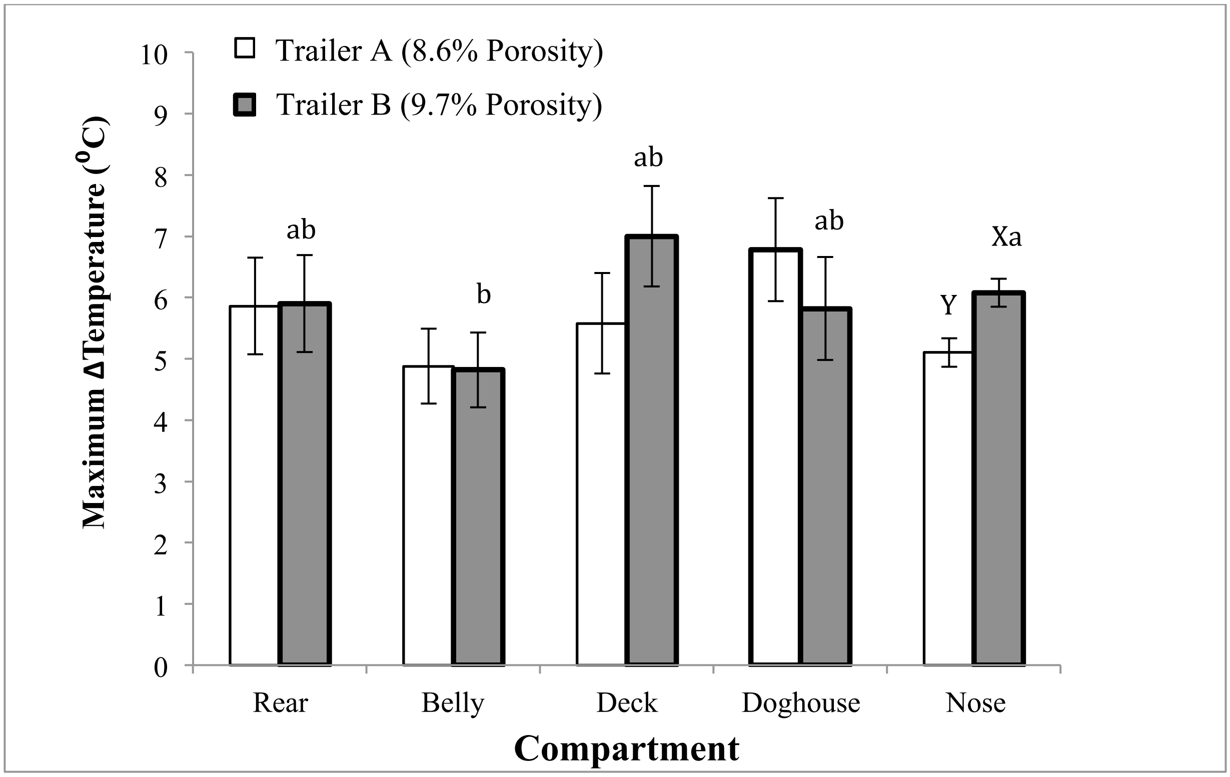


Figure 5.12 Least squares means (±SEM) for maximum ΔT within and between compartments during stationary events (*P* = 0.10).
[abc] Bars with different letter differ within Trailer B (*P* < 0.10).
[XY] Bars with different letter differ between Trailers (*P* < 0.10).

Mean $T_{(trailer)}$ °C and minimum and mean ΔT differed by compartment location during the stationary event (Table 5.9) and did not differ by trailer porosity. Mean $T_{(trailer)}$ °C did not differ between the rear, deck and doghouse compartments. However, the rear had lower (*P* < 0.006) mean $T_{(trailer)}$ °C than the nose (*P* = 0.006) and greater mean $T_{(trailer)}$ °C than the belly (*P* < 0.02) compartment. In addition, mean $T_{(trailer)}$ °C in the doghouse compartment was similar to mean $T_{(trailer)}$ °C in the deck and nose compartments and the doghouse tended to be lower than the belly (*P* < 0.08). Finally, the belly compartment had a lower mean $T_{(trailer)}$ °C compared to the deck (*P* < 0.02) and the nose (*P* < 0.0001) compartments.

The nose had greater minimum ΔT than the rear (*P* = 0.001), belly (*P* = 0.007), deck (*P* < 0.02) and doghouse (*P* = 0.0004) compartments. In addition, the deck had greater (*P* = 0.04) minimum ΔT than the doghouse compartment. Finally, the minimum ΔT in the rear and belly compartments did not differ (*P* > 0.13) from the deck and the doghouse compartments.

The deck compartment had greater mean ΔT values than the rear (P = 0.06), belly (P = 0.007) and doghouse (P < 0.05) compartments while the deck did not differ (P = 0.41) from the nose compartment. Furthermore, the nose mean ΔT was similar to the rear (P = 0.11) and doghouse (P = 0.15) but greater (P < 0.05) than the belly compartment. Finally, mean ΔT in the rear compartment did not differ from the belly (P < 0.45) and doghouse (P < 0.66) compartments.

Differences were found by trailer porosity for minimum $T_{(trailer)}$ °C and minimum ΔT during the stationary event. Trailer A had minimum $T_{(trailer)}$ °C and minimum ΔT values that were 1.5°C (P < 0.07) and 0.5°C (P < 0.10) lower, respectively, than in Trailer B (Table 5.9).

5.4.2 Relative humidity

No interactions between compartment and trailer porosity were observed for any of the $RH_{(trailer)}$% variables during the stationary event. Compartment had an effect on minimum and mean $RH_{(trailer)}$% and ΔRH in the stationary event. Minimum $RH_{(trailer)}$% in the belly was greater (P = 0.002) than the deck and doghouse (P < 0.004) and lower than in the nose (P < 0.07) while the belly compartment did not differ (P = 0.11) from the rear compartment. In addition, minimum $RH_{(trailer)}$% in the nose was greater than in the rear (P < 0.001), deck (P < 0.0001) and doghouse (P < 0.0001) compartments. Finally, minimum $RH_{(trailer)}$% values in the deck and doghouse did not differ (P = 0.65) however, the doghouse and deck differed from the rear (P < 0.05) and belly (P < 0.004).

Mean $RH_{(trailer)}$% in the nose, rear and belly compartments was greater (P < 0.03; Table 5.9) than in the deck and the doghouse compartments. In addition, the nose compartment tended to differ (P < 0.10) from the belly compartment. Furthermore, no differences (P > 0.19) were observed between the deck and doghouse compartments or between the nose, rear and belly compartments.

Compartment location had an effect on minimum ΔRH values (Table 5.9) indicating no differences between the deck and the doghouse compartments. However, the minimum ΔRH in the doghouse was lower than the nose (P < 0.001) and rear (P < 0.02) compartments. In addition, the minimum ΔRH in the doghouse compartment was similar to minimum ΔRH in the deck and rear while the deck compartment differed from the nose (P < 0.0001) and belly (P < 0.04).

The rear and belly compartments were found to have greater mean ΔRH than the deck ($P < 0.0001$) and doghouse ($P < 0.0001$) while the nose, rear and belly did not differ. Mean ΔRH in the doghouse compartment was similar to minimum ΔRH in the deck while the deck and doghouse compartments differed from the nose ($P < 0.03$).

There were no differences in maximum ΔRH between rear and belly compartments. However, the rear and belly compartments had greater maximum ΔRH when compared to the doghouse ($P < 0.004$) and nose ($P < 0.02$) compartments. In addition, the deck had greater maximum ΔRH values than the nose and doghouse ($P < 0.06$) and the deck was similar to the rear and belly compartments. Finally, the maximum ΔRH in the doghouse did not differ ($P = 0.35$) from the nose compartment.

Trailer porosity affected minimum RH, mean RH and minimum ΔRH. Trailer A had greater ($P < 0.09$) minimum RH, minimum ΔRH and mean RH values ($P < 0.10$) than Trailer B.

5.4.3 Temperature humidity index

A C×Tr interaction was observed for mean $THI_{(trailer)}$ ($P < 0.01$; Table 5.9) and maximum ΔTHI ($P = 0.09$) during the stationary event. Mean $THI_{(trailer)}$ in Trailer A was greater in the nose than the deck ($P < 0.03$) and belly ($P < 0.004$) compartments. In addition, the rear and nose compartments of Trailer A did not differ from any of the other compartments. Furthermore, mean $THI_{(trailer)}$ in the doghouse did not differ from the rear, belly, deck and nose compartments in Trailer A.

Mean $THI_{(trailer)}$ in the nose of Trailer B was greater than in the rear ($P < 0.0001$), belly ($P < 0.0001$), deck ($P < 0.005$) and doghouse ($P = 0.0004$; Figure 5.13) compartments. Furthermore, the doghouse and deck compartments did not differ in mean $THI_{(trailer)}$ in Trailer B. In addition, the rear and belly compartments had lower mean $THI_{(trailer)}$ values compared to the deck ($P < 0.02$) compartment. Finally, in Trailer B, the deck compartment had greater mean $THI_{(trailer)}$ than the rear ($P < 0.02$) and belly ($P < 0.001$) compartments and the deck did not differ from the doghouse.

Mean $THI_{(trailer)}$ in the nose compartment of Trailer B was greater ($P < 0.05$) than in Trailer A.

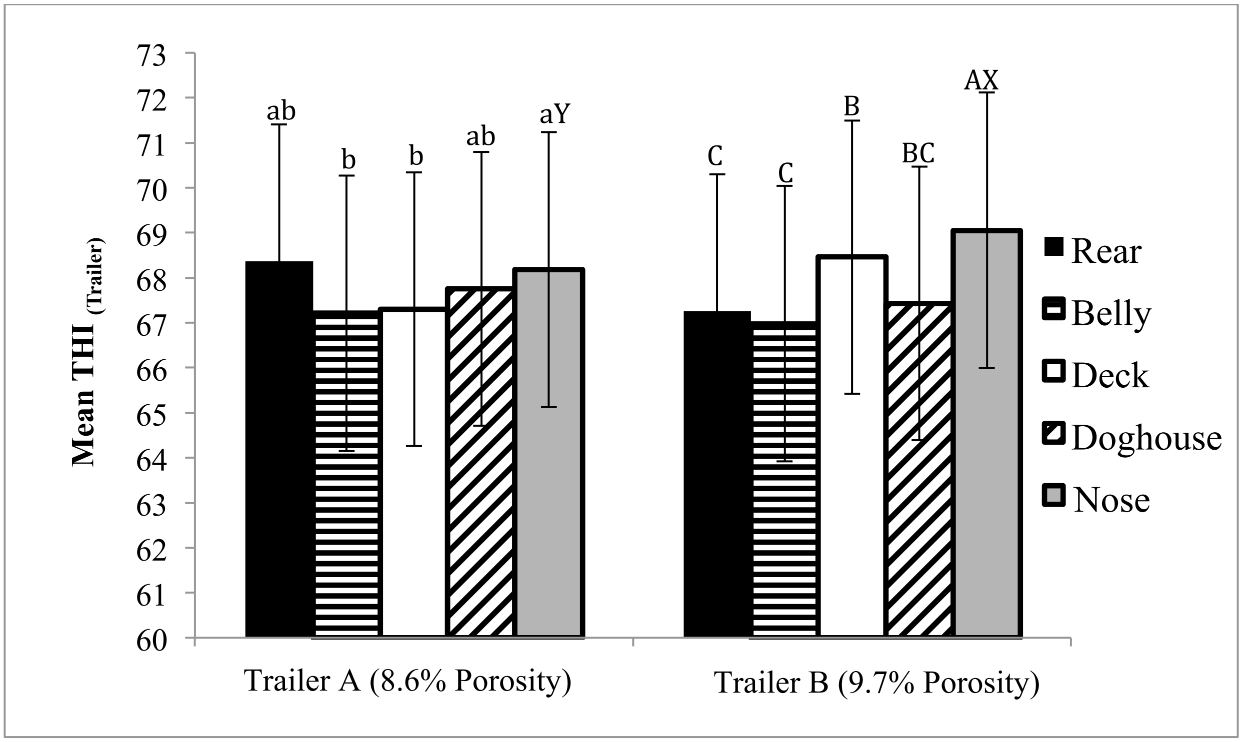


Figure 5.13 Least squares means (±SEM) for mean $THI_{(trailer)}$ by compartment and trailer porosity during stationary events ($P = 0.01$).
^{abc} Bars with different superscripts differ within Trailer A ($P < 0.05$).
^{ABC} Bars with different superscripts differ within Trailer B ($P < 0.05$).
^{XY} Bars with different superscripts differ between trailers ($P < 0.05$).

An interaction between compartment and trailer porosity was observed for maximum ΔTHI ($P < 0.09$; Figure 5.14) during the stationary event. The maximum ΔTHI in the doghouse of Trailer A was greater than the deck ($P < 0.08$) and nose ($P < 0.10$) compartments while the doghouse did not differ from the rear and belly. In addition, the maximum ΔTHI in the deck and nose did not differ from the rear and belly for Trailer A. The maximum ΔTHI in Trailer B was greater in the deck when compared to the belly ($P < 0.04$) while the deck did not differ from the rear, doghouse and nose. The maximum ΔTHI in the nose compartment of Trailer B was greater ($P = 0.03$) than in the nose of the Trailer A.

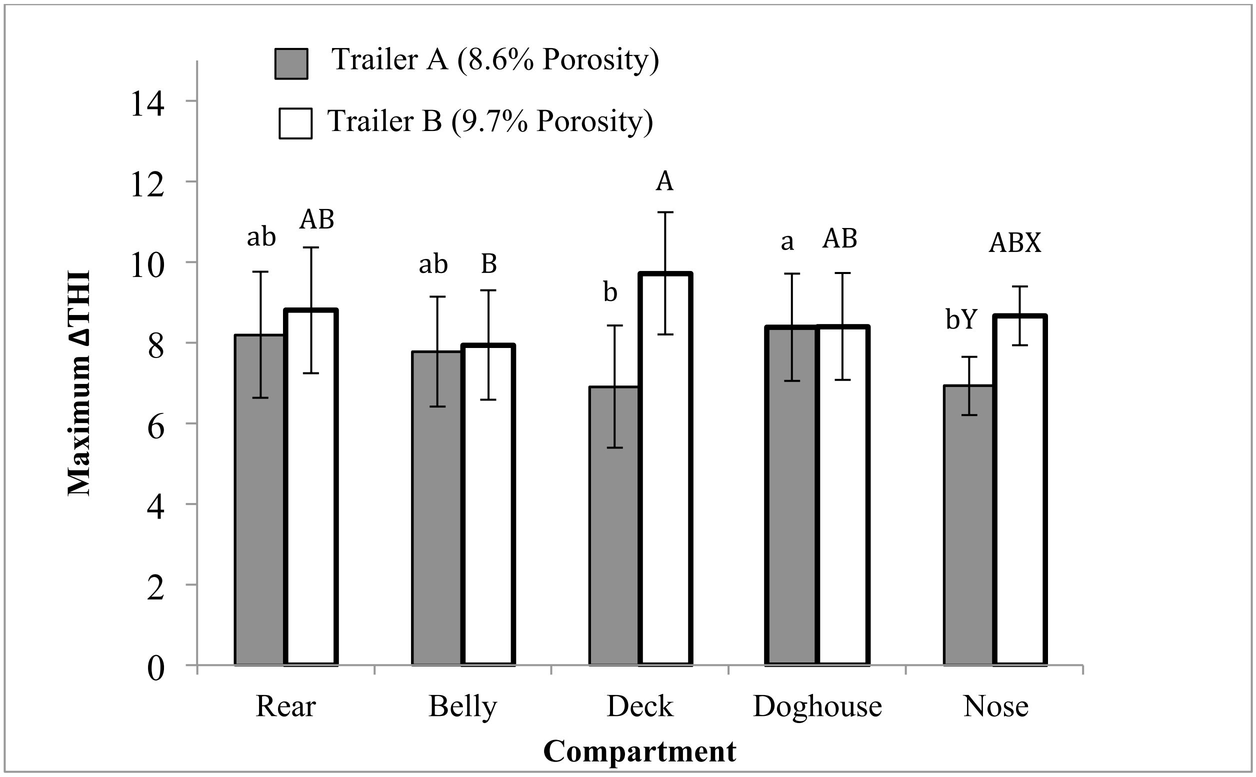


Figure 5.14 Least squares means (±SEM) for maximum ΔTHI within trailer compartment during stationary events ($P = 0.09$).
[abc] Bars with different letters differ within Trailer A ($P < 0.10$).
[ABC] Bars with different letters differ within Trailer B ($P < 0.10$).
[XY] Bars with different letters differ between trailers ($P < 0.09$).

There was a compartment effect for minimum and mean $THI_{(trailer)}$ and minimum and mean ΔTHI during the stationary event. The minimum $THI_{(trailer)}$ in the nose was greater ($P < 0.05$) when compared to belly ($P < 0.0001$) and deck ($P < 0.05$) compartments. In addition, minimum $THI_{(trailer)}$ in the nose did not differ ($P = 0.17$) from the doghouse and rear compartments and the doghouse did not differ ($P > 0.16$) from the rear, belly and deck compartments. Minimum $THI_{(trailer)}$ was greater ($P < 0.01$) in the rear compared to the belly.

When mean $THI_{(trailer)}$ was observed there were no differences between the rear, belly, deck and doghouse compartments. However, mean $THI_{(trailer)}$ in the nose was greater than the rear ($P = 0.03$), belly ($P = 0.001$), deck ($P = 0.003$), and doghouse ($P = 0.02$) compartments.

Furthermore, the nose compartment had a greater mean ΔTHI compared to the rear ($P = 0.02$), belly ($P < 0.02$) and doghouse ($P = 0.07$) compartments and the nose did not differ from deck compartment. Finally, mean ΔTHI in the belly was lower than in the deck ($P < 0.02$) and doghouse ($P < 0.10$) while the belly did not differ from the rear compartment.

Table 5.9 The effect of compartment location and trailer porosity on trailer micro-climate during stationary events

		Compartment Location(C)						Trailer porosity (Tr)			*P-Value*		
Micro-climate Variable		Rear	Belly	Deck	Doghouse	Nose	SEM[1]	A	B	SEM[1]	C	Tr	C×Tr
$T_{(trailer)}$ °C	Min	19.1	17.4	17.8	19.1	20.1	1.95	17.9^{B}	19.4^{A}	1.87	NS[3]	0.07	NS
	Mean	21.9^{ab}	21.5^{b}	22.3^{ab}	22.4^{ab}	22.7^{a}	2.01	21.9	22.3	2.85	0.0001	NS	NS
	Max	26.7	25.5	28.0	27.8	26.45	2.54	26.7	27.1	3.56	0.03	NS	0.07
$RH_{(trailer)}$%	Min	43.5^{bc}	45.3^{ab}	40.6^{d}	41.9^{cd}	47.4^{a}	6.96	45.3^{A}	42.2^{B}	6.93	<0.0001	0.0004	NS
	Mean	57.4^{a}	58.6^{a}	54.3^{b}	52.9^{b}	56.9^{a}	7.92	57.6^{A}	54.4^{B}	7.95	0.0001	0.09	NS
	Max	71.8	71.1	72.2	72.1	71.2	3.37	71.9	71.4	3.38	NS	NS	NS
$THI_{(trailer)}$	Min	63.1^{ab}	61.2^{c}	62.0^{bc}	62.7^{abc}	64.5^{a}	3.39	61.4	64.0	3.55	0.0002	NS	NS
	Mean	67.4	67.1	67.7	67.6	68.6	3.52	67.6	67.7	3.03	< 0.0001	NS	0.01
	Max	71.8	71.7	72.2	72.1	71.2	3.71	71.9	71.4	3.72	NS	NS	NS
$\Delta^{2}T$ °C	Min	0.28^{bc}	-0.39^{bc}	0.68^{b}	0.04^{c}	1.85^{a}	0.460	0.20^{B}	0.76^{A}	0.486	0.003	0.10	NS
	Mean	2.69^{ab}	2.41^{b}	3.26^{a}	2.83^{ab}	3.80^{ab}	0.370	2.82	3.18	0.302	0.023	NS	NS
	Max	5.60	5.42	5.50	5.75	5.72	1.080	5.46	5.73	0.379	0.05	NS	0.10
$\Delta^{2}RH$%	Min	-8.18^{ab}	-5.58^{a}	-10.50^{b}	-9.27^{b}	-5.43^{ab}	2.466	-5.83^{B}	-9.76^{A}	2.375	0.0006	0.09	NS
	Mean	4.98^{a}	5.49^{a}	0.52^{c}	1.28^{bc}	5.34^{ab}	3.161	5.19	1.85	3.501	0.0003	NS	NS
	Max	20.31^{a}	22.22^{a}	18.23^{ab}	11.62^{b}	13.04^{b}	3.768	23.64	15.60	5.123	0.001	NS	NS
$\Delta^{2}THI$	Min	0.87^{b}	-0.48^{b}	-0.09^{b}	-0.71^{b}	3.19^{a}	0.876	0.683	1.00	0.675	0.01	NS	NS
	Mean	4.14^{ab}	3.75^{c}	4.67^{a}	4.30^{bc}	6.88^{a}	0.588	5.08	4.41	0.609	0.007	NS	NS
	Max	8.49	7.85	8.30	8.39	7.79	0.984	7.63	8.70	1.207	NS	NS	0.09

[1]pooled SEM
[2]Δ Internal trailer micro-climate minus ambient micro-climate (sensors on mirrors of truck)
[3]NS = Not significant
[abcd] differ by compartment (P < 0.10)
[AB] differ between trailer (P < 0.10)

5.5 Shrink

A tendency towards a C×Tr interaction was observed for shrink. The rear compartment and combination of deck and doghouse compartments of Trailer A had greater (*P* < 0.05, Table 5.10; Figure 5.15) shrink than the belly compartment. However, there were no differences (*P* = 0.11) in shrink between the belly and the nose compartments. Shrink was lower (*P* = 0.06) in the rear compartment of Trailer B than the deck and doghouse compartments. Shrink in the nose compartment of Trailer B did not differ (*P* > 0.25) from the rear and belly compartments.

[1]Doghouse
[2]Pooled SEM

Table 5.10 The effect of compartment and trailer porosity on shrink

	Compartment location (C)					Trailer porosity (Tr)			*P-Value*		
	Rear	Belly	Deck* & DH[1]	Nose	SEM[2]	A (8.7)	B (9.6)	SEM[2]	C	Tr	C×Tr
Shrink	4.20[ab]	4.02[b]	4.38[a]	4.42[ab]	0.33	4.26	4.25	0.032	0.0009	NS[3]	0.0919

[3]NS = Non Significant
[ab]values differ by compartment (P < 0.05).
[*]Deck and Doghouse compartments were combined due to the redistribution of animals at the US/Canada border

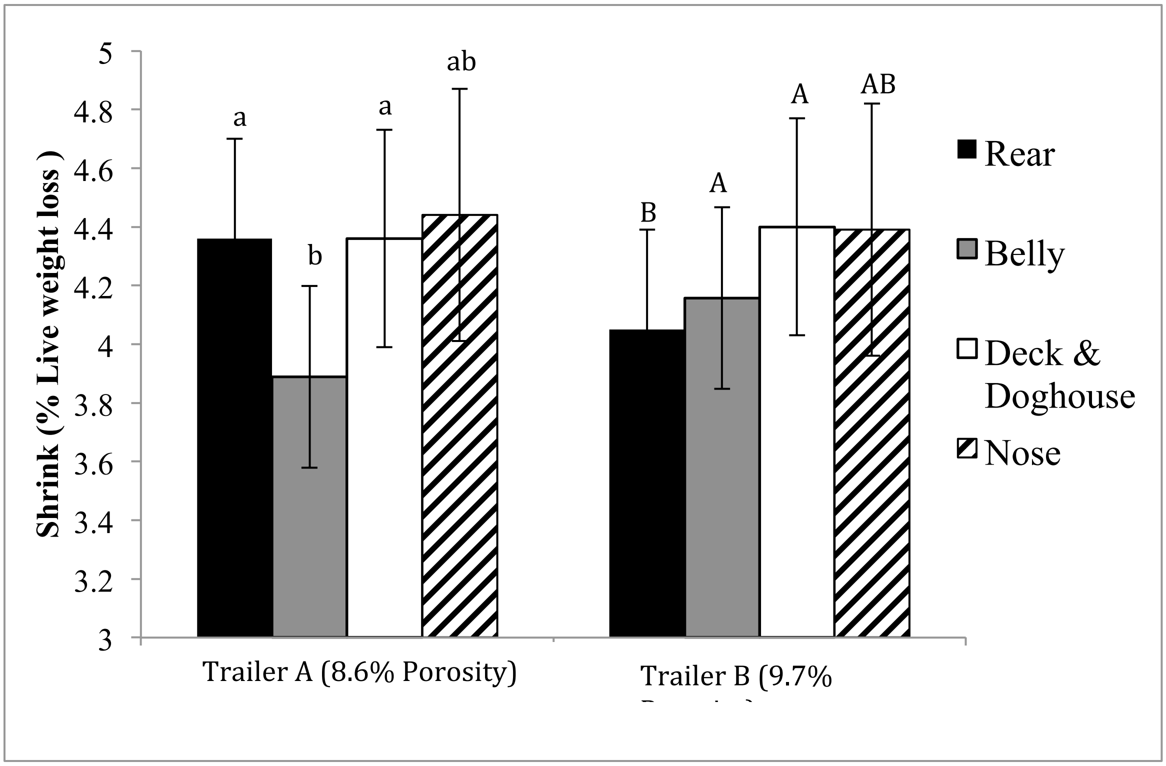


Figure 5.15 Least squares means (±SEM) for shrink by compartment location and trailer porosity (P < 0.10).
^{abc} Bars with different superscripts differ within Trailer A (P < 0.10).
^{ABC} Bars with different superscripts differ within Trailer B (P < 0.10)

5.6 Core body temperature

Least squares means (±SEM) for ΔCBT by compartment location (C), trailer porosity (Tr) and transport status (S) (stationary or in-transit) are presented in Table 5.11. There were no differences ($P > 0.47$) in ΔCBT observed for the main effects of compartment (C) and trailer porosity (Tr) or the interactions between compartment×status (C×S) and compartment× trailer×status (C×Tr×S). However there was a Tr×S interaction observed for ΔCBT. The change in CBT during the stationary status was 3 times greater ($P < 0.001$) than when the tractor-trailer was in-transit. The ΔCBT in Trailer A during the stationary status was greater ($P = 0.003$) than the ΔCBT in Trailer B for both the in-transit ($P = 0.002$) and stationary status ($P = 0.03$). In addition, ΔCBT in Trailer A during the in-transit status did not differ from the stationary status in Trailer B (Figure 5.16).

A C×Tr interaction ($P < 0.10$, Figure 5.17) was observed for ΔCBT between compartment and trailer porosity. There were no differences observed between the compartments within Trailer B however, there were differences observed within Trailer A. The deck compartment of Trailer A had a ΔCBT almost 5 times greater ($P = 0.003$) than the ΔCBT in the deck of Trailer B. Furthermore, the deck of Trailer A was different from the rear ($P = 0.10$), belly ($P = 0.03$), and doghouse ($P = 0.006$) compartments, while the deck did not differ from the nose compartmen

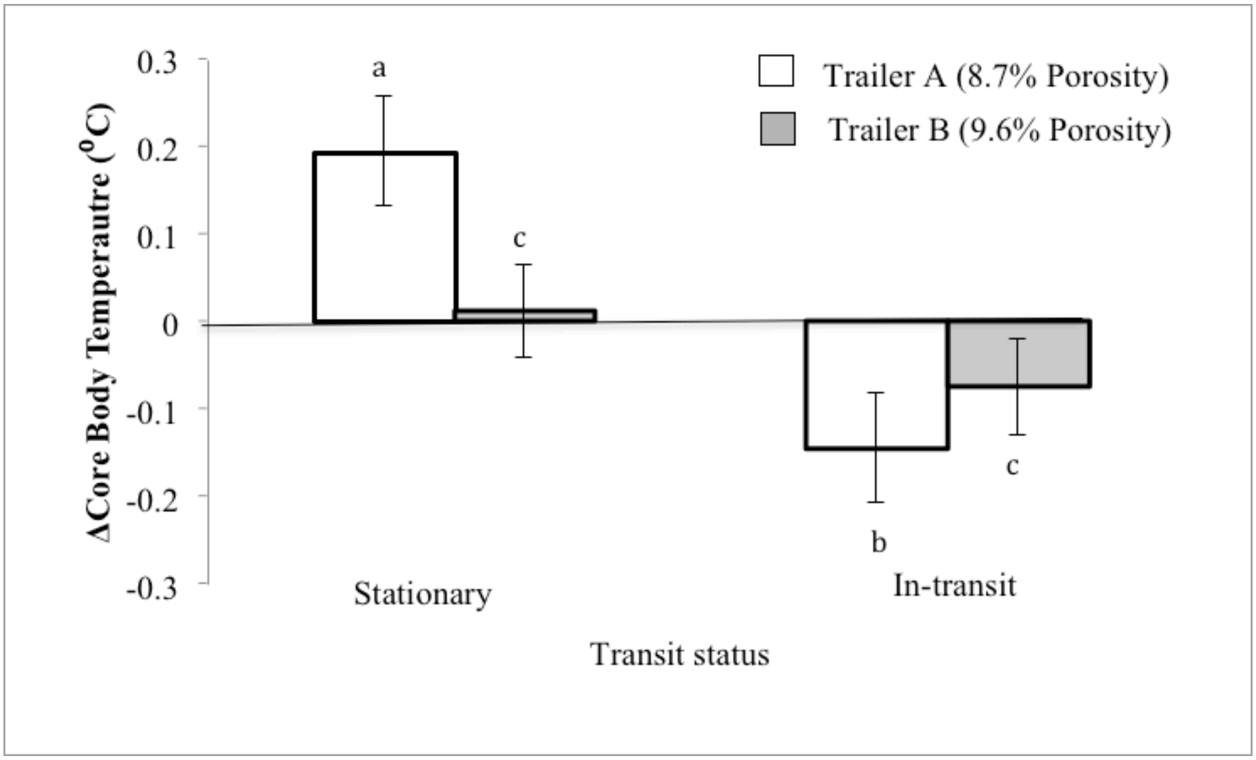


Figure 5.16 Least squares means (±SEM) for ΔCBT by trailer porosity and transit status ($P < 0.006$).
[abc] Bars with different letters differ ($P < 0.001$).

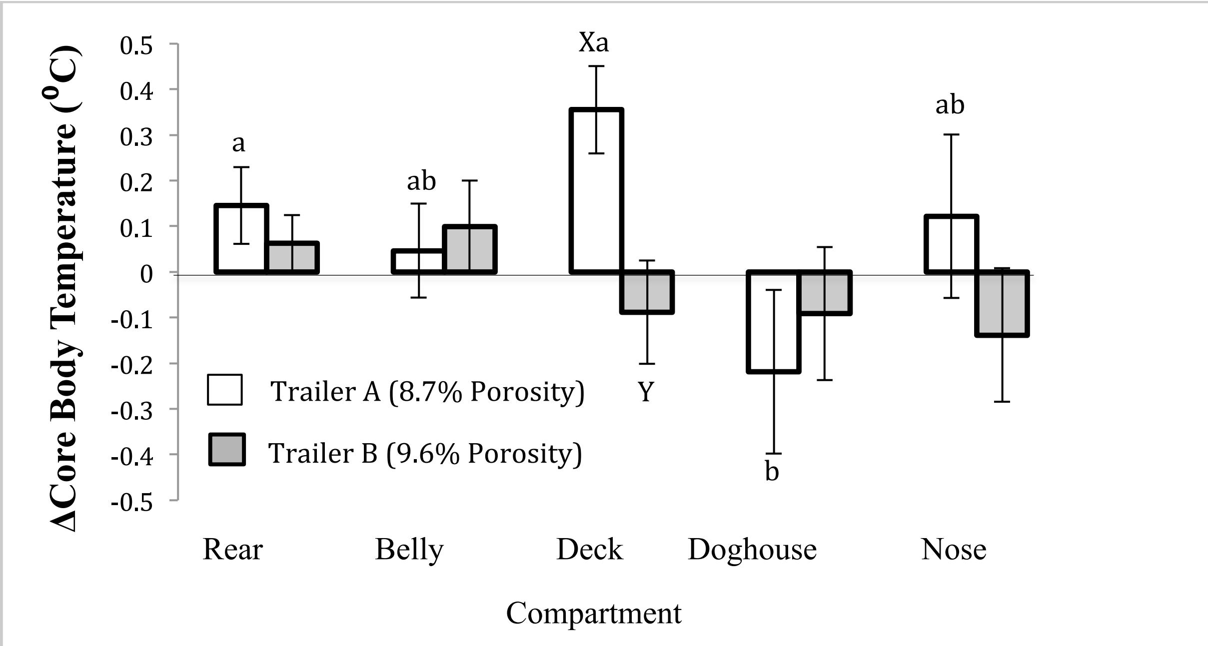


Figure 5.17 Least square means (±SEM) for ΔCBT by compartment location and trailer porosity ($P < 0.09$).

[abc] Bars with different letters differ within Trailer A (P < 0.10).

[XY] Bars with different letters differ between Trailers (P < 0.10).

Table 5.11. Effect of transit status, compartment and trailer porosity on ΔCBT.

	Compartment location (C)						Transit Status (S)			*P-Value*						
Variable	Rear	Belly	Deck	DH[1]	Nose	SEM[2]	Stationary	In-transit	SEM[2]	S	C	Tr	C×Tr	C×S	Tr×S	C×Tr×S
ΔCBT	0.1038	0.0730	0.1334	-0.1551	-0.0083	0.08458	0.103[A]	-0.044[B]	0.0557	<0.0001	NS[3]	NS	0.09	NS	0.006	NS

[1] Doghouse
[2] Pooled SEM
[3] NS = Non Significant
[AB] Differ by transit status ($P < 0.05$).

5.7 Data logger location

The least squares means (±SEM) for $T_{(trailer)}{}^{\circ}C$ by compartment location, trailer porosity and data logger level (animal level or trailer ceiling) are presented in Table 5.12. No interactions were observed between compartment (C), trailer porosity (Tr), and data logger (L) location. However, an interaction ($P < 0.02$) was observed for trailer temperatures by data logger location and trailer porosity (Tr×L). Overall, trailer temperature recorded at the ceiling level was 2.8°C cooler ($P < 0.001$) than at animal level. Differences between the ceiling and animal level for Trailers A and B were 3.38°C and 2.23°C, respectively (Figure 5.18).

There were no differences observed for trailer temperatures during the in-transit hour between 1500 and 1600 h by trailer porosity (Tr), however there were differences by compartment (C) with the nose and deck having greater ($P < 0.01$) temperatures than the belly, doghouse and deck compartments. Finally, logger placement (L) (drivers side, middle, passenger side and front, middle back) did not affect any of the micro-climate variables assessed in this study.

Table 5.12 The effect of data logger level on trailer temperature

	Compartment location (C)						Data logger level (L)			*P-Value*						
Variable	Rear	Belly	Deck	DH[1]	Nose	SEM[2]	Ceiling	Animal	SEM[2]	L	C	Tr	C×Tr	Tr×L	C×L	C×Tr×L
$T_{(trailer)}$	20.1[b]	20.4[b]	21.0[a]	20.2[b]	21.1[a]	1.13	19.1[B]	21.93[A]	1.11	<0.0001	0.007	NS[3]	NS	0.014	NS	NS

[1]Doghouse
[2]Pooled SEM
[3]NS = Non Significant
[ab] Differ by compartment (P < 0.5).
[AB] Differ by data logger level (P < 0.5).

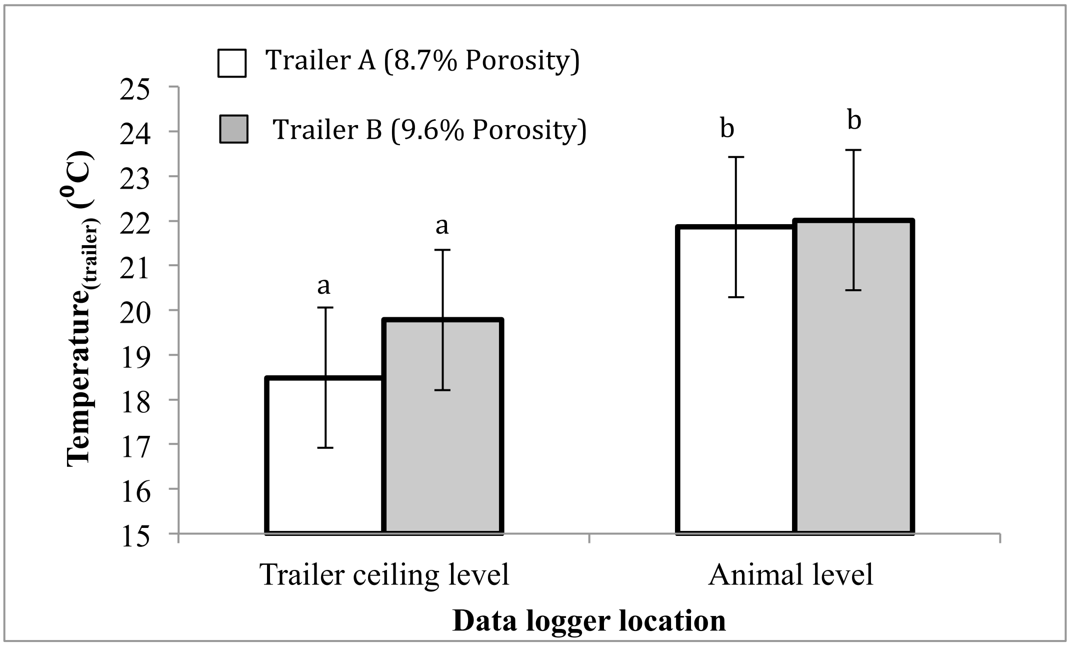


Figure 5.18 Least squares means (±SEM) for trailer temperature ($T_{(trailer)}$ °C) by trailer porosity and data logger location.($P < 0.02$).
[ab] *Bars* with different letters differ between data logger location ($P < 0.001$).

6.0 DISCUSSION

To my knowledge, this is one of the first studies characterising micro-climate conditions within a livestock trailer for slaughter cattle under North American conditions. Results of the current study show that the micro-climatic conditions cattle are exposed to during summer transport vary considerably between the hour of day and among compartment locations within a trailer. There were also varying conditions depending on whether the tractor-trailer was stationary or in-transit.

These results indicate that there were small differences between trailer porosity and the majority of the differences in micro-climate conditions, shrink and change in core body temperature were a result of compartmental location variation. The potential negative effects of stationary events during transport were observed in this study. These results also suggest that porosity can have an impact on the potential risk of heat stress for cattle during summer transport.

6.1 Descriptive statistics: extreme temperatures

Other studies have shown a clear relationship between cattle welfare outcomes during transport and ambient temperature. For example, negative welfare consequences to beef cattle such as lameness and the risk of becoming non-ambulatory during transport were shown to increase when ambient temperatures were greater than 20°C during the long-haul transport of beef cattle under environmental conditions similar to the present study (González *et al.,* 2012d). In addition, a sharp increase in mortality was reported when ambient temperatures were greater than 35°C (González *et al.,* 2012d). No mortalities were recorded in this study. Throughout the present study including all 5 trips, the average trailer temperatures during the warmest in-transit hour were above 30°C, 40% of the time. In a study by González *et al.* (2012a), maximum ambient temperatures were reported to be equal to or greater than 30°C, 22% of the time and greater or equal to 40°C, 1% of the time. However, during the warmest hour of the trip that had the greatest average ambient temperature (25.9 ± 6.06°C), trailer temperatures were greater than 30°C, 97% of the time which could be further broken down into ranges from 30 to 34°C, 16% of the time and 35 to 39°C, 81% of the time. Although, ambient temperatures have been shown to be highly correlated to the trailer temperatures (Goldhawk *et al.,* 2011) the specific effects of compartment location and whether the tractor-trailer unit is stationary or in-transit on animal outcomes are not accounted for by using ambient temperature. This suggests that using internal trailer temperatures may provide a more accurate assessment of the potential risk for heat stress for cattle during transportation.

Trailer micro-climate conditions during summer transport can have the potential to pose a greater risk of heat stress for cattle. According to the Livestock Weather Hazard Index (LWHI) the warmest in-transit hour was categorized as safe 54% of the time, in the danger category 24% of the time, and in the emergency category 1% of the time. However, during the warmest trip that had average ambient temperatures of 25.9 ± 6.06°C, the LWHI was only in the safe category 3% of the time, and in the danger and emergency categories 81% and 14% of the time, respectively. These results indicate that extreme caution should be taken during warm ambient conditions as there is potential risk for cattle to experience heat stress during transportation under similar conditions to this study.

6.2 Descriptive statistics: maximum delta temperature

The average maximum ΔTemperature indicated when there was the greatest difference between the outside ambient and trailer temperature each compartment during the stationary event during the warmest trip. The average maximum ΔTemperature was the greatest in the doghouse for Trailer A and the deck and doghouse for Trailer B. These results suggest that cattle transported in those compartments may have a greater risk of experiencing heat stress during stationary periods. The average maximum ΔTemperature was reached for Trailer A between 19 (doghouse compartment) and 29 (rear and belly compartments) minutes. Whereas maximum ΔTemperature was reached between 18 (deck and doghouse) and 25 (nose) minutes for Trailer B. These results could suggest that when the average ambient temperatures of the entire trip are 25.9 ± 6.06°C that stationary periods should be less than 20 minutes. However, this time limit may not protect the animals and serve as preliminary findings for further research to substantiate and/or refute this theory.

Furthermore, results of the current study found that trailer temperatures can be up to 10.5°C warmer than ambient conditions during stationary events and 9°C warmer during warmest in-transit hour when the trip had average ambient temperatures of 25.9 ± 6.06°C. The difference between internal and external trailer temperatures found in this study were greater than reported by Wikner *et al.* (2003) who indicated that trailer temperatures were 3°C warmer than ambient temperatures during summer (7.8 ± 24.0°C) and 6°C warmer during winter (-24.3 ± 12.7°C) in

Sweden. Reasons for this discrepancy could be explained by differences in ambient temperature as well as trailer type and geographic location.

6.3 Entire journey

There was a time of day effect on all micro-climate parameters for the entire journey analysis. Cattle had an increased risk for heat stress in the afternoon, particularly between 1700 and 1900 h. Although, the micro-climate was assessed while the tractor-trailer was in-transit during the warmest in-transit hour it can be speculated that stationary periods in the late afternoon could pose an even greater risk for heat stress. This is typically the time period when cattle from Alberta would arrive at the US packing plants where waiting times and stationary periods are common.

When discussing relative humidity during the entire journey, psychrometric principles must be taken into consideration, because temperature has a significant effect on relative humidity. Temperatures within Trailer B were 1.1°C greater than within Trailer A and resulted in 30% lower ΔRH values in Trailer B compared to Trailer A for the entire journey. These results are consistent with psychrometric properties of air:water mixtures, where warmer air can hold more moisture. For this reason, relative humidity cannot be discussed independently of temperature and relative humidity will only be discussed in the context of THI.

6.4 Effect of compartment location

Nose compartment

The trailer micro-climate during the stationary event and warmest in-transit hour in the present study were affected by compartment location and are consistent with other studies (Wahrmund *et al.,* 2012; Weschenfelder *et al.,* 2012; Fox*,* 2013; Brown *et al.,* 2011). The nose had the greatest mean Temperature and ΔTemperature values during both the stationary event and warmest in-transit hour in this study. Many studies have reported the front compartments located directly behind the tractor tend to be warmer (Brown *et al.,* 2011; Fox*,* 2013). This can be explained by the fact that the tractor blocks airflow to the front compartment. Greater front compartment temperatures may also be related to heat generated from the drives of the truck that are directly below the compartment as well as the heat generated from the engine that is in close proximity (Brown *et al.,* 2011; Fox*,* 2013).

The airflow into the transport trailer is a result of aerodynamic drag or resistance between the trailer and outside air. Ventilation plays an important role in balancing trailer temperature and moisture and the ventilation for livestock trailers occurs through the openings or porosity in the trailer (Warris, 1999). The nose compartment of the trailers used in this study had the largest air volume per animal which was a positive aspect for balancing micro-climate parameters between the ambient and trailer. A compartment with large air volume has more air available for exchange which could allow for optimum airflow in warm weather (Purswell *et al.,* 2006). However, the nose in this study had the lowest porosity (4.5%) compared to the rest of the compartments in the trailer. The nose compartment of the trailers used in this study had a solid roof and front (porosity of 0%). The combination of aerodynamic properties of the tractor-trailer unit, heat transfer from the drives and low porosity may explain the reduced airflow and could be contributing to high heat load in the nose compartment. Potential design improvements to increase natural ventilation in the nose could include maximizing nose vents or adding a roof hatch.

The nose compartment in Trailer B had a greater maximum ΔTemperature than Trailer A even though porosity was slightly higher in Trailer B. This could be a result of the difference in the aerodynamics of the tractors (Western star and International) used in study. This would include the differences in the shape of the hood, roof, bumper seal and gap, chassis skirt and fender lines.

Upper decks

The upper trailer compartments (deck and doghouse) in this study had greater THI values than the lower compartments (belly and rear). In agreement, with results of the present study, European two-tiered trucks were also found to have higher temperatures in the upper decks when compared to the bottom deck compartments (Christensen and Barton-Gade, 1999; Fiore *et al*., 2009). Evidence of the greater potential for cattle to experience heat stress in the upper compartments could be a result of solar radiation (Brown *et al*., 2011; Stanford *et al*., 2011) associated with the thermal conductance of the aluminium roof. Trailers used in this study had a solid aluminium roof (minus the roof hatches) with a large surface area facilitating heat transfer (from solar radiation) into the deck and doghouse compartments. Although, it is likely that convective heat loss from the roof of the trailer occurred when the tractor-trailer unit was in-transit thereby reducing some of the effects of the thermal conductance, it may not be sufficient to mitigate heat gain due to solar radiation. Another, factor that could contribute to the increased THI in the deck compartment could be obstruction of side-wall perforations by the internal gate.

The porosity of internal gates in this study was not measured as it was not a primary objective in this thesis. However, internal gates in the trailers could reduce airflow by blocking perforations. The internal gate in the deck of the trailers used in this study were not used during transportation and remained in position flat against the sidewall of the trailer. The internal gate in the deck has the potential to block 30% or more of the side perforations on the passenger sidewall of the trailer which, could reduce airflow in the compartment.

Higher THI values found in the upper level compartments may also be related to heat transfer from the cattle in the lower deck compartments facilitated by air movement through internal gates and the ¾ doghouse configuration. This theory can be supported by thermal buoyancy principles indicating warm air is less dense than cold air, thus warm air rises. Additional reasons for the doghouse having greater THI values than the rest of the compartments in the trailer, is that it has less air volume per animal as a consequence of a lower ceiling height. It is common industry practice to place smaller framed animals in the doghouse compartment, however, depending on the frame and volume of the cattle the animals themselves could be obstructing perforations and impeding airflow. The combination of the thermal buoyancy, solar radiation, and lower air volume could contribute to the risk of heat stress in the doghouse compartment and upper decks.

Lower decks

In general, the lower decks (belly and rear) in this study tended to have the lowest temperature and THI values within the trailer. These findings are in agreement with the findings of Brown *et al.* (2011) and Christensen and Barton-Gade, (1996) and Fiore *et al*. (2009) who also reported lower temperature variables in the lower decks of the trailer during pig and cattle transport. This could be due to the fact that both of the lower decks are shielded from solar radiation resulting in a lack of thermal transmission from the roof and minimal effect of thermal buoyancy.

6.5 Effect of trailer porosity

Trailer B had greater maximum temperature, maximum THI and maximum ΔTHI values than Trailer A. This suggests that trailer porosity had an effect on temperature variables within the trailers however, whether this difference is entirely due to porosity is not known and additional research is needed. For example, factors such as the type and aerodynamics of tractor, the use of roof hatches and effects of perforation obstructions could have substantial impact on trailer temperatures. It is interesting to note, that although Trailer B had 0.9% greater overall porosity compared to Trailer A, it also had higher THI values than Trailer A. This could be a result of the location of the perforations in the trailer or the fact that Trailer A had 4 roof hatches while Trailer B only had 2 roof hatches. The presence of roof hatches may allow heat and moisture to escape more readily than the side-wall perforations of the trailer. It could be speculated that the roof hatches have a key role in alleviating heat stress in transport trailers in summer months. The two trailer types used in this study had similar compartment porosities with the exception of the rear and the deck compartments and these differences will be discussed below.

6.5.1 Rear compartment of Trailer A

The maximum temperature values in the rear compartment of Trailer A tended to be similar to the nose and doghouse compartments that had the greatest temperature values in the trailer. In contrast, the rear of Trailer B had lower maximum temperature values than the deck and doghouse compartments and was comparable to the belly compartment. This difference is interesting since the rear compartment of Trailer A had 5.8% lower porosity than the rear compartment of Trailer B indicating that porosity could play an important role in managing heat stress in the rear compartment. Our finding of greater temperatures in the rear compartment of Trailer A differs from Brown *et al.* (2011) and Fox (2013) who reported that the rear compartment was one of the compartments with the lowest THI values which they attributed to greater airflow. Although, airflow was not measured in the current study, it was speculated that the differences in compartmental micro-climate could be due to airflow and ventilation properties. Other studies have also suggested that airflow patterns differ by compartment location. For example, Brown *et al*. (2011) and Kettlewell *et al*. (2001) reported that air enters the trailer from the rear and moves forward towards the tractor. However, other studies have reported the opposite theory, where the direction of airflow in livestock trailers occurs opposite to the direction of travel, entering from the front of the trailer and exiting out the back (Burlinguette *et al*., 2011; Hoxey *et al*., 1996; Baker *et al*., 1996). It should be noted that the vast majority of cattle trailers have solid back doors, thus obstructing airflow from the rear towards the front of the trailer. If the airflow in the cattle trailer flows from the front of the trailer to the rear, heat and moisture could accumulate in the rear compartment. The results of this study are in agreement with Burlinguette *et al*, (2011), Hoxey *et al*, (1996), and Baker *et al*, (1996) suggesting that the air flows from front to back in the rear compartment. In addition, the rear compartment may have less ventilation as a result of the loading rail that could block up to 40% of the side perforations on the passenger sidewall. Because the rear compartment of Trailer A had greater $THI_{(trailer)}$ values than expected, it could be speculated that as the tractor-trailer unit is traveling at high speeds the air could become trapped in the rear compartment because airflow is reduced due to obstructions. Another reason for greater $THI_{(trailer)}$ values in the rear of Trailer A could be due to the accumulation of heat and moisture from the rest of the trailer.

6.5.2 Deck compartment of Trailer A

The deck compartment of Trailer A tended to have lower $THI_{(trailer)}$ values than the nose while the deck was similar to the belly, which had the lowest $THI_{(trailer)}$ value. Possible reasons for the difference in temperatures in the deck compartment of the two trailers could be related to porosity and the location of the inlet/outlets within the deck compartment. The sidewall porosity of Trailer A was 10.3% while the sidewall porosity of Trailer B was 12.2%. However, the deck roof porosity of Trailer A was 7.5% while Trailer B had a roof porosity of 4.8%. Although, Trailer B had greater sidewall porosity, its roof had a lower porosity than Trailer A resulting in a total compartment porosity difference of 2%. This finding suggests that the location of the inlets could have a significant impact on the micro-climate within a compartment and that roof hatches play a critical role in allowing heat to escape from the deck and doghouse. Future manufacturing considerations could include maximizing porosity, including roof hatches that could improve airflow in cattle liners during summer transport.

6.5.3 Doghouse compartment of Trailer A

Trailer temperature and ΔTemperature values in the doghouse were the same as the nose, deck, belly and rear compartments in both trailers during the stationary event. Trailer B did not have a roof hatch in the doghouse while Trailer A had a roof hatch located above the opening of the ¾ doghouse configuration. The porosity in the doghouse compartment of Trailer A was 7.43% and in Trailer B it was 6.97%, yielding a difference of 0.46%. It was expected that the doghouse in Trailer A would have lower trailer temperatures than the doghouse in Trailer B, however, the opposite was found. Higher temperatures were generally found in the doghouse of Trailer A even though Trailer A had 0.46% greater porosity. This may have been due to the fact that substantial accumulation of heat in the rear compartment influenced the doghouse temperature even though Trailer A had a roof hatch.

In general, there was no common pattern in the micro-climates of the compartments between the different trailer types. It is possible that within a trailer type, the micro-climate of one compartment could influence the micro-climate of an adjacent compartment. For example, the belly of Trailer A had similar temperatures to the deck compartment. However, the belly in Trailer B had similar temperatures to the rear compartment. The micro-climate of each compartment has an impact of the overall trailer micro-climate where heat could be transferred from a warmer to colder compartment in an attempt to reach a balanced homogenous environment. It is possible, once there is an imbalance in micro-climate conditions within the trailer, other compartments could be absorbing or transferring the extra heat to reach equilibrium. For example, the doghouse in Trailer A could be compensating for heat load from the rear compartment below.

6.6 Shrink

The average shrink (4.31 ± 0.3 %) found in this study was less than the Alberta industry standard of 4.5% (Albert Feedlot Guide, 2002) and less than similar transport studies. For example, Greer *et al.* (2011) reported average shrink values of 4.47 ± 0.3 % while González *et al.* (2012b) reported values of 4.9 ± 0.1 % for fat cattle transported in Alberta. When González *et al.* (2012b) corrected shrink values to include the effects of origin, loading time, driver experience, time on truck and temperature (4.36 ± 0.3 %) similar values to the shrink found in this study were reported. Giguere (2006) reported shrink to be 4.7% for cattle transported within Texas in a trailer fitted with scoops to increase ventilation. González *et al.* (2012b) noted that the combined effect of transport duration and high ambient temperature are important factors when predicting shrink.

Results here showed a significant effect of compartment location on shrink. This was in contrast to the findings of Camp *et al.* (1981) who indicated that the compartment of the trailer that the cattle were transported in did not affect shrinkage. Reasons for this discrepancy could be due to the fact that Camp *et al*. (1981) used feeder calves in Kentucky and Tennessee, where this study used fat cattle ready for slaughter in Alberta. Feeder cattle tend to have greater shrink (González *et al.*, 2012b) Furthermore, our results indicated that compartments with greater risk of heat stress (greater THI) also had greater shrink. The compartments that were the hottest (nose, deck and doghouse) also had the greatest shrink, while the belly had the lowest shrink. This is similar to the results reported by Greer *et al.* (2011) who also found that fat cattle had greater shrink in the deck/doghouse (4.86± 0.2 %) and the nose (4.72± 0.2 %) compartments compared to the belly (4.24± 0.2 %) and rear (4.04± 0.4 %) during long-distance transportation.

Average shrink was not different between the two trailer porosities used in the study. However, there were compartmental differences within each trailer that can be explained by the micro-climate patterns associated with trailer temperatures and THI variables. As indicated previously, there were differences in porosity between the rear compartment and the deck of each trailer. The belly of Trailer A had lower THI and shrink values than the rest of the compartments within the same trailer. In Trailer B, the rear and belly compartments had the lowest THI variables and also lower shrink values. Airflow can play an important role in reducing trailer temperature and THI during transportation. For example, a study conducted in Texas compared the cattle shrink values for animals transported in a trailer with added ventilation using wind scoops and animals transported in a trailer without scoops. The results showed that increased ventilation reduced the shrink from 5.75% to 4.70% (Giguere, 2006). However, the scoops were deemed not industry relevant due to the substantial increase of fuel costs the scoops posed the truck.

6.7 Core body temperature

Results here indicate that transit status and trailer porosity had an effect on CBT as demonstrated by differences in the change from baseline vaginal temperatures when cattle were subject to transportation events (stationary or in-transit). Many studies have reported a decrease in CBT or negative change from baseline during the in-transit event when the trailer is moving and airflow is maintained in pigs (Fox, 2013) and sheep (Ingram *et al.,* 2002) and cattle (Stockman *et al.,* 2011). The decrease in CBT when the trailer was in-transit and airflow was maintained could be explained by a homoeothermic response to dissipating heat from physical exertion during loading (Tamminga *et al*., 2009) or that livestock are not subject to stress.

In the present study, the ΔCBT of fat heifers in Trailer A during in-transit events was the same as the ΔCBT in Trailer B during both stationary and in-transit events. It appears that the stationary event in Trailer A tended to have the greatest impact on homoeothermic balance during transportation which suggests that animals were unable to cope with heat challenge during stationary events which could be explained by reduced airflow and lower overall trailer porosity. Tamminga *et al*. (2009) reported similar results during pig transport where CBT was higher during stationary periods when compared to other periods (pre-loading, in-transit, in-lairage). The stationary events are associated with higher heat loads and less airflow to remove accumulated heat and moisture that can have an effect on thermoregulation and result in greater CBT (Tamminga *et al*., 2009) or ΔCBT.

Cattle transported in Trailer A had greater variation in ΔCBT than those transported in Trailer B which may indicate that the animals in Trailer A were using heat dissipating mechanisms to return to homeostasis. Although Trailer A had lower micro-climate values when compared to Trailer B, the animal's ΔCBT response could explain the importance of porosity location within the trailer. For example, Trailer A had fewer side-perforations than Trailer B and it could be proposed that porosity along the side wall of the trailer is beneficial to the animals to dissipate heat and provide fresh air exchange since the ventilation provided by the side perforations is in close proximity to the respiratory tract of the animals standing perpendicular to side-wall during transport. The roof hatches may facilitate the removal of accumulated heat and moisture and lower micro-climate thermal conditions at a compartment level. In addition, the two eclipse shaped (5.1 X 7.6 cm) perforations on Trailer B is similar to the size of a muzzle (nose) of a fat heifer and may better facilitate air exchange when compared to the perforation punch hole pattern of Trailer A comprised of 3 circles with a radius of 3.8 cm. This could explain why the ΔCBT results did not follow the micro-climate results that would be expected.

Cattle transported in the top deck compartments of Trailer A had greater ΔCBT values than the other compartments in Trailer A. This finding was in agreement with Tamminga *et al*. (2009) who also reported that CBT in pigs was higher in the top deck compartments. It is unclear why cattle transported in the deck compartment had greater ΔCBT because the trend does not follow the micro-climate patterns observed. The deck compartment in Trailer A tended to have similar micro-climate parameters (mean THI) as the belly compartment which was the coolest compartment in Trailer A. One possible explanation could be that the stationary events in our study occurred at the Canada/US border crossing where animals were relocated from the deck compartment to the doghouse, causing stress which, may have increased their ΔCBT values. The same findings were not observed for Trailer B.

Recent research by Wahrmund *et al*. (2012) found that there was an effect of compartment location within the trailer on ruminal temperature. They found greater ruminal temperatures in the heifer calves that were transported in the bottom deck of the nose. The deck compartment was gated into three sections, and heifers transported in the middle deck section had the greatest ruminal temperatures. They also found that the heifers located in the doghouse had the lowest ruminal temperatures. Heifers that experienced greater ruminal temperatures (bottom deck of nose) also had a higher incidence of respiratory disease suggesting the compartment location and micro-climate can affect animal health. White *et al.*, (2009) also suggested differing compartmental conditions may have a negative effect on animal health and performance. There was a clear effect of compartment location on micro-climate and animal welfare outcomes found in this study.

6.8 Data logger location

The temperature difference between the location of the data logger at animal level and trailer ceiling was 3.38°C for Trailer A and 2.23°C for Trailer B. This could suggest that excess heat in the trailer with the lower porosity, that also had lower overall temperatures, exited through roof hatches, while in the trailer with the higher porosity, the heat escaped through the side-wall perforations. This also suggests that the porosity location on the trailer may be important to alleviating heat stress in summer months during transport. Greer *et al.* (2011) also found that the animal-level temperature was 1.18°C higher than at the trailer ceiling during the transport of slaughter heifers however, the difference was not statistically significant as in our study. This may be due to the fact that data in their study were averaged over morning, afternoon and evening periods while the data in this study was the average of a 1-h time period in the afternoon, because there was a significant time of day effect. Goldhawk *et al*. (2010) reported that during the transport of feeder cattle, the temperature at animal level was 1.07°C higher than at the trailer ceiling level. It is expected that animal-level temperatures during the transport of slaughter cattle would be greater than for feeder cattle because slaughter cattle produce greater metabolic heat and are larger and occupy more space, which could result in less volume of air in each compartment that is available for air exchange. Goldhawk *et al*. (2011) reported that the location of the sensor within the compartment also had an effect on estimating animal-level conditions. They noted that data loggers in the middle of the compartment of the belly and deck had the closest relationship with animal-level temperature.

The results of this study also support that the animal-level temperatures are affected by compartment location. The animal-level temperatures were consistent with the micro-climate results for this study where the nose and deck were warmer compartments than the rear and belly.

The results of this study also indicated that there was no difference in the location of the data logger plane (driver, middle passenger) and within the compartments (front, middle, back), suggesting that the compartment location effect is substantial when considering micro-climate but temperatures within a compartment are mostly homogenous.

6.9 General discussion for future research designs

Cattle are more susceptible to heat stress than cold stress and studies like these are important to improve the welfare of cattle during transport and provide science-based information for trailer modification to improve micro-climate conditions during transportation.

This study found a large variation of ambient conditions. Because this study had a large geographical range (940km) in a north-to-south orientation, this also contributed to the greater variation in micro-climate parameters. Smaller ranges of ambient conditions would be beneficial for investigating and fine-tuning patterns for trailer micro-climate. The large variation between trips had an effect on the statistical analysis as some of the extreme micro-climate parameters (August 21st; August 28th) were considered outliers in a statistical sense. The large variation in the ambient conditions could have masked the porosity effect that was investigated.

A recommendation for future research would be to stay within a small geographical range and analyze micro-climate data in ranges by ambient conditions, such as 20-25°C; 26-30°C, 30-35°C etc. including the time of day effect. However, this research design would require a much larger sample size, thus increasing the costs of the study. Furthermore, the large variation in ambient conditions also proved challenging for analysis of stationary event data. There were high hopes in determining the amount of time it would take to reach maximum trailer temperatures during stationary periods. Unfortunately, the wide variation in ambient conditions between trips made it impossible to do so. To properly assess this, more microclimate data at similar ambient temperature ranges would be required. Another factor that would improve the ability to compare trailer types would be to eliminate crossing the US/CAN border so that cattle would not have to be moved from the original compartments part way through data collection. This would have allowed the determination of more accurate shrink values for the deck and doghouse compartments. Further, a trend for compartment and trailer porosity effects were observed for shrink. However, the model was not robust enough with only 5 data points (5 replicates per compartment, per trailer).

7.0 TRANSPORT INDUSTRY RECOMMENDATIONS

Evaluating trailer micro-climate during transport provides a snapshot of the environmental challenges that cattle may experience. To date, no commercial environmental monitoring systems are available for use in livestock transport trailers. Ambient temperature has a large influence on the internal micro-climate, however, air exchange between the inside and outside of the trailer is the primary factor determining trailer micro-climate. The ability to remove internal trailer heat and moisture accumulated from the cattle in the trailer is the ultimate goal to minimize the micro-climate challenge for cattle during warm summer months.

Currently, there are no Canadian standards for minimum porosity requirements in livestock trailers, thus there is no means of comparison for current research. However, wind fences that are used to protect livestock from wind and harsh winter conditions have a minimum porosity recommendation that ensures that the livestock have adequate fresh air and airflow near wind shelters. Saskatchewan Agriculture (1993) recommends a minimum of 20% porosity for wind fences and the Alberta Feedlot Guide (2002) recommends 25 to 33% porosity for optimum protection taking into account wind chill factors and winter weather elements and providing fresh air for livestock. The trailers used in this study had overall porosities of 8.7% and 9.6% while some commercial livestock trailers can have compartment porosities less than 5%. Because there are no recommended porosity standards for livestock trailers, the recommended porosity of wind fences could initiate a hypothesis to test in livestock trailers. For example, if the environment to which livestock are exposed were on a 3-D spatial scale there would be 6 surfaces that could influence the environment for the livestock, that would include 4 sides and the top and bottom (like a box). A single wind fence could have all surfaces exposed to weather elements except for the side with the fence (4 surfaces with 100% porosity) and the wind fence has a recommended porosity between 20 and 33%. Whereas a livestock trailer may have 2 to 3 (out of 6) surfaces exposed to weather elements depending on the trailer type and 2 or 3 surfaces with a compartment porosity between 5 to 15%. The recommended minimum porosity for wind fences was a guideline used to ensure proper airflow and a fresh air supply for livestock and could suggest that the minimum porosity for livestock trailers should meet or exceed porosity of 20%.

Recommendations:

1. Waiting and stationary times should be avoided in the afternoon during summer months.
2. Extreme caution should be used when transporting cattle when ambient conditions are greater than $25.9 \pm 6.06^{\circ}C$.
3. Livestock driver education programs should be updated to include recent micro-climate research.

7.1 Trailer porosity design suggestions

Transportation events during ambient temperatures of $25.9 \pm 6.06^{\circ}C$, trailers should attempt to maximize the amount of available porosity to reduce the heat stress experienced by cattle the following ways:

1. Internal gates such as the bull rail and gates within the deck and belly compartments should be manufactured in a way that does not impede airflow.
2. Vents in the nose and rear compartments should be a standard feature for all cattle trailers.
3. Roof hatches should be maximized in the nose, deck and doghouse compartments to allow heat and moisture to escape during summer months.
4. Minimum trailer porosity requirements should be developed and standardized among livestock trailers to account for type of cattle and season of the year.

8.0 CONCLUSION

There has been little research done involving North American style commercial road transportation vehicles, and this research may shed some light on potential design improvements and recommendations for minimizing the heat load cattle experience during summer transport. The Canadian Food Inspection Agency (CFIA) regulations specify that adequate ventilation is required during transport to reduce thermal discomfort (Canadian Agri-Food Research Council, 2001). Minimizing extreme thermal conditions is crucial to welfare during transport and all measures should be taken to optimize airflow and reduce heat load during summer months.

This study found a clear effect of compartment location on micro-climate and animal welfare outcomes for both the warmest in-transit hour and stationary events. The results could also indicate that the combination of porosity, compartment location and transit status (in-transit or stationary) could be useful tools to understand the conditions within different compartments of trailers and lead to a reduction of the heat load experienced by cattle in summer months.

This study also found that the temperatures inside the trailer can be 10.5°C greater than ambient temperatures during stationary events and 9°C greater than ambient levels during warmest in-transit hour. The average amount of per-animal weight loss was 4.3 ±0.3 % and was affected by trailer porosity and compartment, which followed the trends in thermal environment variables. The transit status (stationary or in-transit) and trailer porosity affected the vaginal core body temperature. The core body temperature was greater during stationary events for animals transported in the trailer with lower porosity. It is suggested that the lower side-wall porosity and/or the shape of perforation pattern could impair the movement of fresh air to respiratory tract of heifers, thus impacting the main mechanism for dissipating heat. The difference in temperature from the trailer ceiling to the animal level was 3.38°C in the trailer with lower porosity (cooler at the ceiling) and 2.23°C in the trailer with the higher porosity. This relationship also had a compartment location effect that followed the micro-climate compartmental differences. This could suggest that excess heat in the trailer with the lower porosity that also had lower overall temperatures, exited through roof hatches from lower compartments, while in the trailer with the higher porosity, the heat escaped through the side-wall perforation pattern. This theory also supports the idea that the location of where the porosity is located on trailer may be important to alleviating heat stress in summer months during transport. The results of this study also indicated that there was no difference in the location of the data logger plane (driver, middle passenger) and within the compartments (front, middle, back), suggesting that compartment location effect is substantial when considering micro-climate but temperatures within a compartment are mostly homogenous. During the trip with an average ambient temperatures of $25.9 \pm 6.06^{\circ}C$ for the entire journey, the Temperature Humidity Index was considered in a danger or emergency category according to the Livestock Weather Heat Index 95% of the hour during the warmest in-transit hour. This could propose that during ambient temperatures of $25.9 \pm 6.06^{\circ}C$, both trailers used in the study did not have sufficient ventilation to mitigate the risk of heat stress for cattle.

A critical component of this research is simply awareness. Once truckers and industry are aware of the extreme micro-climate conditions that have been measured, inevitably discussions and initiatives will take place. Improved management practices at the slaughter plant could be as simple as providing passive or mechanical ventilation and shade shelter at border crossings and plants. Truck drivers can alleviate heat load by keeping trucks in motion. Communication and scheduling between the feedlot, dispatch and slaughter plant ultimately determines the length of time the cattle are on board. Improved logistics can only enhance the well-being of the animals in transit and potentially decrease waiting times and stationary times.

The Canadian beef industry and their stakeholders have an interest in improved beef quality not only from an economic standpoint but also from consumer perceptions. Market and trade issues all stem back to the choice of the consumer. Domestic and international consumers are demanding that animals are treated and handled in a humane manner during transportation events. Providing research to ensure that animals are being transported in comfortable conditions and making improvements is good commerce for those buying and raising beef.

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APPENDIX A

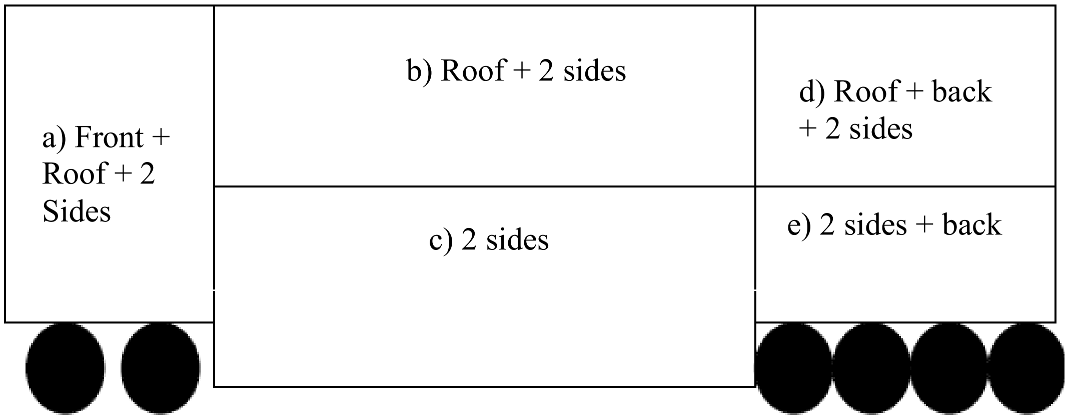
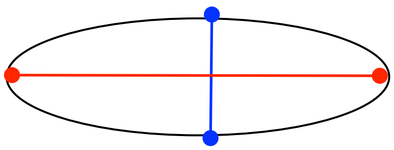


Figure A.1 Schematic of trailer for purposes of determining surface area and porosity

A: Calculating outside surface area of Trailer

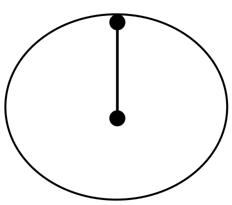
1. Determine area of each compartment and sum (a + b + c + d + e) = total area (ft^2)
   B) Determine the area of ellipsoidal holes = (½ a) (½ b)(π)



a = semi-major axis of length a
b = semi-minor axis of length b
π = 3.14 (pi)

Figure A.1 Schematic of ellipse

2. Equation for area of circular holes = πr^2



r = distance from the centre of the circle to a point on the circle
π = 3.14 (pi)

Figure A.2 Schematic of a circle.

C) Determine the area that is open by adding the area of the ellipsoidal and circular holes

D) Determine the porosity by:

$$\frac{\text{Total area of ellipses and circular holes}}{\text{Total area of Trailer}} = \text{Percent Porosity}$$

Same format is used to calculate porosity of compartment.

Appendix B. Diagram of trailer dimension.

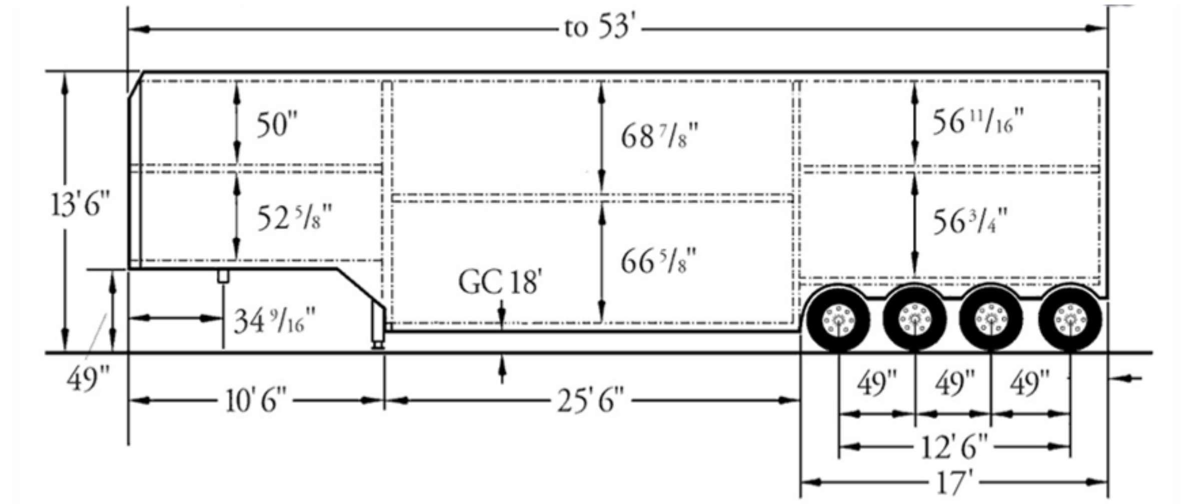


Figure B.1 Dimensions of the Merritt trailer.
Source: Merritt trailers (http://www.merrittequipment.com/new-trailers/livestock-trailers.html)

Figure B.2 European livestock trailer.
Source: http://www.hankstruckpictures.com/pix/trucks/mark_manders/2004/aug/kamphof_2.jpg