BROILER TRANSPORTATION IN SASKATCHEWAN

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by

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ABSTRACT

The thermal micro-environment of trailers transporting broiler chickens in Saskatchewan was investigated by recording temperature and relative humidity (RH) with data loggers. Initially, four cold weather journeys, where the ambient temperature ranged from -28.2 to -7.1°C, were conducted and conditions at the core of the trailer were monitored. Temperature variations were evident throughout the trailer and results demonstrated the potential for cold stress near air inlets and heat stress in areas with poor air circulation, particularly around the step in the trailer frame. The physiological effects of transportation on the birds were measured by taking rectal temperatures immediately before and after transportation and by introducing birds that had been previously implanted with devices for recording deep body temperature to selected modules. Body temperature recordings indicated the probability of hyperthermia and hypothermia developing while birds were transported. Mortality associated with the cold weather journeys was high and ranged from 0.7 to 1.4%. The need to distinguish between birds dying in transit (DOA) and birds dying in lairage, while awaiting slaughter (DOS), was revealed.

Horizontal and vertical temperature and RH gradients were examined in 27 additional journeys where the ambient temperature ranged from -27.2 to 21.9°C. The RH sensors did not function in cold weather, but when the ambient temperature was above 0°C, ambient RH ranged between 30 and 89%. Mean temperature lift, or the difference between ambient and on-board temperature recordings, was more pronounced during cold weather journeys with the curtains lowered compared to warm weather transportation with the curtains retracted. With both curtains lowered, open vent area affected mean temperature lift. With both curtains raised, the maximum temperature lift with the headboard and tailboard vents open was 2.5°C lower than with the front and rear vents closed. Apparent equivalent temperature (AET), indicating the effective temperature for broilers in transit, suggested that as ambient temperature dropped below 0°C, more birds were exposed to potentially dangerous AET due to cold air entry on the trailer. At the same time, dangerous AET indicative of heat stress developed in the core of the trailer. As ambient temperature approached 16°C, AET values reflected safe conditions for transported broilers; however, as the ambient temperature surpassed 16°C, the potential for bird stress increased. Moisture on the trailer, primarily from bird respiration, contributed significantly to the AET experienced by the broilers. Mean DOA and DOS mortality was 0.14 and 0.28%, respectively, and dead birds were found distributed throughout the trailers. DOA losses were not affected by journey length, but both DOA and DOS mortality were affected by ambient temperature and stocking density. Ambient temperature below -16°C and a stocking density of 26 birds per crate significantly increased DOA and DOS values. However, high mortality losses associated with one cold weather journey, which was the only journey conducted at a stocking rate of 26 birds per crate, may have skewed the results. Despite higher than recommended levels at some facilities, atmospheric ammonia did not affect bird mortality. Although on-farm management can predispose birds to transportation stressors, the barns participating in this study were well managed and contained birds in good condition.

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LIST OF ABBREVIATIONS

A	alert zone
AAFC	Agriculture and Agri-Food Canada
AET	apparent equivalent temperature
CARC	Canadian Agri-Food Research Council
CCOHS	Canadian Centre for Occupational Health and Safety
CFIA	Canadian Food Inspection Agency
CK	creatine kinase
D	danger zone
DEFRA	Department for Environment Food and Rural Affairs
DOA	dead-on-arrival
DOS	dead-on-shackling
EET	effective environmental temperature
H:L	heterophil:lymphocyte
HPA	hypothalamo-pituitary-adrenal
Hz	hertz (cycles/second)
MAFF	Ministry of Agriculture, Fisheries and Food
n	number of replications
NSERC	Natural Sciences and Engineering Research Council
PD	potentially dangerous zone
ppm	parts per million
RH	relative humidity
S	safe zone

T_a	ambient temperature	
T1	temperature group 1	< -16.0°C
T2	temperature group 2	-15.9°C to -6.0°C
T3	temperature group 3	-5.9°C to 5.9°C
T4	temperature group 4	6.0°C to 15.9°C
T5	temperature group 5	> 16.0°C
W	watt (joules/second)	

1.0 INTRODUCTION

Intensive broiler chicken operations are typically located away from the processing facility, thereby making transportation prior to slaughter a necessity. Transported broilers are exposed to stressors such as feed and water withdrawal, catching and handling, behavioural restriction, social disruption, noise, motion, vibration, acceleration, impacts, and temperature and moisture accumulation (Freeman, 1984; Nicol and Scott, 1990). However, the thermal environment within the trailer is the most significant of these stressors (Kettlewell, 1989; Mitchell and Kettlewell, 1994) and is dictated primarily by the interaction of heat and moisture within the trailers and airflow through the transporter. Unfortunately, passively ventilated broiler carriers commonly generate inadequate levels of ventilation that can lead to hostile microenvironments for the birds (Mitchell and Kettlewell, 1993; Mitchell and Kettlewell, 1998). Ventilating for this heat and water production poses considerable challenges for passively ventilated broiler transporters, particularly when trailer tarpaulins are in use.

The airflow within a poultry transporter is ruled by the pressure distribution on the outside surface of the trailer and the dense packing inside the trailer (Hoxey et al., 1996). The air flows from high-pressure areas to low-pressure areas, generally taking the most direct route. Because the largest negative pressure occurs at the top of the trailer near the headboard, vents open in this area will act as exhaust outlets for the trailer and openings at the back of the trailer will act as air inlets (Götz, 1987; Hoxey et al., 1996). The high stocking density within the trailer creates an obstruction for air movement within the load and limits air mixing. With the transporter curtains lowered, air may short circuit between vents on the roof, or between openings at the bottom of the curtains and the vents in the roof directly above those openings. This pressure distribution is typical of blunt, sharp-edged objects (Götz, 1987) and becomes useful when interpreting the temperature and humidity data collected from broiler transporters.

Three-dimensional thermal mapping of the microenvironment has been achieved by equipping the transport lorry and trailers from the United Kingdom with data loggers (Kettlewell et al., 1993). Multi-site recordings of temperature and humidity showed variations in temperature depending on location in the trailer, indicating heterogeneous air flow distribution and inadequate ventilation. In the summer months, with curtains in an open configuration, there were no temperature gradients established in the lorry, but temperatures did increase slightly from the back to the front of the trailer. If the vehicle was in motion, passive ventilation was sufficient to prevent temperature gradients in the trailer. During winter months, with curtains in the closed configuration, large temperature and moisture gradients developed due to reduced air movement, with areas immediately behind the headboard being exposed to high temperature and humidity conditions capable of causing heat stress for the birds. These data suggested that the greatest risk of hyperthermia actually occurs during winter transportation when ambient temperature is low and ventilation is restricted by the closed curtain arrangement (Kettlewell et al., 1993).

A study conducted Mitchell et al. (1997) suggested if birds remain dry they can maintain body temperature in external temperatures as low as -4°C. The research also indicated that broiler journeys conducted when the ambient temperature is as low as -4°C is acceptable if birds are dry. However, bird size and feathering as well as temperature conditioning can also affect the effective environmental temperature and consequently bird welfare under these conditions. Because outdoor temperatures below -4°C were not investigated, research is required to determine the physiological response of broilers being transported at temperatures lower than -4°C.

Due to the lack of data for transporting broilers at low ambient temperatures, conducting transportation studies under winter conditions typical of Saskatchewan will add to the foundation of poultry transportation research. In addition, the applicability of previous findings to transporting conditions encountered year-round in Saskatchewan, a Canadian prairie province, will be verified.

Therefore, the objectives of this study were to characterize the thermal environment imposed on broilers transported in Saskatchewan conditions by recording temperature and humidity conditions within broiler transport vehicles. Additional objectives included quantifying the physiological effects of winter transportation on the birds by collecting rectal temperatures immediately before and after transportation and by monitoring the deep body temperature of sentinel birds previously implanted with recording devices. Mortality data associated with all broiler journeys was also reviewed to assess the impact transportation has on bird welfare.

2.0 LITERATURE REVIEW

Comprehension of the systems used for transporting broilers to processing facilities and the stresses imposed on birds during this period, along with the associated bird morbidity and mortality, is crucial before improvements to bird welfare during transportation can be achieved. This review of broiler transportation will examine the stresses associated with transportation, with emphasis on the thermal load created in the broiler transport carriers. In addition, transportation related broiler mortality is described and the transportation systems used in Saskatchewan and the United Kingdom, along with climates characteristic of both regions, are compared.

2.1 STRESSES ASSOCIATED WITH BROILER TRANSPORTATION

2.1.1 Definition of Stress

Stress is a term commonly used in association with animal agriculture practices. Several definitions for stress have been proposed, including one by Fraser et al. (1975) that stated, "An animal is said to be in a state of stress if it is required to make abnormal or extreme adjustments in its physiology or behaviour in order to cope with adverse aspects of its environment and management." A similar definition more recently presented by Terlouw et al. (1997) suggested stress "describes the animal's state when it is challenged beyond its behavioural and physiological capacity to adapt to its environment." Freeman (1987) recommended that the definition imply negativity because stress is detrimental to an animal's well being and should be avoided. It was also suggested that the stimuli be referred to as the "stressor" and that "stress" be used to describe the response such that the stimuli and the response could be differentiated (Freeman, 1987).

2.1.2 Responses to Acute Stress

Behavioural and physiological stress responses can be exhibited when responding to a stressor, with the function of both responses being to maintain homeostasis (Barnett and Hemsworth, 1990). Common behavioural reactions undertaken by a threatened animal may include immobilization to remain unnoticed or active responses such as fight or flight. These behavioural responses occur concurrently with physiological changes.

Physiological responses to stress include a primary alarm or emergency phase followed by a secondary adaptive phase (Freeman, 1987). Initially, the sympathetic branch of the autonomic nervous system is activated, which elevates plasma concentrations of adrenaline and noradrenaline, and increases cardiac output. The hypothalamo-pituitary-adrenal (HPA) axis is also stimulated during acute stress, resulting in the release of glucocorticosteroids such as cortisol and corticosterone into the bloodstream. Though both responses are important, the HPA response is slower than the response from the sympatho-adrenal system, thus concentrations of adrenaline and noradrenaline escalate more quickly in the circulation of the blood. The breakdown of these catecholamines also occurs quickly and as a result, their direct measurement cannot be used to describe the magnitude of a stress response (Knowles and Broom, 1990). However, indirect indicators of elevated catecholamine concentrations have been demonstrated (Freeman, 1976) and include increased cardiac output by increasing heart rate and stroke volume, elevated blood pressure caused by peripheral vasoconstriction and heightened plasma glucose levels due to the catabolism of glycogen (Terlouw et al., 1997).

In comparison, glucocorticoid secretion is mediated by blood factors causing plasma concentrations to escalate slowly (Knowles and Broom, 1990; Terlouw et al., 1997). Additionally, cortisol and corticosterone do not break down as quickly as catecholamines, thereby making them an easier stress response to monitor.

With specific reference to the domestic fowl, cortisol production ends shortly after hatching (Knowles and Broom, 1990) leaving corticosterone the primary glucocorticoid (Freeman, 1976). Furthermore, corticosterone secretion is a heritable trait in poultry (Freeman, 1976; Hill, 1983); therefore, concentrations monitored in response to a stressor may vary between individual birds and between different strains of birds, although resting levels are similar in both flighty and docile birds.

Pancreas mediated stress responses have also been observed. An increase in plasma glucagon concentrations following the application of a stressor causes rapid mobilization of lipids resulting in elevated levels of non-esterified fatty acids in the blood (Freeman, 1976; Hill, 1983; Mitchell and Kettlewell, 1993).

When a stressor is applied, additional endocrinological interactions occur that affect blood chemistry (Freeman, 1987). The presence of glucocorticoids can alter the ratio of heterophils to lymphocytes circulating in the blood such that the number of lymphocytes in circulation is reduced, creating a negative influence on the immune system (Knowles and Broom, 1990). As well, elevated plasma activity of creatine kinase, an intracellular muscle enzyme, can indicate tissue dysfunction and damage (Mitchell and Kettlewell, 1993).

Clearly, stress responses can be easily demonstrated but whether or not the responses produce a successful adaptation is not always obvious. Difficulties interpreting stress responses can be encountered because the responses vary between individuals, and depend on past experiences and the environment in which the stimulus is applied (Hill, 1983). Therefore, combining behavioural and physiological responses will provide the most representative assessment of stress.

2.1.3 Stressors Encountered by Broilers during Transportation

Behavioral, physiological, metabolic and endocrinological measurements have been examined to determine bird response to transportation. In transit, birds encounter stressors including removal of feed and water, behavioural restriction, social disruption, noise, motion, vibration, acceleration, impacts, and temperature and moisture accumulation (Freeman, 1984; Nicol and Scott, 1990). Several studies investigating these stressors and the accompanying bird responses are reviewed.

2.1.3.1 Feed withdrawal

It is common practice to withdraw broiler feed prior to transportation to facilitate digestive tract clearance, thus reducing carcass contamination at the processing plant; however, food deprivation is regarded as a stressor (Kannan and Mench, 1996). Prior to a 4 h crating period, broilers were either full-fed or food deprived for 8 to 10 h. Plasma corticosterone levels in the food-deprived birds were significantly greater than those of birds on full feed before crating (Kannan and Mench, 1996).

Feed withdrawal associated with extended dark cycles incorporated into a lighting program during broiler rearing is also customary. The dark period, which may be as long as 12 hours (Classen et al., 2003), reduces early growth rate and changes metabolism resulting in stronger skeletal and cardiac systems (Classen and Riddell, 1989). Although birds may learn to eat during these periods of dark exposure (Classen, 1992), feed withdrawal related to extended dark periods is a practice to which broilers may be accustomed.

2.1.3.2 Social disruption

Social disruption at catching has been listed as a stressor associated with transportation (Freeman, 1984; Nicol and Scott, 1990). Studies from the past have indicated that the introduction of an unfamiliar individual into a socially established group of birds may have detrimental effects on bird welfare because it results in heavier adrenal weights (Siegel and Siegel, 1961), an elevated level of agonistic activity (Craig et al., 1969), reduced performance and higher heterophil to lymphocyte ratios (Anthony et al., 1988). However, research has suggested it is improbable that domestic birds will establish and sustain social relationships with flocks consisting of more than 100 birds (Guhl, 1953).

Presently, broilers are raised in large commercial barns in flocks of several thousand birds with few, if any, restrictions on their movement. Newberry and Hall (1990) reported that broilers in large enclosures used more space than birds in small enclosures, and that range in movement was greater when chores were being performed. Because broilers do not remain in one particular area, they are continually coming into contact with unknown birds during the grow-out period. Preston and Murphy (1989) observed individual broilers as they moved within a commercial sized flock and reported a lack of agonistic behaviour and other social interactions. If broilers become accustomed to being around unfamiliar birds or if social recognition is restricted because broiler appearance changes so quickly, stress associated with social disruption at catching may be disputed, or perhaps more imminent transport-related stressors supersede social disruption.

2.1.3.3 Noise and motion

Motion itself is a stressor as crated birds transported for 40 min had greater corticosterone levels, 11.1 ng/ml, than birds that were crated and remained stationary, 4.7 ng/ml (Duncan, 1989). Kannen et al. (1997) reported similar corticosterone levels (11.5 ng/ml^3) from birds transported for 3 h prior to processing. Significant increases were also detected in free fatty acid concentrations of birds transported for 2 and 4 h when compared to birds that were not subject to transportation (Freeman et al., 1984). As well, measurements of tonic immobility showed that transported birds are more fearful than non-transported birds (Cashman et al., 1989).

Utilizing passive avoidance techniques, Nicol et al. (1991) demonstrated broilers avert from noise and motion. However, noise exposure by itself did not affect latency to peck for birds trained to key peck for a food reward, suggesting that motion may be a more aversive stimulant. The results also revealed that particular types of motion are more repugnant than others. Birds were subjected to simple harmonic motion in the vertical or horizontal plane, along with uniform circular motion in the horizontal plane and gentle random vibration followed by a 1 sec jolt. There were significant differences in latency to peck showing that motions are not equally aversive. Birds exposed to the jolt had an increased latency to peck compared to birds treated with vertical or horizontal motion, and the latency to peck for circular motion was significantly greater than for vertical motion.

2.1.3.4 Vibration

Rutter and Randall (1993) examined aversive responses of feed-restricted broilers exposed to sinusoidal horizontal vibration at frequencies of 0.5 and 1.0 hertz (Hz) or cycles per second. Again, operant conditioning techniques were used to train birds to peck a plastic dish for a food reward. Control birds, not exposed to vibration, had the highest pecking response whereas birds exposed to vibration at 1.0 Hz had the lowest pecking response, demonstrating that motion at 1.0 Hz was aversive.

Responses to vibration depend on the frequency content, acceleration magnitude, point of action, and duration of the vibration (Rutter and Randall, 1993). Randall et al. (1993) determined vibration levels on the chassis, or frame, of the lorry in a lorry-trailer poultry transporter and on the floor of a plastic crate within the loaded vehicle using accelerometers. In the vertical axis, the fundamental frequency on the lorry frame for both air and leaf suspension vehicles was between 1 and 2 Hz, although the magnitude of the vibration was approximately four times greater for leaf suspension compared to the air suspension vehicle. However, the measurements from all three axes on the lorry frame were not equivalent to those in the crates, which are most reflective of the conditions to which the birds are exposed. The fundamental frequency in the vertical axis on the floor of the crate was similar to that of the frame (1 to 2 Hz), though a secondary peak occurred at 10 Hz. Results indicated that the magnitudes of vibration recorded in the laden bird containers would cause humans to become fairly uncomfortable, though no conclusions could be made regarding the comfort level of the birds (Randall et al., 1993; Randall et al., 1994).

During transportation, if the vibration frequency of the vehicle causes resonance within the internal organs, birds may experience considerable discomfort (Randall et al., 1996; Scott, 1994). Using a spring mass model, Scott (1994) calculated the resonant frequency for the viscera of a 2 kg broiler subjected to vertical vibration to be 8 to 10 Hz, whereas the resonant frequency in the lateral axis ranged between 16 and 21 Hz, depending on the organ. Comparatively, Randall et al (1996) used a vibrating beam technique to measure whole-body resonant frequency of 22 growing chickens weighing between 0.75 and 4.5 kg in both standing and sitting positions. Resonant frequencies for a 2 kg bird in standing and sitting positions were 3.7 and 14.6 Hz, respectively. Although the frequencies determined for the whole-body and organs of the chickens did not match precisely, there was sufficient overlap with the frequency resonances recorded during transportation to imply that transportation may be uncomfortable for birds (Randall et al., 1993; Randall et al., 1994).

Although studies investigating the response of chickens to vibration are limited, the responses of humans to whole-body vibration have been researched extensively and include fear, nausea, distress, muscle fatigue and discomfort (Randall et al., 1993; Rutter and Randall, 1993). Investigations on mammalian species show that vibration can affect postural stability, respiration, cardiovascular function, blood chemistry and behavior (Scott, 1994).

Carlisle et al. (1998) collected blood samples from broilers subjected to vibration frequencies characteristic of transport vehicles. The treatment groups included birds exposed to frequencies of 2, 5 and 10 Hz as well as a control group that received no vibration. Concentrations of plasma creatine kinase (CK), glucose, triglyceride, and corticosterone were determined. Triglyceride level was not affected by treatment, but CK, glucose and corticosterone levels were, indicating the development of muscle fatigue, hypoglycaemia and HPA activity, respectively.

2.1.3.5 Behavioral restriction

Birds are transported in confined spaces at high stocking densities that impede behavioural responses to stresses in transit (Nicol and Scott, 1990; Webster et al., 1993; Weeks and Webster, 1997). Normally, birds would change their posture or move to a more suitable environment to adapt to changing thermal conditions; however, birds in laden transport containers lose this ability to adjust.

2.2 THERMAL LOAD

Broilers are reared in an environment where temperature, humidity and ventilation are controlled despite variations in external climatic conditions; however, these parameters are poorly controlled when broilers are transported to slaughter.

The internal environment of broiler transporters is dictated principally by the heat and moisture produced by the birds, ventilation rate, and the temperature and humidity of the air entering the trailer (Kettlewell and Mitchell, 2001). Solar radiation may also contribute to the internal environment of the trailer, with the effects being dependent upon the reflective properties of the transporter. Thermal loads primarily result from the interaction of heat and moisture produced by the birds and the level of ventilation within the transporters.

A review of the thermoregulatory responses of chickens, the heat and moisture produced by chickens and the methods of quantifying thermal loads is essential in understanding the implications that thermal loads can have during broiler transportation.

2.2.1 Thermoregulatory Responses of Chickens

Birds are homeotherms. Their deep body temperature is maintained within a narrow range and follows a circadian rhythm, whereas the temperature of superficial tissues may fluctuate significantly under changing environments (Dawson and Whittow, 2000). The core temperature of domestic fowl (*Gallus gallus*) weighing 2.4 kg is 41.5°C when at rest, under thermal neutral conditions (Dawson and Whittow, 2000). Upper lethal body temperature for birds is between 46° and 47°C (Dawson and Whittow, 2000), only slightly above normal body temperature, whereas lower lethal body temperature is far below normal body temperature, ranging from 22.8 to 23.6°C and 19.4 to 22.2°C for hens and cockerels, respectively (Sturkie, 1946). Nicol and Scott (1990) reported that upper and lower critical temperatures for chickens are approximately 45-47°C and 19-22°C, respectively. The upper critical temperature is the effective environmental temperature (EET) at which the bird's thermoregulatory processes for dissipating heat are functioning at utmost effectiveness, whereas the lower critical temperature is the EET where insulative and behavioural heat conserving responses are operating at maximum effectiveness (Curtis, 1983).

Chickens display several behavioural responses to conserve heat such as altering posture to reduce effective surface area (squatting or tucking their heads under feathers on their back), changing position (huddling) and seeking out a more favorable environment. Birds will also ruffle their feathers (ptiloerection) to increase their insulation, constrict peripheral blood vessels and shiver before increasing their metabolic rate in response to cold. In contrast, heat stress will cause birds to reduce their activity levels and increase their surface area by extending their wings and necks. Vasodilation lowers tissue insulation and due to the lack of sweat glands, evaporative cooling is accomplished though respiratory means via panting. Bird response to EET depends largely on the size of the birds, plumage density and prior thermal conditioning (Dawson and Whittow, 2000). Air movement and wetting of the plumage will exacerbate or enhance a bird's thermoregulatory abilities dependant on the circumstance.

2.2.2 Heat and Moisture Production by Broilers

Commercial-scale broiler transporters rely on passive ventilation to dissipate the heat and moisture produced by birds within the trailer. Metabolic heat production and obligatory water loss from a single 2 kg market age broiler are reported as 10 to 15 W and 10.5 g/h, respectively (Mitchell and Kettlewell, 1998). Similar values were described when calorimetric measurements were performed on laden broiler carriers equipped with fan ventilation (Kettlewell et al., 2000). Using Saskatchewan as an example, in a typical trailer containing 8200 broilers with an average body weight of 1.8 kg, the broilers would produce around 82 kW of metabolic heat and 86 kg of water per hour. However, these rates of heat and moisture production were determined under warm ambient conditions and may vary if conducted under colder conditions typical of Saskatchewan winters.

2.2.2.1 Humidity

The influence of humidity during transportation is frequently neglected by livestock transportation researchers but becomes significant as temperature within the broiler carrier increases. Sensible heat losses diminish as on-board temperatures escalate, leaving the birds increasingly reliant on evaporative heat losses. Evaporative cooling is dependent upon a water vapour gradient between the evaporative surface and the surrounding air. Therefore, if high temperatures exist in the transport environment, the humidity level will dictate whether or not the birds will be able to thermoregulate effectively.

Mitchell and Kettlewell (1994) reported that at a dry-bulb temperature of 28°C, an increase in relative humidity from 20% to 80% would cause the core body temperature of a broiler to rise 0.42°C per hour during transportation. In another study, birds were exposed to a high thermal load (32.6°C and 94% RH) for 90 min (Mitchell and Sandercock, 1995). Results indicated that rectal temperatures rose by 2.8°C and plasma creatine kinase concentrations increased 24% over levels from control birds.

Body temperature, venous blood pH and pCO_2, heterophil:lymphocyte (H:L) ratio and plasma creatine kinase (CK) activity, which are all considered characteristics indicative of thermoregulatory and physiological stress responses, were measured in 2.2 kg broilers exposed to temperature-humidity combinations typically recorded on commercial broiler carriers (Mitchell et al., 1994). At temperatures of 25 and 30°C, water vapour densities between 14.8 and 27.0 g/m^3 were applied to crated birds in a climate-controlled chamber. Although no changes in acid-base balance or H:L ratio were recorded, body temperature increased 0.7°C and CK activity rose 50% in birds subjected to a temperature of 25°C and water vapour density of 14.8 g/m^3 (RH = 61%). As the water vapour density rose to 20.2 g/m^3, increases in CK activity and H:L ratio were noted, along with a further increase in bird temperature. An increase in blood pH and a reduction of pCO_2 were also observed. Furthermore, all measured variables reflected severe stress when a dry-bulb temperature of 30°C was imposed on broilers in conjunction with high relative humidity. The consequential hyperthermia, hypocapnia, alkalosis and increased H:L ratio demonstrated the detrimental contribution high humidity can have on the transport environment, especially at high dry-bulb temperature.

2.2.3 Quantification of Thermal Load

Several methods have been explored to quantify thermal load development within broiler transporters.

2.2.3.1 Simulation of broiler heat exchanges with an artificial chicken

An artificial chicken, named Gloria, was created to simulate heat exchanges of broilers during transportation (Webster et al., 1993). Gloria was a chicken-sized heated box thermostatically controlled to maintain an internal temperature of 41°C. With two types of vehicles and with the curtains either closed or open, Gloria was inserted in crates among live birds for 28 commercial journeys. The results indicated that temperatures between 7 and 8°C would ensure thermal comfort for a well-feathered bird in an enclosed vehicle at rest or in motion (Webster et al., 1993). This is a very narrow temperature zone for transported birds and implies that forced ventilation would be required to achieve thermal comfort for broilers when the transport vehicle is stationary. However, if the ambient temperature is not appropriate, thermal comfort for the birds may be impossible to attain even with mechanically ventilated trailers.

2.2.3.2 Mathematical model for broiler heat production

A mathematical model for heat production and heat loss of a single crated broiler was proposed and used to predict the ventilation rate required, at given external temperature and humidity conditions, to maintain a balance between heat production and heat loss for crated birds (Kettlewell and Moran, 1992). Through a progressive series of equations, a myriad of factors affecting the heat balance was included. The resulting equation consisted of extrapolated values obtained from other studies on birds physiologically dissimilar from market age broilers. Although the accuracy of the predicted values was questionable, the model did suggest that decreasing crate density, reducing humidity, and fasting the birds prior to transportation would ease heat stress. It was proposed that an extension of this model incorporating a row of broilers in an air stream could be used to develop new strategies for ventilating broiler transporters. Overall, the study supported the idea that interactions between animals and the thermal microenvironment are complex and require rigorous analyses.

2.2.3.3 Thermal mapping

Three-dimensional thermal mapping of the microenvironment was achieved by equipping transport trailers with data loggers, which continuously monitored temperature and relative humidity. The loggers were placed at bird level to obtain an accurate recording of the internal conditions. To investigate the distribution of thermal loads, data loggers were placed in six specific locations (front, middle and rear of both the lorry and trailer), mid-line of the vehicle and in the upper layer of the stacked modules. Journeys were studied in the summer and winter months during ambient conditions typical of the United Kingdom. Variability among trips was reduced by using the same driver, vehicle, farm location, and journey length and route. Multi-site recordings showed variations in temperature depending on location in the trailer, indicating heterogeneous air flow distribution and inadequate ventilation (Kettlewell et al., 1993).

On average, ambient temperature and water vapor density were 19.3°C and 9.4 gm^{-3} for summer and 9.9°C and 8.5 gm^{-3} for winter, respectively. However, conditions within the lorry and trailer for summer were 22.8°C and 9.8 gm^{-3}, and 24.0°C and 10.1 gm^{-3}, respectively; and average conditions during winter were 21.8°C and 11.1 gm^{-3}, and 23.5°C and 14.5 gm^{-3} for the lorry and trailer, respectively. With curtains removed in the summer months, there were no temperature gradients evident in the lorry immediately behind the tractor, but temperatures did increase slightly from the back to the front of the trailer. If the vehicle was in motion, passive ventilation prevented the development of temperature gradients in the trailer. During winter months, with curtains in the closed configuration, large temperature and moisture gradients developed due to reduced air movement, with areas immediately behind the headboard being exposed to high temperature and humidity conditions capable of causing heat stress in the birds. These data suggested that the greatest risk of hyperthermia actually occurs during winter transportation when ambient temperature is low and ventilation is restricted by the closed curtain arrangement (Kettlewell et al., 1993). Unfortunately, in this research, the birds' physiological response was not measured and temperature gradients within the crate and across the trailer were not taken into account.

2.2.3.4 Aerodynamic characteristics of broiler transportation vehicles

The airflow within a poultry transporter is ruled by the pressure distribution on the outside surface of the trailer and the dense packing inside the trailer. The pressure distribution over the surface of the trailer is characteristic of blunt, sharp-edged objects (Figure 2.4). The headboard of the trailer has a positive pressure that is greatest near the top leading edge of the trailer and decreases down the headboard (Götz, 1987). Therefore an opening in the headboard will become an air inlet. Flow separation occurs at the leading edge of the top of the trailer and at the leading edges of both sides of the trailer, thereby creating large negative pressures on the top and sides of the front end of the trailer. This negative pressure on the top and sides of the trailer declines towards the tailboard or back end of the trailer. Because the largest negative pressure occurs at the top of the trailer near the headboard, vents open in this area will act as exhaust outlets for the trailer and openings in the tailboard or on the roof near the back of the trailer will act as air inlets. The high stocking density within the trailer creates an obstruction for air movement within the load and limits air mixing. With the tarpaulins lowered, air may short circuit between vents on the roof, or between openings at the bottom of the curtains and the vents in the roof directly above those openings.

In an effort to better understand the transport vehicle's aerodynamic characteristics that govern the ventilation and therefore influence the internal thermal conditions, Hoxey et al. (1996) measured external surface pressure distribution along the side of a transport vehicle by attaching tapping plates to predetermined modules. Flow visualization along the roof was accomplished by applying water-based paint in equally spaced points on the roof and examining the streaks after vehicle motion, whereas flow visualization along the length of the vehicle was determined by fixing small wool tufts along the trailer side.

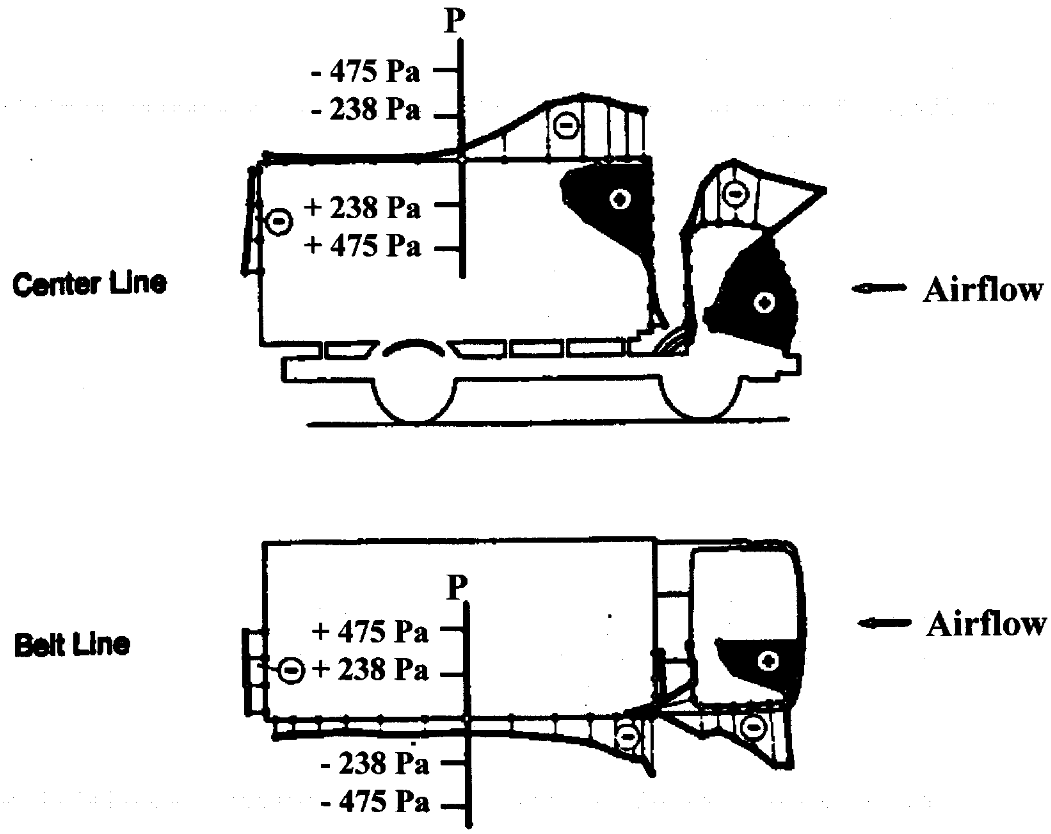

Figure 2.1. Pressure distributions on the cab and body of a typical truck traveling at 100 km/h. Air flows from high pressure areas to low pressure areas, generally taking the most direct route (adopted from Götz, 1987).

Tuft reversal indicated separated flow at three locations within 0.7 m of the headboard. Pressure measurements illustrated air movement from the rear to the front of the lorry when the vehicle was in motion, which is characteristic of blunt, sharp-edged bodies (Götz, 1987), but uniform pressure measurements inside the trailer suggested little ventilation due to pressure differences arising from vehicular motion. It was noted that pressure fluctuations caused by factors such as cross winds are more influential at slow vehicle speeds but further experimental research would be required for a precise assessment. Flow visualization techniques demonstrated surface airflow patterns over the transporter, with areas of separated flow (airflow opposite of mean flow direction) evident over the front roof edge and front side of the lorry.

Using results from the full-scale aerodynamic study to calibrate the measurements, wind tunnel experiments were conducted to further enhance the aerodynamic data pertaining to broiler transporters (Baker et al., 1996). Again, flow visualization and pressure measurements were taken, along with measurements of wind velocity and turbulence for various vehicle configurations and cross wind conditions. Wind tunnel pressure coefficients were underestimated near the front of the lorry but otherwise, full scale and wind tunnel measurements at low yaw angles (angle between air flow and a line perpendicular to the longitudinal axis of the vehicle) were similar (Baker, 1994). Therefore, the results from the wind tunnel measurements could be used to determine environmental conditions within a broiler transportation vehicle through computational methods (Dalley et al., 1996). An important characteristic of passively ventilated poultry transport vehicles confirmed by the wind tunnel results is that the direction of airflow in a moving broiler transporter is the same as the direction of motion. Thus, a thermal core is generated at the front of the lorry where warm, saturated air exits.

The predicted values from the mathematical calculations of internal flow fields were compared to full-scale recordings taken during a typical journey and several sensitivity analyses were performed to ensure reasonable and representative results (Dalley et al., 1996). Mathematically generated temperature and relative humidity values were similar to the measurements recorded during a full-scale journey, but generally, predicted temperatures were overestimated whereas relative humidity was underestimated. Sensitivity analyses demonstrated that crate temperatures are influenced by heat diffusion, as well as heat and water generated by the birds; however, water diffusion had a minimal impact on crate environment. Sensitivity analyses also indicated that if the vehicle is traveling directly into the wind or moving slower than 10 ms^{-1}, the crate environment is susceptible to change. This mathematical model was capable of computing apparent equivalent temperature values for each crate; therefore stress measurements could be simulated for crates in poorly ventilated areas (Dalley et al., 1996).

2.2.3.5 Apparent equivalent temperature

Apparent equivalent temperature (AET) is a value derived from temperature, water vapor pressure, and a psychrometric constant. It is an index of the thermal loads imposed on birds in transit, and was elucidated through simulated laboratory studies on birds by determining equivalent biological effects under different combinations of temperature and humidity (Mitchell and Kettlewell, 1993; Dalley et al., 1996). Figure 2.2 shows temperature and relative humidity combinations in conjunction with the corresponding AET for transported broilers.

AET values <40°C, 40-65°C, and >65°C indicate mild stress/safe zone, moderate stress/alert zone and severe stress/danger zone, respectively (Mitchell and Kettlewell, 1993; Mitchell and Kettlewell, 1998; Kettlewell and Mitchell, 2001). Temperature-humidity combinations associated with AET >90°C result in bird death (Mitchell and Kettlewell, 1998).

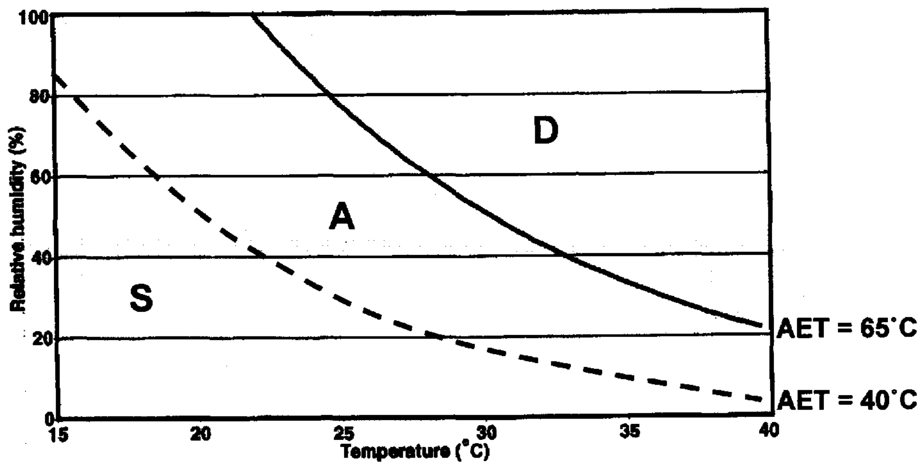

Figure 2.2. Zones of thermal comfort for transported broilers. Dry-bulb temperature (°C) and relative humidity (%) combinations yield AET values in the danger zone (D), alert zone (A) or safe zone (S).

Unfortunately, the temperature axis only begins at a dry-bulb temperature of 15°C. A significant portion of the broiler transport journeys in Saskatchewan and the rest of Canada are conducted when the ambient temperature is below 15°C. Additional data must be collected during cold ambient conditions such that the dry-bulb temperature axis of the AET chart can be extrapolated below15°C.

2.2.3.6 Continuous monitoring of broiler deep body temperature

In addition to investigating and characterizing the thermal environment within broiler transport vehicles, the birds' physiological response to the transport environment was examined using implantable radio-telemetry devices for continuous monitoring of deep body temperature (Kettlewell et al., 1997). The logger consisted of a small, light-weight printed circuit board, temperature sensor, processing chip and power supply on a single non-encapsulated card. These devices provided the opportunity to record physiological responses of broilers to transportation stress and to examine the birds' thermoregulatory ability for the entire journey duration. The radio-telemetric packages were surgically implanted into the body cavity of the bird and once the bird had recovered, it was placed into a crate on a broiler transport trailer. After the research was completed, the data loggers were removed from the birds and the information was downloaded. Data from these loggers is capable of indicating whether or not the internal transport environment induced hypothermic or hyperthermic responses from the birds.

For example, a 6 week old implanted broiler chicken was introduced to a commercially stocked transport crate located in a climate control chamber. For 5 hours, the birds were exposed to a temperature-humidity combination of 30°C and 70% RH, which are conditions proven to generate heat stress in transported birds (Kettlewell et al., 1993; Mitchell and Kettlewell, 1993). The deep body temperature of the implanted broiler increased promptly after the thermal load developed, reaching a maximum of 43.0°C during the first hour. Body temperature decreased during the remainder of the treatment period, but remained considerably higher than the control temperatures. An additional increase in deep body temperature was noted when the birds were handled during crate removal, but subsequently, the body temperature of the sentinel bird returned to normal. Not only did the data demonstrate that the crate conditions led to hyperthermia, but it also suggested that bird handling may be stressful (Kettlewell et al., 1997).

2.2.3.7 Concept 2000

Welfare driven research conducted in the field of broiler transportation has led to the development of a mechanically ventilated broiler transporter, identified as Concept 2000 (Kettlewell and Mitchell, 2001). Controlled mechanical ventilation was explored because adjusting passively ventilated broiler carriers to take advantage of existing pressure profiles and airflow patterns and distribution was limiting. Concept 2000, which was developed by research organizations and industry partners in the UK, specifically Silsoe Research Institute, Roslin Institute and Premier Poultry, was officially launched on May 6, 1999 (SRI News, 1999).

Features of Concept 2000 include an on-board generator, located under the chassis, which powers extraction fans controlled by a computer. The computer monitors the thermal micro-environment, determines the ventilation flow rates required and works to harmonize the internal temperature and humidity conditions with the biological requirements of the birds, whether the vehicle is stationary or in motion. Insulated curtains remain closed for the entire journey and contain the inlets that are constructed of perforated mesh material. Fans extract air from both the headboard and tailboard, exploiting natural airflow characteristics of the trailer.

A benefit of the force-ventilated trailer is that it provides the processors with more operational flexibility as birds can remain on a stationary vehicle for extended periods. In addition, stressors imposed on broilers during transportation are minimized compared to transportation accomplished with standard carriers because Concept 2000 can maintain birds in their thermal comfort zone during this period (Kettlewell and Mitchell, 2001).

Therefore, bird welfare and meat quality are improved and poultry consumers can be further assured that bird welfare is being addressed by the industry.

2.3 BROILER MORTALITY ASSOCIATED WITH TRANSPORTATION

Bird mortality occurring during the transport of broilers from the production unit to the processing facility is an economic and animal welfare concern, and is conventionally reported as dead-on-arrival (DOA) data. However, to achieve a true reflection of the losses occurring during transportation, a distinction between DOA and dead-on-shackling (DOS) mortality should be drawn. By definition, DOA mortality should represent bird losses transpiring during the transportation period only, while DOS mortality should include death losses occurring in transit and while the birds are held in lairage, awaiting slaughter. Unfortunately, death loss during these periods is rarely differentiated in the literature and as a result, DOS fatalities are often described as DOA mortality. In this section, DOA mortality refers to bird losses occurring during the transportation period only.

Several studies have been carried out to quantify broiler mortality transpiring after the birds have left the production site. Bayliss and Hinton (1990) summarized reports from Europe and North America where broiler mortality occurring between loading and processing ranged from 0.06% to 3%. However, the reports were criticized by Bayliss and Hinton due to their lack of details such as sample size and period of data collection. Warriss et al. (1992) conducted a survey of 1113 broiler journeys to one processing plant in England. The survey included 3.2 million birds and the average DOA mortality was 0.19%. There were no dead birds in 11% of the journeys and only 2.6% of the journeys had DOA levels surpassing 1%, with 15.8% being the maximum mortality recorded from one journey due to exceptional circumstances. Because lairage effects were not considered in this survey, bird losses were associated entirely with transportation. In a more recent report, Metheringham (1996) suggested that broiler mortality associated with relocation from the production site to the abattoir represented 0.1% of the birds marketed in the United Kingdom broiler industry, signifying a loss of more than 600,000 birds per year. It was unclear whether or not losses occurring during lairage were included in this estimation.

Quantifying death loss aids in determining the impact that transportation and lairage have on the economics and welfare of broiler production. Mortality is an indicator of the effects a transport system and holding conditions have on the birds and is an irreversible loss. Acquiring a better understanding of the causes of DOA and DOS mortality and the factors that influence bird death is an essential step towards reducing these losses.

2.3.1 Cause of Mortality in Broilers Dead at Processing

Bayliss and Hinton (1990) cited research conducted between 1968 and 1986 that indicated causes of broiler transportation mortality (Wilson et al., 1968; Hails, 1978; Spackman, 1984; Bayliss, 1986; Binstead, 1986). Primary causes included collapse and suffocation; injuries and hemorrhages, such as fractures of the femoral head and crushed heads from multiple floor modules; and small birds classified as runts. Further data categorizing the cause of death in transported birds found the majority of losses were due to stress and suffocation (40%), followed by injuries related to catching and transportation (35%) and pathological lesions (25%).

Postmortems preformed on broilers that died during transport implied that mortality occurring during transportation was influenced by the health of the flock prior to transportation, thermal stress arising from the transport environment and any physical injuries sustained prior to or during transportation (Bayliss and Hinton, 1990).

Comparatively, Gregory and Austin (1992) necropsied approximately 200 broilers that died after loading and prior to processing from each of six abattoirs in England. The catching and transportation methods varied between plants and included multiple-floor and dump modules, as well as loose and fixed crate systems. Heart failure was responsible for 51% of dead birds, with the majority of cases attributed to congestive heart failure without ascites suggesting that the stresses imposed on the broilers prior to arrival at the processing plant overwhelmed their cardiovascular systems. Trauma accounted for 35% of the dead birds examined with the primary cause being a dislocated or broken femur. Ruptured livers and severe head injuries were also recorded. A further 3% of the deaths were caused by neck dislocation and 11% of the deaths were unattributed. Disease conditions were prevalent in 20% of the dead bird population including ailments such as ascites, lung infection, pericarditis and perihepatitis. Had these birds not died in transit, 79% would have been fit for human consumption.

2.3.2 Factors Influencing Broiler Mortality at Processing

Previous studies on the incidence of broiler mortality occurring between loading at the production site and arrival at the processing plant varied by country, the number of processors surveyed, the data collection period, the sample size of the birds, and the catching method and transportation system used (Bayliss and Hinton, 1990; Warriss et al., 1992). Additional factors influencing bird mortality include ambient conditions during loading and transportation, stocking density of the load, position on the transport vehicle, time in transit, the length of time birds are held in lairage, the quality of the environment while awaiting slaughter and the type of bird being transported (Bayliss and Hinton, 1990).

2.3.2.1 Catching method and transportation system

Catching broilers can be accomplished manually or mechanically using automated broiler harvesters (Kettlewell and Turner, 1985). Regardless of method, catching is a source of injury that increases the birds' sensitivity to transport stressors (CARC, 2001).

A Swedish study compared carcass rejection rates relating to manual and mechanical catching (Ekstrand, 1998) to determine if automated catching would reduce rejection rates as previously reported. Data from one major processing plant covering a nine-month slaughter period involving 5.2 million birds were analysed. The birds were either caught in pairs and held upright with support around their bodies (manual method) or captured with a mechanical sweeping broiler catcher manufactured by a Finnish company (automatic method) and then loaded into the Dutch Laco modular system. The data demonstrated a large variation between flocks regardless of catching method and no significant differences between techniques. However, bird mortality was numerically higher in the mechanically caught group (0.39%) compared to the manually harvested birds (0.32%). It was proposed that automated harvesters did not cull birds like the catchers do while gathering broilers manually. Although carrying two birds in an upright position to the crates may be practiced in some countries, results in a similar study using more conventional catching techniques, such as each handler catching several birds each by one leg, may have yielded a different outcome.

Compared to loose or fixed-crate systems, modular systems that contain crates held collectively within a metal frame tend to reduce the incidence of bird injury (Kettlewell and Turner, 1985) and lower broiler mortality at processing facilities (Bayliss and Hinton, 1990). UK research affirmed prior to the introduction of the modular handling system in the mid 1980's, a range of 0.33% to 0.54% bird mortality was recorded; whereas once modules were adopted, death losses fell to 0.12% and 0.2% (Aitken, 1985 and Stuart, 1985, respectively).

2.3.2.2 Ambient conditions during transportation

In addition to the catching and transportation methods used, ambient conditions during loading and transportation can influence broiler mortality. Under cold conditions, high wind speeds enhance the likelihood of hypothermia. Freeman (1984) suggested exposure to wind speeds of 80 km/h would increase the wind chill factor during cold weather transportation but would cool the birds during hot, humid conditions. Mitchell et al. (1997) concluded that broilers could be transported comfortably in ambient temperatures as low as -4°C if the birds remain dry, whereas temperatures around 6°C will induce moderate hypothermia if the birds are wetted down. Wetting will increase mortality when the environmental temperature approaches 0°C because it reduces the insulating capacity of the feathers, which can lead to rapid cooling (Mitchell et al., 1997).

As the ambient temperature increases, sensible heat loss during transportation becomes limited because the temperature gradient between the bird and its environment is reduced. Thus the birds must rely on evaporative cooling as ambient temperatures exceed 25°C (Kettlewell and Turner, 1985). Under hot, humid transport conditions, if the air movement across the birds is inadequate, evaporative heat losses may not suffice and the body temperature of the bird may increase. Death is likely if the deep body temperature of the bird rises above 45°C (Kettlewell and Turner, 1985).

In Canada, CARC (2001) published a Recommended Code of Practice for the Care and Handling of Farm Animals specifically geared towards live haul transportation. Several recommendations were made for transporting broilers under different ambient conditions: during hot and humid periods, animal transportation should be scheduled at night and in the early morning (Section 5.4.1 (e), pg 11); covers should be used to protect birds in crates from wind, rain and adverse weather conditions (Section 8.7.12, pg 25); birds should be protected from getting wet (Section 8.7.14, pg 25) and when temperature exceeds 32°C, birds should not be loaded unless scheduled for same-day delivery (Section 8.7.22, pg 26).

2.3.2.3 Stocking density

Behavioral responses to extreme ambient conditions are limited during transportation due to stocking density within the crates (Nicol and Scott, 1990). Again, CARC (2001) issued suggestions pertaining to stocking densities, which included: The number of birds per crate or bin depends on available floor space, body size of birds, and prevailing environmental conditions at time of transport (Section 8.7.11, pg 25); Weather conditions should be considered when determining load densities. For growing and adult chickens, the recommended maximum live weight loading densities for crates and bins in cold weather is 63 kg/m^2 (Section 8.7.21, pg 26); During winter travel, increased loading density beyond recommendations can predispose to frostbite in individual animals because it prevents them from repositioning in the trailer (Section 5.3.1 (b), pg 10).

Because chickens are contained in crates or drawers during transportation, they do not have the opportunity to alter their position within the trailer. Additionally, as the stocking density is increased, there is a reduction in the birds' ability to reposition in the crate itself. Weeks and Webster (1997) stated load volumes may reach 150 kg/m^3 and that as stocking densities are increased, birds are forced into direct contact with others, which impedes postural thermoregulation and reduces the effective surface area available for convective heat losses. Although this characteristic of increased stocking density may have undesirable affects during summer transportation, it could be an advantage during cold weather transportation.

Between March and August of 1988, a broiler transportation survey was conducted in England and the effect of sample month on broiler mortality was investigated (Warriss et al., 1992). As the average distance traveled and average journey time increased, the bird mortality dropped slightly from 0.22% to 0.16% (Table 2.1). Although there were additional influencing factors, the decrease in mortality was chiefly attributed to a corresponding reduction in average stocking density from 17.3 to 15.8 birds per crate (Table 2.1). This survey demonstrates one of the possible effects of reducing stocking density during warm weather transportation, although there was no reason for accrediting the reduction in mortality entirely to the lower stocking rate.

The effect of stocking density is related to factors such as ambient conditions, airflow within the transport trailer and bird size, as well as journey distance and time.

TABLE 2.1. Average distance, journey time, mortality and stocking density for four months from a processing plant in England

Month	Avg. distance (km)	Avg. journey time (h)	DOA (%)	Stocking density (birds/crate)
March	29.2	3.1	0.22	17.3
June	29.7	3.3	0.19	17.3
July	28.1	3.3	0.18	16.6
August	31.9	3.6	0.16	15.8

Adopted from Warriss et al., 1992.

2.3.2.4 Position on trailer

Not only can load density affect mortality, but position on the trailer can also influence bird death. Mitchell et al. (1997) found that broiler mortality was highest in the module positioned at the very back of the lorry, at the bottom of the stack. Observations of wet birds, and crates containing water and grit were made in this location. Thirty-six percent of all mortality occurred in the back-bottom module, which was deemed the inlet for the passively ventilated vehicle. A combination of cold air entering and moving over the birds as well as wetting caused by the introduction of road spray likely led to the elevated mortality levels in that lorry position. The latter half of the lorry contained 75% of the mortality, whereas 60% of the dead birds were located across the entire bottom tier of the modular stacks (Mitchell, 1997). This mortality pattern can also be related to the tarping technique used on the broiler carriers. In this particular study, the curtains were in a closed configuration, which minimized ventilation rates. Because the curtains did not reach the floor of the transporter, the space between the bottom of the curtain and the floor of the trailer became an air inlet and exposed the birds in this area to cold, wet, moving air.

2.3.2.5 Transportation distance and time

Once the birds are loaded onto the transportation vehicles, the journey distance and transportation length may influence bird mortality (Warriss et al., 1992; Ziggers, 1999). Typical journey distance and journey length in the United Kingdom were determined from a study involving 19.3 million broilers transported to four processing plants between March and August of 1989 (Warriss et al., 1990). The average distance traveled and average journey time, measured from the end of loading on the farm to the completion of unloading at the processing plant, was 33.5 km (range of 24.5 to 48.3 km) and 2.7 h (range of 1.3 to 4.4 h), respectively.

Another broiler transportation survey resulted in a generalization that as journey distance or time increased, so did the incidence of bird mortality (Warriss et al., 1992). The average and maximum distance, journey time and total time from the survey were 29.4 km and 72 km, 3.3 h and 9 h, and 4.2 h and 10 h, respectively (Warriss et al., 1992). Because an average journey covering 29.4 km took 3.3 h to complete, the survey suggested that birds spent a substantial part of their journey on stationary vehicles, which likely led to the establishment of a hostile on-board thermal environment due to reduced airflow. In journeys lasting less than 4 h, bird mortality was 0.16%, whereas journey lengths over 4 h showed a 75% increase in mortality (0.28%). For clarification, the distance traveled was underestimated because it was determined as the minimum radial distance between the grow-out site and the slaughtering facility as opposed to the actual road distance traveled (Warriss et al., 1992). Journey time began once the birds were loaded onto the transport vehicle and ended once the birds were unloaded at the plant. Total time, which did not incorporate the time birds were held in lairage, was calculated as the difference between the time at start of loading and the end of unloading.

CARC (2001) recommendations regarding poultry transportation times in Canada proposed that the total time in transport and lairage during which the animals have not received feed and water, from the premises of origin to final destination, should not exceed 40 hours for poultry (Section 5.5.2, pg 11) and that the recommended maximum transport time for poultry is 36 hours (Table 4, pg 13). A review of the CARC (2001) recommended times allowed for poultry in transit should be completed by industry personnel to reflect animal welfare concerns and to ensure the maximum transportation lengths are appropriate.

2.3.2.6 Lairage

It has been suggested that the lairage period, or the amount of time that birds are held at the plant awaiting slaughter, may be comparable to the journey time (Quinn et al., 1998) or possibly longer, depending on the processing schedule. Quinn et al. (1998) described the lairage conditions in two facilities, including measurements of temperature, relative humidity, air velocity and carbon dioxide. It was concluded that broiler-holding areas are generally open, with heterogeneous airflow patterns and many sources of heat and water. Due to inadequate ventilation at bird level, the thermal conditions may present additional strain on birds previously exposed to transportation stressors.

Subsequently, Warriss and others (1999) investigated the effects of one, two, three and four-hour lairage periods on the glycogen reserves and body temperature of broilers contained in modules. The birds sampled were extracted from the centre crates of the modular stack located in the third position from the front of the transport vehicle. The greatest increase in body temperature occurred during the first hour in lairage (0.3°C), and each additional hour awaiting slaughter resulted in a 0.1°C rise in body temperature. In contrast, liver glycogen levels depleted expectantly and were lowest after four hours in lairage. These results were pertinent to the publication of recommendations for the "Guide to Alleviation of Thermal Stress in Poultry in Lairage," distributed by the Ministry of Agriculture, Fisheries and Food (MAFF) in the United Kingdom (1998). This publication suggested that when possible, birds should be killed immediately upon arrival at the slaughter house and that the lairage period should be kept to a maximum of two hours. Still, published data on lairage conditions is limited, and the relationship between lairage period and its influence on bird mortality has yet to be investigated.

Clearly, bird mortality is influenced by several factors which all need to be considered when adopting new procedures to alleviate bird losses associated with transportation.

2.3.3 History of Dead-On-Shackling Broilers in Saskatchewan

A significant economic loss to the Saskatchewan Poultry Industry is the market-age broiler chickens that die after loading and prior to slaughter. The University of Saskatchewan Poultry Extension Program (Dr. Sandra Stephens and Mr. Guillaume Audren) gathered broiler DOS data from the processing plant in Saskatchewan from 1997 to 1999. During this time, live haul transportation was converted from a loose crate system, where crates were individually lifted and stacked into the commercial transport trailer, to the Anglia Autoflow modular system with the supposition that DOS losses would be reduced. The transformation of the live haul system was completed in April

1997; however, the incidence of DOS mortality persisted despite assumptions to the contrary (Figure 2.3).

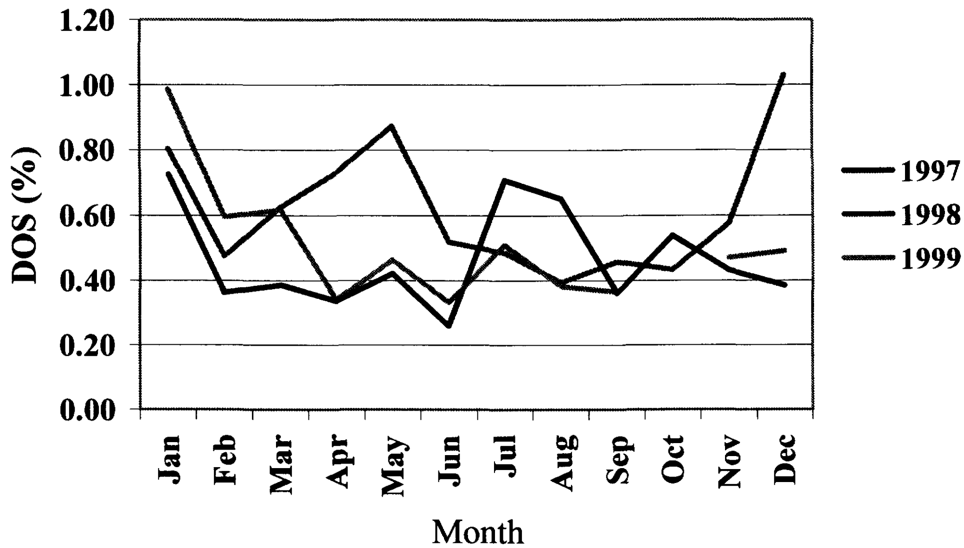

Figure 2.3. Saskatchewan DOS data for 1997-1999.

There are peaks in DOS mortality occurring on a seasonal basis (Figure 2.3), which coincide with exposure to temperature extremes during summer and winter transportation. In 1997, DOS losses exceeded 0.5% in January, July, August and October; whereas in 1998, January, March to June, November and December had DOS values surpassing 0.5%. In 1999, there are elevated bird losses in January, February and March but the summer DOSs appear to have declined compared to the previous two years (Figure 2.3). Unfortunately, data for October 1999 was not available, and post mortems were not performed on any of the DOS mortality, so further classification with regards to the cause of death was not available. During the three years of data collection, the lowest incidence of DOS birds occurred in June 1997 (0.26%) and the highest DOS percentage was recorded in December 1998 (1.03%). Average broiler DOS values for Saskatchewan in 1997, 1998 and 1999 were 0.46, 0.62 and 0.50%, respectively.

Provincial and national chicken mortality data prior to 1999 was posted by Agriculture and Agri-Food Canada (AAFC) in annual reports for chicken condemnations. In these reports, results for Saskatchewan and Manitoba were combined, as were chicken condemnations in the Maritimes (AAFC, 1998). Data for all other provinces were reported separately and the overall national results were included. In 1999, the format of the condemnation report changed such that the category for "birds found dead" was eliminated. However, the Canadian Food Inspection Agency (CFIA) tracked DOS birds through another yearly report that differentiated between species. The data from the CFIA reports represent all classifications of poultry, including turkeys and spent fowl, in addition to meat chickens. Table 2.2 lists DOS mortality data for Saskatchewan and Canada from 1997 to 2002.

Saskatchewan DOS values in Table 2.2 are higher for 1997 and 1998 than those determined by Saskatchewan Poultry Extension because AAFC pooled DOS data from Saskatchewan and Manitoba, a province with greater bird losses during transportation. In 2002, Saskatchewan's mortality was comparable to the nation's average; however, the losses were still significant. If Saskatchewan and the rest of Canada could reduce DOS levels to those achieved in the United Kingdom (0.1% to 0.2%), it would create considerable economic savings for the commercial poultry industry and reflect an improvement in bird welfare.

Table 2.2. DOS mortality (%) for Saskatchewan and Canada from 1997 to 2002.

Year	Saskatchewan DOS (%)	Canada DOS (%)	Source
1997	0.704	0.481	AAFC[1]
1998	0.648	0.468	AAFC[1]
1999	0.502	0.563	CFIA[2]
2000	0.519	0.477	CFIA[2]
2001	0.524	0.438	CFIA[2]
2002	0.475	0.462	CFIA[2]

[1]Chicken Condemnations Annual Reports – combination of Saskatchewan and Manitoba data.
[2]Selected Species Found Dead at Registered Canadian Establishments by Province – poultry data includes turkeys and spent fowl, along with meat chickens.

2.4 BROILER TRANSPORTATION

Because the preponderance of broiler transportation research has been conducted in the United Kingdom, it is valuable to compare the transportation systems used in both Saskatchewan and the United Kingdom, and the climates they must perform in.

2.4.1 Broiler Transportation in Saskatchewan

Intensive broiler operations are typically located away from the processing facility, thereby making transportation prior to slaughter a necessity. At the time of data collection for this study, there were 73 broiler producers located throughout the province of Saskatchewan that transported their birds to Lilydale Co-operative Limited in Wynyard for processing (Audren, personnel communication). In 2000, approximately 16 million broiler chickens were processed at this abattoir (Bartoshewski, personnel communication).

During the broiler transportation research period, Saskatchewan broilers were reared until they attained a body weight of approximately 1.8 kg, which typically required 36 to 42 days (Audren, personal communication). At the end of the production cycle, catching and crating broilers was accomplished manually. Once birds were loaded onto the transport vehicle, the journey to the processing facility ranged from 2 to 400 km, with the average travel distance being approximately 200 km (Bartoshewski, personnel communication).

2.4.1.1 Catching and crating broilers

Prior to 1997, birds were handled extensively due to the transportation system that existed. Catching crews were required to catch birds in the barn, usually by one leg, and walk a considerable distance to the transport vehicle parked outside the facility, with the broilers hanging upside down by the catchers' sides. Birds were then transferred to a handler on the trailer who placed the broilers in loose crates. The loose crates were stacked from the trailer floor to ceiling, leaving a considerable space between stacks for ventilation. Problems associated with this method of bird collection included the distance the birds were carried and the bird exchange at the trailer, both of which resulted in dislocated legs, bruising and other injuries. In addition, the loose crates utilized had small openings that caused damage to the birds as they were inserted.

In April 1997, the Anglia Autoflow modular system (Wortham Ling, Norfolk, England, IP22 1SR) was introduced for catching and crating broilers for transportation. Twelve or 15 perforated plastic drawers are collectively held in the modular containers constructed of metal framing (Figure 2.4). The modules are transferred from the transport trailer to the barn by a forklift and positioned in close proximity to the birds.

Catching is accomplished manually by grabbing a bird by one leg and carrying multiple birds in each hand, in an inverted position, to an empty open-top crate. The crates are filled with broilers from the top to the bottom of the module to prevent head and neck injuries that may occur if the birds were loaded in the reverse manner. Once the module is fully loaded, it is removed from the barn by the forklift and returned to the trailer, which may be a 16 m single trailer or a B-train.

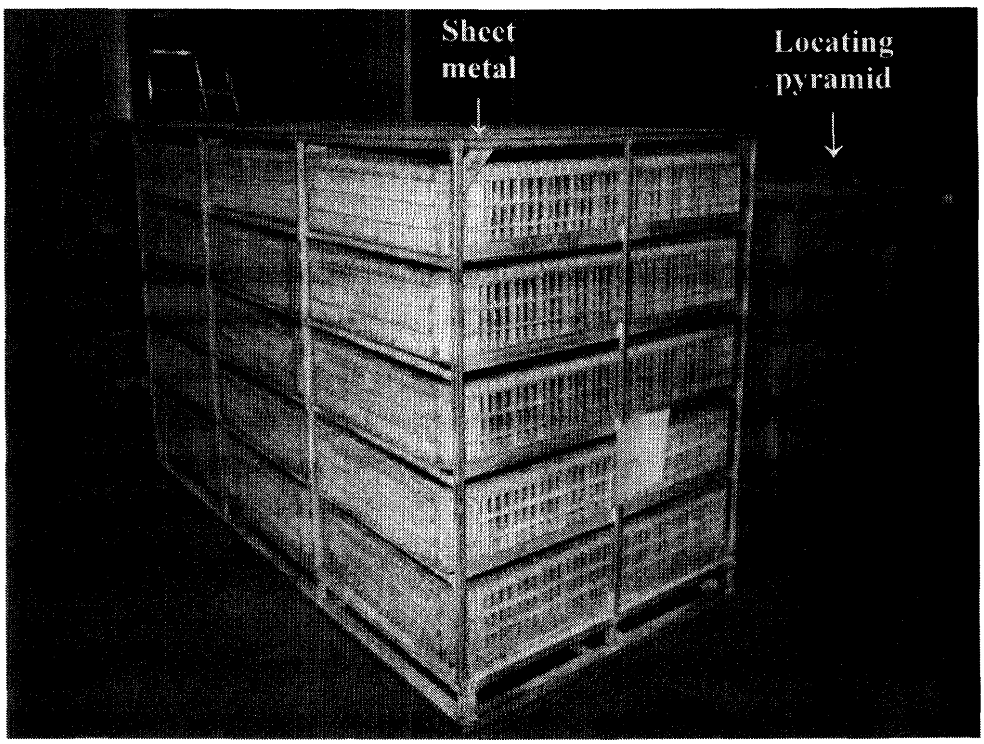

Figure 2.4. Anglia Autoflow modules used for transporting chickens in Saskatchewan. The modules are constructed of a metal frame and contain perforated plastic drawers. The top rows of crates are covered by thin sheet metal, and locating pyramids secure the stacked modules in position on the trailer.

Loading birds with the Anglia Autoflow modular system is an improvement from the loose crate system for several reasons. There is less physical strain on the broiler catchers as they have shorter distances to carry the birds and are not required to lift heavy loose crates (Kettlewell and Turner, 1985). Additionally, the broilers are exposed to shorter handling periods that may reduce stress (Kannan and Mench, 1996), and the possibility of injury to the birds occurring as the catchers walk through restrictive areas such as doorways or when the handlers exchange birds is reduced.

2.4.1.2 Broiler transportation trailers

The dimensions for the 16 m passively ventilated commercial transport trailers used in Saskatchewan are included in Table 2.3. All trailers have a solid floor, with a step in the trailer frame located 3.74 m from the headboard (Figures 2.5). There are vents running midline through the headboard, roof and tailboard of the trailer that are manually adjusted according to the ambient conditions. The three centrally located vents on each of the headboard and rear of the trailer are opened by sliding wooden panels along horizontal tracks attached to the trailer (Figure 2.7). The wooden vents on the headboard and tailboard of the trailer are solid, with the exception of a small hand-sized hole (14.5 cm by 7.0 cm) located on the top headboard vent. Running continuously through the center of the trailer roof are eight hinged wooden vents, numbered from the front to the back of the trailer, that are secured in position with latches (Figure 2.8). The width of all roof vents is 0.235 m, but the length varies (vents 1 and 8 are 1.22 m long; vent 5 is 1.50 m; and vents 2, 3, 4, 6 and 7 are 2.43 m long). The roof of the trailer is fixed and when loaded with modules, free space between the top of the modular stack and the roof of the trailer is approximately 0.33 m and 0.55 m before and after the step in the trailer frame,

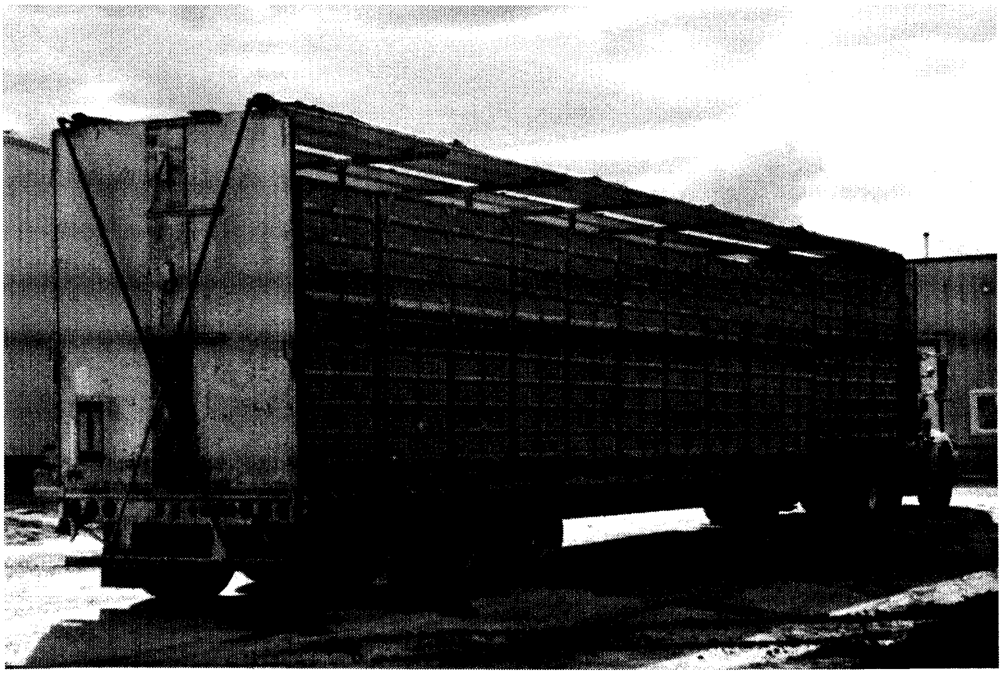

Figure 2.5. 16 m trailer used for transporting broilers in Saskatchewan. A step in the trailer frame is located 3.74 m from the front of the trailer, creating less free space between the top of the modules and the roof of the trailer for 3 stacks in the trailer.

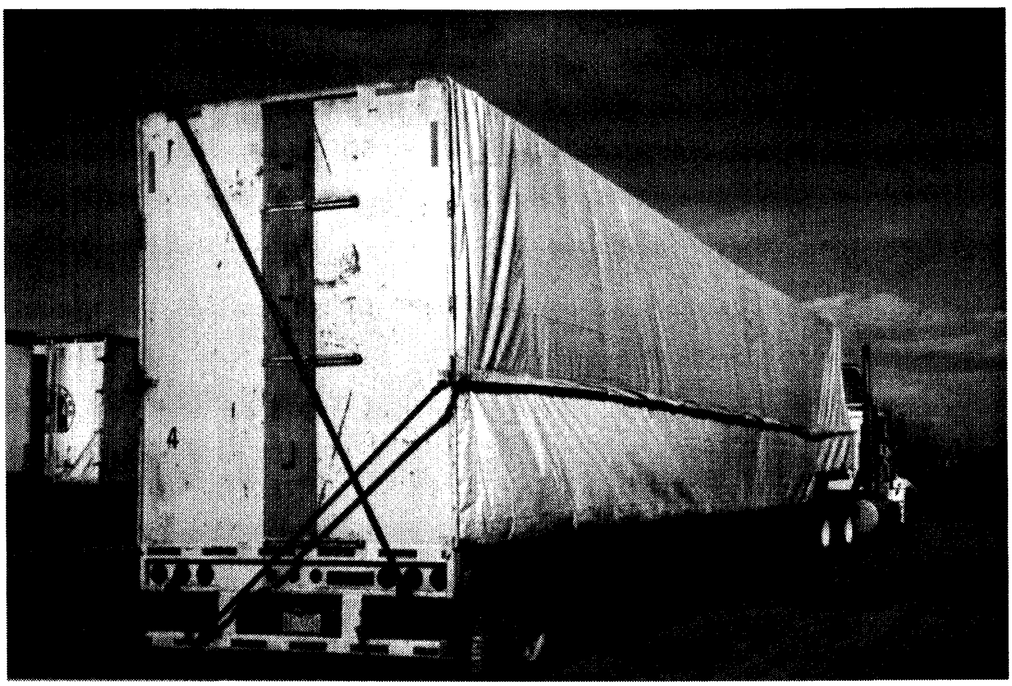

Figure 2.6. Lowered curtain on the passenger side of the trailer unit. Curtains are secured to the floor of the trailer with a continuous bungee cord and a metal rod running the length of the trailer. Tarps are not fastened at the ends to the headboard or tailboard of the trailer.

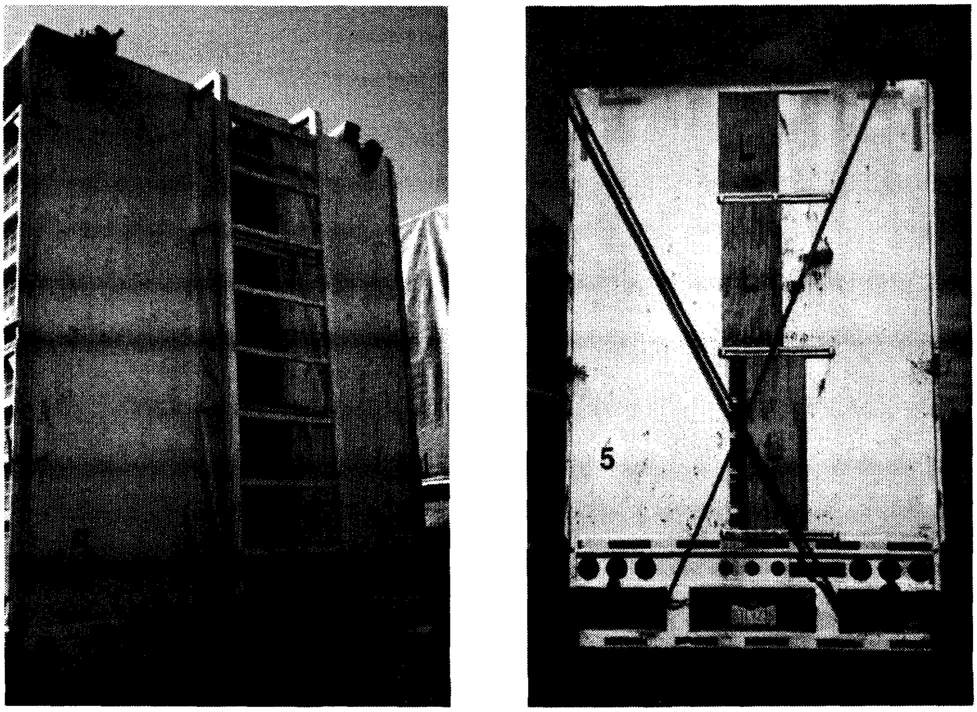

Figure 2.7. Headboard (left) and tailboard (right) vents on the trailers are opened or closed by sliding wooden panels along horizontal tracks.

Figure 2.8. Vents running midline along the roof of the trailer are adjusted according to the ambient conditions to provide air circulation. Latches are used to secure the wooden vents.

respectively (Figure 2.5). The open sides of the trailer can be covered with a retractable solid curtain that is permanently attached to the roof. To protect the birds during adverse weather conditions, the curtain is unrolled and fastened to the floor with a bungee cord. (Figure 2.6).

TABLE 2.3. Dimensions of the 16 m commercial broiler transportation trailers, modules and crates used in Saskatchewan

Component	Section	Length (m)	Width (m)	Height (m)
Trailer	In entirety	16.01	2.50	-
	Anterior step in frame	3.74	2.50	2.80
	Posterior step in frame	12.27	2.50	3.10
Module	12 crates	2.44	1.17	1.15
	15 crates	2.44	1.17	1.40
Crate	-	1.11	0.71	0.20

2.4.1.3 B-trains

In addition to the 16 m trailer, new transport vehicles comprised of two units were introduced and are commonly referred to as "B-trains." A significant difference between the two trailer systems is that the B-train does not have a fixed roof, whereas the 16 m trailers do. Specifically, the roof of the B-train is raised to accommodate loading modules and then lowered prior to transportation such that there is no free space between the roof of the trailer and the top of the modules. This system, with a greater load capacity, is similar to the lorry-trailer combinations used for transporting broilers in the United Kingdom (Kettlewell et al., 1993). At the time of this study, there were only 2 B-trains available for transporting broilers in Saskatchewan; therefore, the majority of broiler journeys were completed with 16 m trailers. The 16 m trailers were used exclusively in this broiler transportation research.

2.4.1.4 Modules and crates

Modules are stacked in pairs on both trailer systems and positioned transversely so that the crates cannot be opened until the modules have been unloaded at the processing plant. When loaded on the 16 m trailer, there are 6 modules, each composed of 12 crates, on the raised floor immediately behind the headboard and 20 modules in the remaining portion of the trailer (Figure 2.5). The stacks of modules positioned after the step in the trailer frame have 12-crate modules on the top and 15-crate modules on the bottom of the stack; hence, there are 342 crates in entirety. Modules on the floor of the trailer are held in place with locating pyramids that interlock with the module frame. The locating pyramids are also found on the top surface of the bottom modules to secure the top modules in position (Figure 2.4). Spaces between modular stacks are narrow (approximately 4 cm to 7.5 cm), with several of these gaps containing T-supports for the trailer roof. Free space between the roof of the trailer and the top of the modular stacks facilitates loading and unloading procedures. Modular dimensions are included in Table 2.1.

Each crate is approximately 0.71 m wide, 1.11 m deep and 0.20 m high. The crates are constructed of durable plastic with blunt edges to minimize injury to the birds (Figure 2.4). Ventilation is achieved through perforations on the floor (1 cm x 1 cm) and sides (5 cm x 2.5 cm) of the containers. Crates in the top row of the modules are covered by thin sheet metal welded to the frame of the module to keep the birds contained and to prevent excess fecal material from falling into the modules at the bottom of the stack.

2.4.1.5 Stocking density

Bird stocking density on the trailer is determined by the procurement manager at the processing plant and varies according to the weight of the birds, the number of birds to be transported and the ambient weather conditions (Bartoshewski, personnel communication). Generally, 22 to 26 birds are loaded into each crate, which is equivalent to 7524 or 8892 birds loaded onto a 16 m trailer, respectively. Under winter conditions, the stocking density is increased to counter the cold temperatures. During summer transportation, the stocking density may be reduced to facilitate air movement and to lessen the effects of heat and moisture production by the birds.

2.4.1.6 Curtain and vent configurations

During winter transportation, both curtains on the trailer are lowered and secured to the floor of the trailer with a bungee cord. Additionally, a metal rod running the length of the trailer assists in keeping the curtains positioned; however, the tarps are not fastened at the ends to the headboard or tailboard of the trailer (Figure 2.6). The headboard and rear vents of the trailer are kept closed, while the truck drivers alter the configuration of the roof vents according to the outdoor conditions to provide air circulation.

In mild winter weather all roof vents are open, but in cold conditions only one or two vents near the front or middle of the trailer are agape. Depending on the spring and fall conditions, the roof vents are typically open and the curtains may be rolled up. The trailer tarps are lifted during summer transportation unless adverse weather conditions, such as heavy rain, strong winds or hail, warrant otherwise. All vents are opened to allow maximum ventilation.

2.4.1.7 Lairage

Upon arrival at the processing plant in Wynyard, laden transportation trailers are parked outdoors with the curtains retracted during mild weather and if the temperature climbs, the curtains are used as shades. Under winter conditions, the first two trailers reaching the processing plant are unloaded in the Live Receiving shed located adjacent to the shackling equipment at the plant, and in fact, trailers used during data collection were driven directly to this area. Additional trailers are parked in a simple shed, which offers some protection from the elements, but has no heating or ventilation.

At the time of this study, catching began around 10 pm at each production site for birds that were to be slaughtered the following day. The amount of time birds are held in lairage depended on the distance between the farms and processing plant and the position of the truck in queue, awaiting slaughter.

2.4.1.8 Climatic conditions

Throughout the year, transport conditions vary over a wide range of environmental conditions. Environment Canada (2003) indicates the average daily temperature in January for Saskatoon (located in central Saskatchewan) from 1892 to 1990 was –17.0°C with high and low extremes of 10.0°C and –48.9°C, respectively. The average daily July temperature was 18.2°C with 40.0°C and –0.6°C being the high and low extremes, respectively. The extreme temperatures of these seasonal ranges pose animal welfare and production based challenges for broiler transportation in addition to detrimental effects of other environmental elements such as wind, rain, sleet, hail and snow. The average number of days with precipitation equal to or greater than 0.2 mm, including rainfall and snowfall, for the Saskatoon area is 111.9 days representing 31% of the year (Environment Canada, 2003).

2.4.2 Broiler Transportation in the United Kingdom

In 2004, annual broiler production in the United Kingdom exceeded 883 million birds (DEFRA, 2005). The method of catching broilers and transporting them to slaughter varies considerably throughout the area. However, approximately 90% of broiler production in the UK has adopted the Easyload modular system manufactured by Anglia Autoflow Limited (Kettlewell and Mitchell, 1994). Catching is accomplished manually, though mechanical broiler harvesters have been developed and are available for commercial use (Kettlewell and Mitchell, 1994). Bird density in modules is dependent upon several factors such as bird weight and weather conditions; therefore, number of birds per crate can range from 18 to 30 (Bayliss and Hinton, 1990).

Typical poultry transport vehicles in the United Kingdom are similar to the B-trains used in Saskatchewan. They are comprised of a lorry and separate trailer, together carrying 22 modules of stacked crates (10 modules on the lorry, 12 modules on the trailer). These vehicles have a solid headboard and roof but the rear is always open. The floor of both the lorry and trailer is flat.

In addition, the vehicles are generally outfitted with curtains that open or close horizontally, however, vertically controlled curtains are being pursued (Kettlewell et al., 2000). Because the curtains do not reach the floor on all vehicles, there is a greater possibility that water and other material from the road may enter through this area.

Nicol and Scott (1990) reported that broiler journeys in the UK are typically no longer than three hours, although a survey conducted by Warriss et al. (1992) described the average journey time as 3.3 hours. In the same survey by Warriss et al. (1992), the average distance traveled was 29.4 km and the total average time birds remained on the vehicle was 4.2 hours. In comparison, Mitchell and Kettlewell (1994) suggested birds might remain on the vehicle for as long as 12 hours, indicating an elongated wait in lairage.

2.4.2.1 Climatic conditions in the United Kingdom

The climatic conditions in the UK are not as severe as those found in Saskatchewan. The maximum and minimum average daily temperatures in January for the United Kingdom from 1971 to 2000 were 6.1°C and 0.7°C, respectively, with a low extreme of –27.2°C, whereas the maximum and minimum average daily July temperatures were 19.2°C and 10.6°C, respectively, with 38.5°C being the high extreme (Met Office, 2003a; Met Office, 2003b). The difference in the average daily temperature in Saskatchewan from January to July is 36.1°C, compared to 19.9°C in the UK. The range in extreme temperatures from the UK is a 65.7°C difference, whereas the range in extreme temperatures in Saskatchewan is 88.9°C. Clearly, the UK does not experience the same temperature extremes as Saskatchewan; however, the UK contends with rainfall equal to or greater than 1mm for 154.4 days or 42% of the year (Met Office, 2003a), which can adversely affect transportation conditions.

2.4.3 Broiler Transportation under Winter Conditions

Performing transportation studies under winter conditions typical of Saskatchewan will add to the foundation of broiler transportation research as data will be collected when transporting birds at low ambient temperatures. Furthermore, the applicability of previous findings to transport conditions in Saskatchewan will be verified.

The objectives of the winter transportation study were to characterize the thermal environment which develops as broilers are transported in Saskatchewan winter conditions by recording temperature and relative humidity conditions within broiler transport vehicles. Additional objectives included quantifying the physiological effects of transportation on birds by collecting rectal temperatures immediately before and after transportation and by monitoring deep body temperature of sentinel birds previously implanted with recording devices. Mortality data associated with the broiler journeys were also acquired.

3.0 TEMPERATURE GRADIENTS AND PHYSIOLOGICAL BIRD RESPONSES ESTABLISHED DURING FOUR BROILER TRANSPORTATION JOURNEYS IN SASKATCHEWAN DURING WINTER

3.1 INTRODUCTION

The thermal environment within the transportation trailer is the most significant stressor that broilers are exposed to in transit (Kettlewell, 1989; Mitchell and Kettlewell, 1994). This microenvironment is dictated principally by the interaction of heat and moisture within the trailer and airflow through the transporter. Passively ventilated broiler carriers commonly generate inadequate levels of ventilation that can lead to unfavourable conditions for the birds (Mitchell and Kettlewell, 1993; Mitchell and Kettlewell, 1998).

The airflow within a poultry transporter is ruled by the pressure distribution on the outside surface of the trailer and the dense packing inside the trailer (Hoxey et al., 1996). The headboard of the trailer has a positive pressure that is greatest near the top leading edge of the trailer and decreases down the headboard (Götz, 1987). Therefore an opening in the headboard will become an air inlet. Flow separation occurs at the leading edge of the top of the trailer and at the leading edges of both sides of the trailer, thereby creating large negative pressures on the top and sides of the front end of the trailer (Götz, 1987; Hoxey et al., 1996). This negative pressure on the top and sides of the trailer declines towards the tailboard or back end of the trailer. The air flows from high-pressure areas to low-pressure areas, generally taking the most direct route. Because the largest negative pressure occurs at the top of the trailer near the headboard, vents open in this area will act as exhaust outlets for the trailer and openings at the back of the trailer will act as air inlets. The high stocking density and dense packing of the crates within the trailer creates an obstruction for air movement within the load and limits air mixing. With the transporter curtains lowered, air may short circuit between vents on the roof, or between openings at the bottom of the curtains and the vents in the roof directly above those openings. This pressure distribution is typical of blunt, sharp-edged objects and an understanding of it becomes useful when interpreting the temperature and humidity data collected from broiler transporters.

Three-dimensional thermal mapping of the microenvironment has been achieved by equipping the transport lorry and trailers with data loggers (Kettlewell et al., 1993). In the summer months with curtains in an open configuration, passive ventilation was sufficient to prevent temperature gradients in the trailer if the vehicle was in motion. During winter months with curtains in the closed configuration, large temperature and moisture gradients developed due to reduced air movement, with areas immediately behind the headboard being exposed to high temperature and humidity conditions capable of causing heat stress for the birds.

Mitchell et al. (1997) suggested if birds remain dry they can maintain body temperature in external temperatures as low as -4°C, and therefore, transportation conditions are acceptable. Due to the lack of data for transporting broilers at ambient temperatures below -4°C, conducting transportation studies under winter conditions typical of Saskatchewan will add to the foundation of poultry transportation research. In addition, the applicability of previous findings to transporting conditions in Saskatchewan will be verified. Therefore, the objectives of this study were to characterize the thermal environment imposed on broilers transported in Saskatchewan winter conditions by recording temperature and humidity conditions within transport vehicles, and to quantify the physiological effects of transportation on the birds by collecting rectal temperatures immediately before and after transportation, by monitoring the deep body temperature of sentinel birds previously implanted with recording devices, and by reviewing mortality data associated with the journeys.

3.2 MATERIALS AND METHODS

In January 2000, four broiler journeys were monitored, with the primary focus being to quantify temperature and humidity conditions within 16 m transport trailers used by the Saskatchewan broiler industry.

The dimensions for the 16 m passively ventilated broiler carriers are included in Table 3.1. All trailers have a solid floor, with a step in the trailer frame located 3.74 m from the headboard (Figure 3.1). There are vents running midline through the headboard, roof and tailboard of the trailer that are adjusted manually according to the ambient conditions. The three centrally located vents on each of the headboard and tailboard of the trailer are opened by sliding wooden panels horizontally along tracks attached to the trailer. These wooden panels on the headboard and tailboard of the trailer are solid, with the exception of a small hand-sized hole (14.5 cm by 7.0 cm) located on the top headboard vent. Running continuously along the center line of the trailer roof are eight hinged wooden panels, numbered from the headboard to the tailboard of the trailer, that are secured in position with latches (Figure 3.1). The width of all roof vents is 0.235 m, but the length varies (vents 1 and 8 are 1.22 m long; vent 5 is 1.50 m; and vents 2, 3, 4, 6 and 7 are 2.43 m long). The open sides of the trailer can be covered with a retractable solid curtain that is permanently attached to the roof and fastened to the floor with a bungee cord to protect the birds during adverse weather conditions. For each journey monitored, curtains on both sides of the trailer were lowered, all headboard and tailboard vents were closed and roof vents were adjusted by the truck drivers according to the external temperature and their previous experience.

TABLE 3.1. Dimensions of the 16 m commercial broiler transportation trailers, modules and crates used in Saskatchewan

Component	Section	Length (m)	Width (m)	Height (m)
Trailer	In entirety	16.01	2.50	-
	Anterior step in frame	3.74	2.50	2.80
	Posterior step in frame	12.27	2.50	3.10
Module	12 crates	2.44	1.17	1.15
	15 crates	2.44	1.17	1.40
Crate	-	1.11	0.71	0.20

The modules are a component of the Anglia Autoflow modular system (Wortham Ling, Norfolk, England, IP22 1SR) and are stacked in pairs, one on top of the other, on the trailer. They are positioned transversely so that the crates cannot be opened until the modules have been unloaded at the processing plant. When loaded on the trailer, there are 6 modules, each composed of 12 crates, on the raised floor immediately behind the headboard and 20 modules in the remaining portion of the trailer (Figure 3.1). The stacks of modules positioned after the step in the trailer frame have 12-crate modules on the top and 15-crate modules on the bottom of the stack (Figure 3.2); hence there are 342 crates in entirety. Free space in between the roof of the trailer and the top of the modular stacks facilitates loading and unloading procedures. Modular dimensions are included in Table 3.1.

Each crate is approximately 0.71 m wide, 1.11 m deep and 0.20 m high (Table 3.1). The crates are constructed of durable plastic with blunt edges to minimize injury to the birds. Ventilation is achieved through perforations on the floor (1 cm x 1 cm) and sides (5 cm x 2.5 cm) of the containers. Crates in the top row of the modules are covered by thin sheet metal to keep the birds contained and to prevent excess fecal material from falling into the modules at the bottom of the stack. Stocking density, determined by the procurement manager at the processing plant, was 24 birds per crate (8208 birds per trailer) for the first three journeys and 22 birds per crate (7524 birds per trailer) for the last journey.

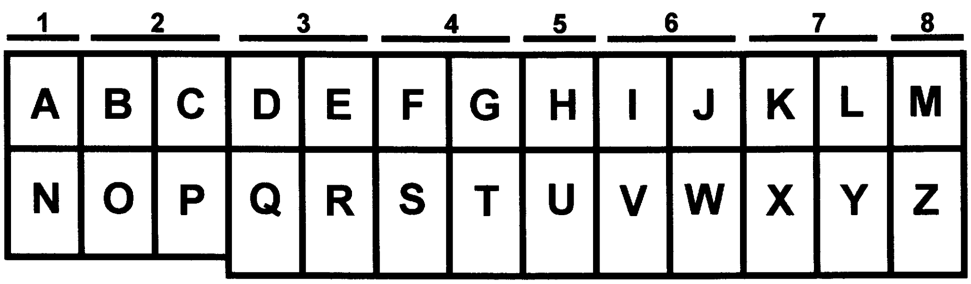

Figure 3.1. Lateral view of a 16 m broiler transport trailer used in Saskatchewan. Modules are labeled alphabetically from the front of the trailer and the numbered solid lines above the trailer indicate vent location on the roof.

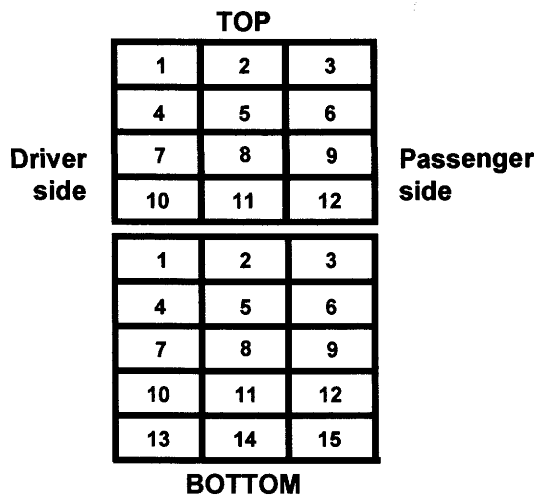

Figure 3.2. Crates within each module are numbered. When viewing the stack of modules from the back of the trailer, crate 1 is positioned on the driver side of the vehicle.

Continual recording of temperature and relative humidity was achieved with the use of Gemini Tinytag Ultra data loggers (Gemini Data Loggers (UK) Limited, Chichester, West Sussex, England) that were programmed to record data at 72-second intervals. The data loggers were attached to a wire frame and clipped onto the front of the crates as modules were being loaded onto the trailer. The monitored modules and crates changed for each journey. Journey 1 had data loggers in crate 5 of modules A, C, E-G, I, K, M, O, Q, S, U, W, Y and Z. The loggers were placed in crate 2 of modules A, C, E, G, I, K, M, O, Q, S, U, W and Z for journey 2. Logger placement for journeys 3 and 4 was in crate 2; however, the modules monitored were A-I, K, M, N, P, Q, S, U, W and Y for journey 3 and modules A-I, K, M, Q and Z for journey 4. The position of the loggers ensured that the conditions being monitored were at bird level, with the exception of 5 data loggers attached to the top of modules A, C, D, F and H in journey 4. Two loggers, one fastened to each of the side view mirrors of the truck cab, recorded ambient conditions of each journey. Times of departure from the production site and arrival at the abattoir were documented so that journey duration and average temperature and humidity conditions for the entire journey length could be calculated.

Rectal temperatures of 8 birds from 4 pre-selected modules on each journey were recorded immediately before and after transportation. An electronic temperature probe was inserted 3 cm into each bird's cloaca until the temperature reading stabilized. In addition, groups of two or three sentinel birds, which were previously implanted with devices to continuously monitor deep body temperature (Kettlewell et al., 1997), were placed in two selected modules per trip. Core temperatures of implanted birds were recorded every four minutes. The modules containing the birds from which rectal and deep body temperatures were taken varied for each journey studied (Table 3.2).

Upon arrival at the processing plant, the broiler transport vehicle was driven into the live receiving area located adjacent to the shackling equipment where the modules were unloaded. Rectal temperatures of the broilers were recorded within 45 minutes of unloading. Data loggers and sentinel birds were retrieved and bird mortality records were obtained after processing, which occurred within 4.5 h of arrival for the first 3 trips and within 9.25 h for the last trip. Mortality losses for journeys 1, 2 and 4 reflected losses taking place during the transportation and lairage periods because the carcasses were counted at the shackling line. In comparison, bird death occurring during the transportation and lairage periods were separated for journey 3, as dead birds were tallied upon arrival at the processing plant by searching each crate for dead birds, and then again, at shackling.

The MEANS procedure of the SAS was used to calculate mean rectal temperatures before and after transportation. Duncan's Multiple Range Test was applied to identify significantly different means ($P<0.05$).

3.3 RESULTS

Trailer unit, vent configuration and crate number to which the data loggers were mounted for each journey are shown in Table 3.2, along with the module and crate location from where broiler rectal and deep body temperatures were recorded. Ambient temperature, transportation times, ranges in average crate temperature, temperature lifts (internal trailer temperature minus ambient temperature) and mortality percentage for each transportation trip are included in Table 3.3. The average crate temperature and relative humidity for the modules monitored in each journey are presented in Tables 3.4 and 3.5, respectively. Average temperatures from additional logger locations monitored during journeys 1, 2 and 4 are shown in Table 3.6.

TABLE 3.2. Trailer unit, vent configuration, logger placement and module/crate location where broiler rectal and deep body temperatures were taken

Journey	Trailer unit	Open vents	Logger location (crate #)	Rectal temp. bird location (module/crate)	Sentinel bird location (module/crate)
1	1	2,4	5	A5, F5, U5, Z5	A5, U5
2	1	4	2	C2, I1, K2, Q2	I1, Q2
3	1	4	2	D2, H2, I2, Q2	D2, H2
4	8	4	2	A2, D2, I2, Q2	I2, Q2

TABLE 3.3. Ambient temperature, journey length, ranges in average crate temperature, temperature lift (internal trailer temperature minus ambient temperature) and mortality data for four broiler transportation journeys

Journey	Ambient temp. (°C)	Journey length (min)	Range of avg. crate temp. (°C)	Temperature lift (°C)	Mortality (%)
1	-7.1	191	10.9 to 30.7	18.0 to 37.8	0.7
2	-27.1	193	8.9 to 28.1	36.0 to 55.2	1.4
3	-28.2	178	2.5 to 26.1	30.7 to 54.3	0.9
4	-18.4	18	-0.7 to 16.5	17.7 to 34.9	0.9

3.3.1 Journey 1

The average external temperature for journey 1, which lasted 191 min, was –7.1°C. Roof vents 2 and 4, respectively situated above modules B/C and F/G, were open. Loggers were mounted in crate 5 of selected modules, thus the average crate temperatures ranging from 10.9 to 30.7°C reflect conditions within the core of the load (Figure 3.3). Crate temperatures were 18.0 to 37.8°C higher than the ambient temperature.

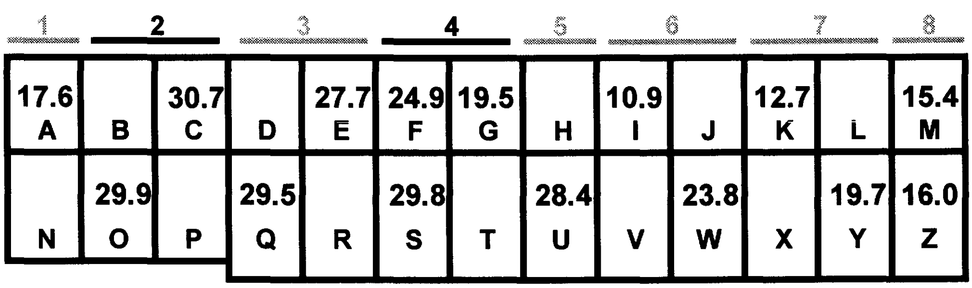

Figure 3.3. Average crate 5 temperatures (°C) for modules monitored in journey 1 with roof vents 2 and 4 open, and a mean ambient temperature of –7.1°C.

Observations made in transit of steam escaping from the trailer roof supported the notion that the roof vents were acting as air outlets. The curtains at the back of the trailer were unattached to the tailboard and were noted to be billowing in and out, likely in response to vehicle motion and crosswinds. Curtain movement and the nature of the frost formation on modules inspected at the plant substantiated the belief that air entered from the rear of the trailer and traveled forward. High temperatures around the step in the trailer frame (modules C, E, O and Q) and a 0.6°C increase in rectal temperatures from birds in F5 (Table 3.7) indicated that the area was poorly ventilated. The average temperature in module A (17.6°C) was lower than other modules in the vicinity and was possibly caused by an ingress of air through the small opening in the top headboard vent. Module I and K had average crate temperatures below 15°C.

Ambient relative humidity (RH) values were not available due to logger malfunction. Functioning data loggers showed that on-board RH ranged from 46.9% in Module E to 68.1% in Module A (Table 3.5). Due to the inconsistent nature of the humidity data for all four journeys, the information was deemed unreliable; however, the potential for hostile environments resulting from high temperature and high humidity combinations was recognized.

Additional data loggers were attached to the exterior crates X4 and X6, such that they were recording conditions closer to the curtains and away from the core of the trailer. The average temperature in crates X4 and X6 was 5.2 and 6.1°C, respectively (Table 3.6). The temperature was not monitored in X5, but average journey temperature in W5 (23.8°C) and Y5 (19.7°C) suggest large variability in on-board trailer temperatures between the core and exterior.

Rectal temperatures were significantly higher after transportation for broilers located in modules A and F (Table 3.7), despite the fact that the average crate temperature was warmer in module U. Rectal temperatures taken from individual broilers in Journey 1 are shown in Appendix A, Table A1. Deep body temperature recordings from sentinel birds (Table 3.8) were representative of domestic fowl at rest, under thermoneutral conditions (Dawson and Whittow, 2000).

3.3.2 Journey 2

Although the journey length was similar to the first trip, the ambient temperature was twenty degrees lower (-27.1°C); therefore, only the fourth roof vent was open. Loggers were positioned in crate 2 of specific modules so conditions in the core of the trailer continued to be monitored, although closer to the top of the module.

The average crate temperatures (8.9 to 28.1°C) were similar to the first journey, but due to the drop in external temperature, the on-board temperatures ranged from 36.0 to 55.2°C greater than the ambient temperature. Figure 3.4 shows a temperature pattern resembling the first trip existed, with the highest temperatures situated at the step in the trailer frame and the lowest temperatures occurring in the top tier of the modules at the back of the trailer (modules I, K and M).

TABLE 3.4. Average temperatures recorded from four broiler transportation journeys conducted in Saskatchewan

Logger	Trip 1[1] Temperatures (°C)				Trip 2[2] Temperatures (°C)				Trip 3[2] Temperatures (°C)				Trip 4[2] Temperatures (°C)			
Location	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Ambient 1	-7.1	0.8	-8.7	-4.0	-27.0	2.1	-31.5	-18.9	-28.3	2.5	-32.6	-18.9	-18.5	2.0	-21.0	-14.6
Ambient 2	-7.1	1.0	-8.7	-1.8	-27.2	2.0	-31.5	-21.7	-28.1	2.4	-32.6	-22.5	-18.3	1.5	-21.0	-16.4
Module A	17.6	2.0	14.0	22.7	24.3	4.2	13.7	29.8	13.8	17.5	-32.8	26.9	4.3	1.5	2.8	8.3
Module B									26.1	4.0	14.2	30.3	13.7	0.9	12.4	14.9
Module C	30.7	3.9	16.2	34.3	24.3	4.8	11.5	30.2	24.9	4.2	12.8	29.8	13.5	2.7	10.1	17.1
Module D									24.0	3.9	12.6	28.5	16.5	1.0	15.3	18.5
Module E	27.7	2.9	15.7	30.2	28.1	5.3	11.7	33.5	21.8	3.8	11.5	26.1	14.0	0.8	12.6	15.4
Module F	24.9	1.4	20.2	27.4					17.7	3.2	10.2	22.0	14.4	0.6	13.8	15.3
Module G	19.5	1.4	14.4	22.6	21.9	3.1	11.4	27.7	12.4	2.9	5.4	16.8	10.7	1.4	8.6	13.5
Module H									6.9	4.0	-3.5	15.6	4.9	2.9	0.7	9.5
Module I	10.9	1.9	6.9	14.9	8.9	2.8	5.0	17.4	3.9	6.5	-12.3	14.2	-0.7	2.8	-4.0	3.9
Module J																
Module K	12.7	2.2	9.5	18.1	14.6	3.2	9.5	20.9	2.5	4.8	-10.2	11.0	7.4	2.3	4.3	11.0
Module L																
Module M	15.4	1.5	10.2	18.4	11.9	2.9	5.0	18.1	2.8	5.0	-7.7	11.3	1.4	1.1	-1.4	3.1
Module N									12.3	4.1	3.0	17.8				
Module O	29.9	4.0	14.5	33.7	20.8	5.9	6.5	28.8								
Module P									22.3	3.6	14.4	26.5				
Module Q	29.5	4.0	14.5	32.2	26.6	4.3	13.1	31.4	25.1	3.5	16.7	29.2	11.6	1.2	9.9	13.8
Module R																
Module S	29.8	4.4	13.8	33.3	26.6	4.9	9.9	32.6	20.6	3.4	11.0	25.2				
Module T																
Module U	28.4	3.1	16.0	31.1	25.2	4.7	9.1	31.8	15.9	3.3	7.7	19.8				
Module V																
Module W	23.8	2.9	12.8	26.6	22.3	3.4	14.2	29.2	11.5	3.3	4.6	18.4				
Module X																
Module Y	19.7	2.1	10.5	23.0	20.2	1.6	16.5	23.0	7.6	3.7	-0.1	15.0				
Module Z	16.0	1.8	11.7	19.1									4.8	1.1	2.7	6.9

[1]Loggers were located in crate 5 for trip 1.
[2]Loggers were located in crate 2 for trips 2-4.

TABLE 3.5. **Average relative humidity values recorded from four broiler transportation journeys conducted in Saskatchewan**

Logger Location	Trip 1[1] Relative humidity (%)				Trip 2[2] Relative humidity (%)				Trip 3[2] Relative humidity (%)				Trip 4[2] Relative humidity (%)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Ambient 1	NA[3]	NA	NA	NA	81.0	6.5	56.8	88.1	NA	NA	NA	NA	NA	NA	NA	NA
Ambient 2	NA	NA	NA	NA	85.5	1.9	78.0	89.6	85.2	1.8	81.3	89.6	88.5	3.1	86.3	96.4
Module A	68.1	6.4	52.8	85.5	93.1	6.9	72.7	99.0	80.1	27.9	14.4	99.0	94.4	7.8	75.2	99.0
Module B									29.1	27.9	0.4	99.3	20.4	0.6	19.4	21.3
Module C	51.5	11.0	38.3	81.7	83.9	9.4	58.4	96.2	NA	NA	NA	NA	NA	NA	NA	NA
Module D									NA	NA	NA	NA	NA	NA	NA	NA
Module E	46.9	11.0	34.4	83.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Module F	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Module G	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Module H									NA	NA	NA	NA	NA	NA	NA	NA
Module I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Module J																
Module K	NA	NA	NA	NA	2.6	5.7	0.1	24.3	NA	NA	NA	NA	NA	NA	NA	NA
Module L																
Module M					NA	NA	NA	NA	19.0	7.1	3.8	34.9	18.7	1.5	15.3	19.9
Module N									NA	NA	NA	NA				
Module O	51.3	20.9	-0.7	99.3	32.2	35.0	-0.3	99.3								
Module P									NA	NA	NA	NA				
Module Q	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Module R																
Module S	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Module T																
Module U	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Module V																
Module W	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Module X																
Module Y	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Module Z	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

[1]Loggers were located in crate 5 for trip 1.
[2]Loggers were located in crate 2 for trips 2-4.
[3]NA = data not available due to logger malfunction.

TABLE 3.6. Average temperatures for additional logger locations from journeys 1, 2 and 4

Journey	Location	Mean (°C)	SD (°C)	Min (°C)	Max (°C)
1	X4 ext[1]	5.2	1.5	2.7	8.3
	X6 ext	6.1	0.8	4.0	8.6
2	I1	10.9	2.6	4.3	16.0
	I1 ext	5.3	1.5	3.3	8.9
	I2 top[2]	2.9	2.2	-1.3	8.0
	I3	11.4	3.2	5.4	18.8
	I3 ext	4.1	2.4	-0.1	10.0
4	A top	2.7	0.7	1.5	3.5
	C top	2.2	1.7	-0.1	5.0
	D top	3.6	1.4	2.0	5.9
	F top	4.0	1.4	1.7	6.4
	H top	-8.3	3.3	-12.0	-1.8

[1]Loggers attached to exterior crates to monitor conditions close to curtains and away from the trailer core.
[2]Loggers attached to the top of the module.

Table 3.7. Average rectal temperatures from broilers measured immediately before (T_1) and after (T_2) transportation

Journey	Bird location (module/crate)	Average T_1 (°C)	Average T_2 (°C)	SE
1	A5	40.4^a	40.6^b	0.0536
	F5	40.4^a	41.0^b	0.1074
	U5	40.6	40.8	0.0748
	Z5	40.5	40.7	0.1123
2	C2	40.6	40.6	0.0826
	I1	40.4	40.2	0.1048
	K2	41.1	40.7	0.0861
	Q2	40.6	40.9	0.0912
3	D2	40.0^a	40.3^b	0.0658
	H2	39.8	38.7	0.4325
	I2	40.1^a	39.1^b	0.1714
	Q2	40.2	40.5	0.0758
4	A2	40.4	40.1	0.1010
	D2	40.1	39.9	0.0774
	I2	40.1^a	39.2^b	0.2002
	Q2	40.3^a	39.4^b	0.1604

^{a,b} Means within rows with no common superscript differ significantly ($P<0.05$).

TABLE 3.8. Deep body temperatures of sentinel birds from all four transportation journeys

Journey	Location	Bird ID	Mean (°C)	SD (°C)	Min (°C)	Max (°C)
1	A5	988	41.8	0.6	40.6	42.4
		992	41.2	0.2	41.1	41.5
		994	41.5	0.3	41.1	41.9
	U5	996	41.6	0.2	41.1	41.9
		998	41.5	0.1	41.1	41.5
		999	41.5	0.4	40.6	41.9
2	I1	989	41.1	0.5	39.8	41.5
		991	41.1	0.2	40.6	41.5
		997	40.3	1.0	37.3	41.1
	Q2	993	42.3	0.3	41.5	42.8
		995	40.6	0.7	38.9	41.5
3	D2	992	40.6	0.2	40.2	41.1
		994	41.2	0.2	41.1	41.5
	H2	988	40.7	0.3	40.2	41.1
		998	41.0	0.2	40.6	41.5
		999	41.3	0.3	40.6	41.5
4	I2	993	41.3	0.2	41.1	41.5
		996	41.1	0.3	40.6	41.5
	Q2	991	40.2	0.0	40.2	40.2
		995	38.9	0.3	38.5	39.4
		997	40.0	0.2	39.8	40.2

Supplementary loggers were placed in the center and at the front of crates I1 and I3, between these exterior crates and the trailer curtains (I1 ext and I3 ext), and on top of module I above crate 2 (I2 top). Average temperatures recorded from the front of the crates were similar (10.9 and 11.4°C); however, the temperatures recorded near the curtains and at the top of the module were lower (Table 3.6). This trend suggests that a temperature gradient is created across the trailer during transportation and that cold air may travel from the back of the trailer along the top of the modules and exit through the open roof vent.

Insignificant changes in rectal temperatures were noted (Table 3.7). A greater proportion of broilers located in I1 and K2 experienced reductions in rectal temperature compared to those in modules C and Q (Appendix A, Table A2), where average crate temperatures were higher. Changes in core body temperature were slight (Table 3.8) but more variable than those from the first journey.

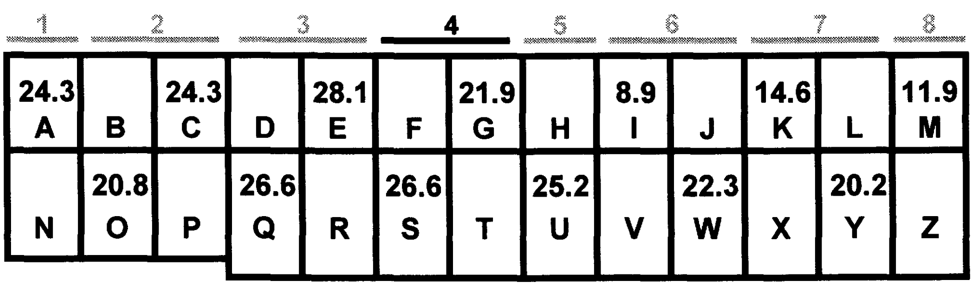

Figure 3.4. Average crate 2 temperatures (°C) for modules monitored in journey 2 with the fourth roof vent open and a mean ambient temperature of –27.1°C.

3.3.3 Journey 3

Journey 3 was conducted in an average external temperature of –28.2°C and once again, only the fourth roof vent was opened. The journey was 178 min in length and included a 15-minute stop. This delay may have skewed the average crate temperatures, which ranged from 2.5 to 26.1°C, because no additional vents were opened during the period of time that the trailer remained stationary. Air flow through the trailer would have been minimized; therefore heat and moisture accumulating during this period would have increased the temperature and humidity of the on-board environment.

Logger placement was concentrated in the top tier of modules at the front of the trailer, where it appeared from preceding trips that a thermal core developed. Again, high temperatures were noted around the step in the trailer frame (Figure 3.5). Several modules had crate temperatures below 15°C including modules A, G-I, K and M from the top tier, as well as modules N, W and Y from the bottom tier that had previously been warmer. This temperature trend implied that cold air entered from the rear of the trailer.

Birds situated in crates H2 and I2, which recorded low average temperatures of 6.9 and 3.9°C, respectively, all had reduced rectal temperatures after transportation (Appendix A, Table A3). The average decline in temperature for these birds was 1.0°C; however, the difference between rectal temperatures before and after transportation was only significant for birds in module I (Table 3.7). Birds in crates D2 and Q2 showed smaller increases in rectal temperature, yet the difference was significant for D2 birds (Table 3.7). Deep body temperatures from sentinel birds in crates D2 and H2 remained relatively stable during transportation (Table 3.8).

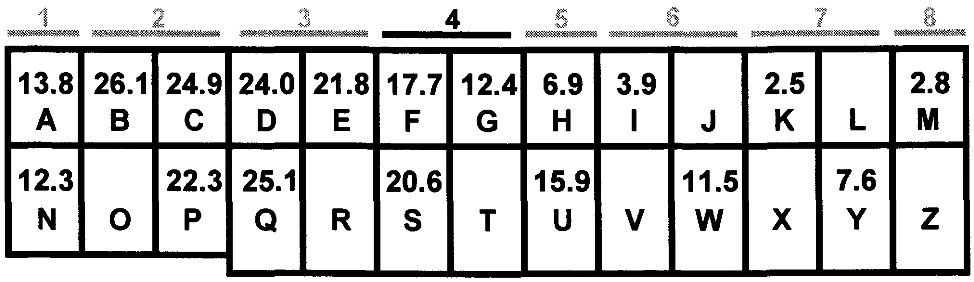

Figure 3.5. Average crate 2 temperatures (°C) for modules monitored in journey 3 with the fourth roof vent open and a mean ambient temperature of –28.2°C.

3.3.4 Journey 4

The last broiler journey was performed using a different trailer unit and decreased stocking density, and was only 18 min in length. The average ambient temperature was -18.4°C and only the fourth roof vent was open. Average crate temperatures were comparatively lower than the previous trips, ranging from –0.7 to 16.5°C, which implied that the short journey length did not allow sufficient time for a thermal core to develop (Figure 3.6).

Additional loggers were fastened to the top of modules A, C, D, F and H. Mean temperatures from the front four loggers ranged from 2.2 to 4.0°C and the temperature from the logger attached to the top of module H was –8.3°C (Table 3.6). These temperatures are comparatively lower than the temperatures recorded from crates located just beneath the module covers. Clearly, the thin sheet metal covering the modules is a benefit during cold weather transportation; however, it may be detrimental under warmer transport conditions.

Though core body temperature remained stable during transportation (Table 3.8), rectal temperatures taken from broilers in all locations were reduced when compared to pre-journey values (Table 3.7; Appendix A, Table A4). Although this reduction in rectal temperatures was only significant in I2 and Q2, the data implies that due to the short transportation distance and reduced time in transit, the trailer had not developed a thermal load comparable to the previous journeys. Because conditions on the trailer were colder, the birds exhibited lower rectal temperatures from all four locations. This data also suggests that concentrating on the beginning and end points of the journey, and the journey means, underestimates low temperature stress conditions.

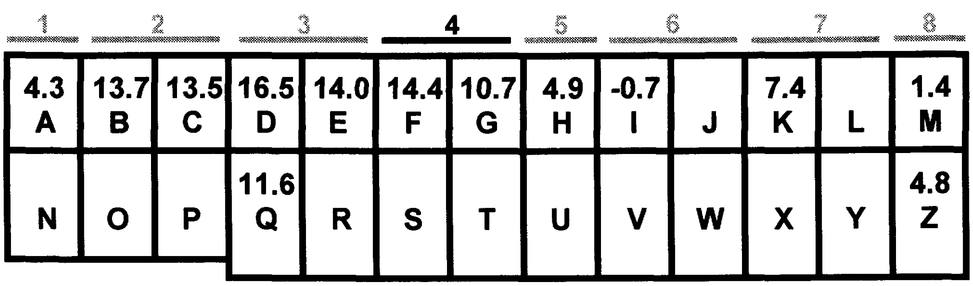

Figure 3.6. Average crate 2 temperatures (°C) for modules monitored in journey 4 with the fourth roof vent open and a mean ambient temperature of −18.4°C.

3.3.5 Broiler Mortality

Bird mortality was 0.7% and 1.4% for the first 2 journeys and 0.9% for each of the third and fourth journeys (Table 3.3). The plant average for birds found dead at shackling in January 2000 was 0.76%, so the last three transportation trips had higher than average death losses.

Mortality was distributed throughout the trailer. The number of dead birds found in each module ranged from 0-7, 0-11 and 0-4 birds for the first three journeys, respectively. Due to complications at the plant, mortality distribution was not available and post-mortems were not performed for the last trip. It was suggested by plant personnel that during winter transportation, elevated levels of bird mortality occurred in the bottom three modules at the back of the trailer (modules X, Y and Z). Twenty-six percent of dead birds were found in this location after the second transportation journey; however, only 10% of bird mortality was in modules X, Y and Z after the first journey and no mortality was recorded in this area upon completion of the third trip. If mortality for each journey were evenly distributed in all 26 modules, the expected death loss in modules X, Y and Z combined would be 11.5%.

Ascites, a condition common to fast growing broilers and influenced significantly by farm management (Zuidhof et al., 1997), was identified in 64% and 57% of dead birds for the first and second trips, respectively. Birds with no visible lesions accounted for 14% and 10% of mortality for the same respective journeys.

Before completing the third transportation trial, the need to distinguish between birds dying in transit and birds dying while awaiting slaughter became evident. Bird mortality from the transportation period of the third trip was 0.4%, whereas the total number of birds dying between departure of the production site and slaughter was 0.9%. Clearly, lairage impacts the level of mortality reported and suggests that birds arriving dead (DOA) should be recorded separately from birds that are dead on shackling (DOS). Mortality losses for the first, second and last journey did not make this distinction.

Of the 0.4% of birds arriving dead after the third journey, ascites was recognized in 79% of the population and 3% of DOA birds had no visible lesions. Although necropsy results were not available for the fourth trip, observations of wet birds at the farm indicated that barn conditions could influence bird mortality, even when the journey length is relatively short. Birds with wet feathers have reduced insulative capacity and will experience a lower effective environmental temperature, which would be exacerbated when exposed to cold temperatures and air movement.

3.4 DISCUSSION

Although the journeys monitored were conducted in cold ambient conditions, temperature trends throughout the trailer were similar to those previously recorded on broiler carriers transporting birds in warmer ambient temperatures (Kettlewell et al., 1993). Because the air inlets and outlets were not clearly defined, the airflow distribution pattern in the broiler transportation vehicles was complex. The small opening on the top headboard vent and the spaces between the curtains and tailboard of the trailer where the tarp remained unfastened are both examples of unintentional air inlets created by the pressure distribution on the trailer. Thermal heterogeneity developed as the air moved from the back to the front of the trailer, creating cold spots in areas of air entry and thermal loads at the front, centre region of the trailers.

Not only were temperature gradients established along the trailer, but gradients also developed across the trailer. Observations of wet birds and frost accumulation on the crates and modules positioned closest to the tarpaulins, as well as the reduced crate temperatures recorded from locations near the curtains suggested that birds outside the trailer core were likely subject to a colder microenvironment. Previous data recorded from broiler carriers has been from the centre of the trailers (Kettlewell et al., 1993) but observations from this study indicated that during cold weather transportation conditions outside the trailer core may be drastically different, and therefore, worth monitoring.

There were increases and decreases in average rectal temperatures taken from broilers before and after transportation. Journey 1 was conducted when the ambient temperature was -7.1°C and the average rectal temperatures taken from all 4 crate locations increased. Mitchell et al. (1997) reported that birds could maintain body temperature in external temperatures as low as -4°C, and data from Journey 1 supports that finding. Comparatively, during the colder weather in Journeys 2 and 3 (-27.1 and -28.2, respectively), crate temperatures diminished along with the average rectal temperatures from birds located in the back half of the trailer. In the fourth journey, average rectal temperatures in all locations were depressed, including those taken from the thermal core. Kettlewell et al. (2000) found that excessive airflow around the birds resulted in reduced rectal temperatures after transportation. Birds in journeys 2, 3 and 4, especially those located near air inlets, would have been exposed to cold air entering the trailer that would lower the effective environmental temperature thereby causing a reduction in rectal temperature. Rectal temperatures subsequent to transportation were measured within 45 minutes of unloading the modules; therefore, the changes in rectal temperature may have been influenced by limitations associated with time delays during the sampling procedure.

In comparison to the national and provincial averages, mortality values for all four journeys were high. In 1999, the Canadian Food Inspection Agency disclosed that the Saskatchewan and Canadian average mortality losses for all poultry classifications were 0.50 and 0.56%, respectively. The mortality ranged from 0.7 to 1.4% in this study. However, there was a considerable difference between bird death associated with transportation and bird mortality occurring during the lairage period for the third trip. The distinction between these bird losses must be drawn to clarify the influence of transportation and lairage on broiler production losses.

In summary, cold weather transportation resulted in compromising transport conditions for the broilers. Use of the trailer curtains reduced airflow around the step in the trailer frame and produced a thermal core capable of causing heat stress for birds in that location. Unplanned sites of air entry and the potential for cold stress near these air inlets were also noted. Consequently, a comprehensive investigation of the temperature gradients that develop across the trailer during transportation is required. Furthermore, mortality occurring during transportation and the lairage period should be separated to determine the impact that each of these periods has on bird losses.

4.0 INVESTIGATION OF HORIZONTAL AND VERTICAL TEMPERATURE AND HUMIDITY GRADIENTS ON TRAILERS TRANSPORTING MARKET-AGE BROILERS IN SASKATCHEWAN: PART I, INDIVIDUAL JOURNEY DATA, THE EFFECTS OF CURTAIN CONFIGURATION, AND APPARENT EQUIVALENT TEMPERATURE

4.1 INTRODUCTION

It has been established that transporting broilers in passively ventilated trailers can lead to hostile conditions in the microenvironment, whether birds are transported in the summer heat or in the cold of winter (Kettlewell et al., 1993; Mitchell et al., 1997). The greatest risk of hyperthermia actually occurs during cold weather transportation when ambient temperature is low and ventilation is restricted by the closed curtain configuration. In contrast, with open curtain arrangements during summer transportation in the United Kingdom, passive ventilation adequately prevented thermal gradients from establishing in broiler carriers as long as the vehicle remained in motion.

Temperature and relative humidity contribute to the complex thermal environment within the trailer unit. Mitchell and Kettlewell (1998) characterized the temperature and relative humidity conditions from broiler transportation journeys conducted in the United Kingdom and simulated those conditions to investigate the physiological stress responses in broilers. The concept of Apparent Equivalent Temperature (AET) was introduced and is considered to be an integrated index of the conditions broilers are exposed to during transportation (Mitchell and Kettlewell, 1993; Dallet et al., 1996). AET combines dry-bulb temperature and relative humidity to give an indication of the effective temperature, much like a wind-chill index. The temperature-humidity conditions capable of inducing severe and moderate stress responses, as well as the conditions which would present no risk to the birds are represented by AET values located in the danger, alert and safe zones, respectively (Mitchell and Kettlewell, 1993; Kettlewell and Mitchell, 2001). Unfortunately, the AET zones do not incorporate the cold temperature-humidity combinations encountered during winter transportation in Saskatchewan and it is unlikely that high humidity in conjunction with cold ambient temperatures would provide a comfortable environment for transported birds.

A study conducted by Mitchell et al. (1997) reported that if birds are wet during transportation, ambient temperatures as high as 6°C could trigger moderate hypothermia; therefore, temperatures below 6°C could be classified as potentially dangerous, particularly if the humidity was high or the birds were wet. However, temperatures between 6°C and 15°C could be considered safe, regardless of humidity.

Data from preliminary studies of Saskatchewan broiler transportation demonstrated that passive ventilation on tightly tarped transport trailers, while allowing some birds to maintain body temperature, produced a heterogeneous distribution of airflow and consequently, less than optimum temperate and humidity conditions (Chapter 3). Paradoxical heat stress was encountered and air entered the trailer from unintentional openings, creating the potential for cold stress to occur for birds positioned in areas of air entry. In addition, wet birds and the accretion of frost on the modules and crates suggested that birds located outside the core of the trailer were subject to more adverse conditions during cold weather transportation.

Based on those results, subsequent data collection was required to comprehensively quantify the temperature and relative humidity conditions on broiler carriers under a range of environmental conditions, as opposed to cold weather conditions exclusively. It was hypothesized that ambient temperature would be positively correlated with average crate temperature. In addition, due to the closed curtain arrangement, there would be less than optimum temperature-humidity combinations during cold weather transportation. Consequently, it was also hypothesized that there would be a greater proportion of birds subjected to a potentially dangerous AET in a closed curtain configuration.

4.2 MATERIALS AND METHODS

Between November 2000 and October 2001, twenty-seven broiler journeys were monitored to comprehensively quantify the temperature and humidity conditions established within the 16 m transportation vehicles used by the Saskatchewan broiler industry.

4.2.1 Vehicular Configuration

The dimensions for the passively ventilated broiler trailers are included in Table 4.1, and Figure 4.1 shows a lateral view of the carrier. Trailer curtains, headboard and tailboard vents, and roof vents were adjusted by the truck drivers according to the external temperature and the driver's previous experience.

TABLE 4.1. Dimensions of the 16 m commercial broiler transportation trailers, modules and crates used in Saskatchewan

Component	Section	Length (m)	Width (m)	Height (m)
Trailer	In entirety	16.01	2.50	-
	Anterior step in frame	3.74	2.50	2.80
	Posterior step in frame	12.27	2.50	3.10
Module	12 crates	2.44	1.17	1.15
	15 crates	2.44	1.17	1.40
Crate	-	1.11	0.71	0.20

4.2.2 Modules and Crates

The modules are a component of the Anglia Autoflow modular system (Wortham Ling, Norfolk, England, IP22 1SR) and contain either 12 or 15 crates per module. Module and crate dimensions are included in Table 4.1. Stocking density was 22, 24 or 26 birds per crate (7524, 8208 or 8892 birds per trailer, respectively) and varied according to the number of birds to be transported from each farm site.

4.2.3 Temperature and Humidity Recordings

Continual recording of temperature and relative humidity was achieved using FlashLink data loggers (DeltaTRAK, Inc., Pleasanton, CA, 94566, USA) that were calibrated by the manufacturer and programmed to record data at one-minute intervals. The range for the internal temperature sensor was -40°C to 66°C with the accuracy being ±1°C, while the operating humidity range was 10% to 100% RH with the accuracy being ±5% when the recordings were between 20% and 90% RH.

The data loggers were attached to a wire frame and clipped onto the crates as modules were being loaded onto the trailer. In a modular stack, loggers were placed in each of the top, middle and bottom rows of crates. In each of these rows, loggers were attached to the centre of the middle crate and the extreme edges of the outside crates (Figure 4.2). The position of the loggers ensured that the conditions being monitored were at bird level. In addition, two loggers recorded ambient conditions of each journey, with one logger fastened to each of the side view mirrors on the truck cab. Loggers were activated prior to arrival at the broiler production site. Times of departure from the farm, adjustment of ventilation configuration and arrival at the processing plant were noted so that journey duration and average temperature and humidity conditions for each vent configuration could be calculated.

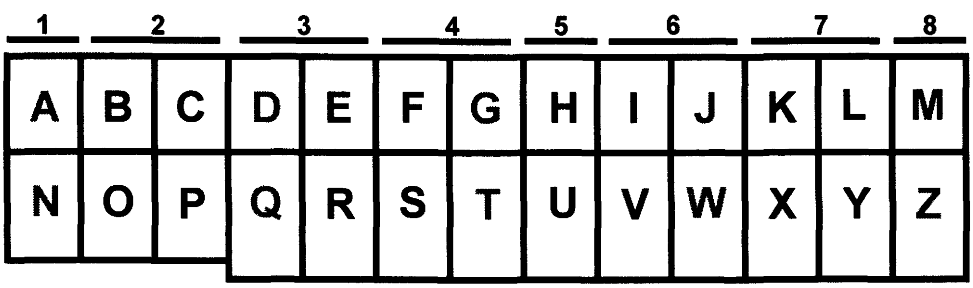

Figure 4.1. This drawing represents the lateral view of a 16 m broiler transport trailer used in Saskatchewan. Modules were labeled alphabetically from the front of the trailer and the numbered solid lines above the trailer indicate vent location on the roof. Loggers were placed in evenly distributed stacks of modules, as indicated by the red letters: A/N, D/Q, G/T, J/W and M/Z.

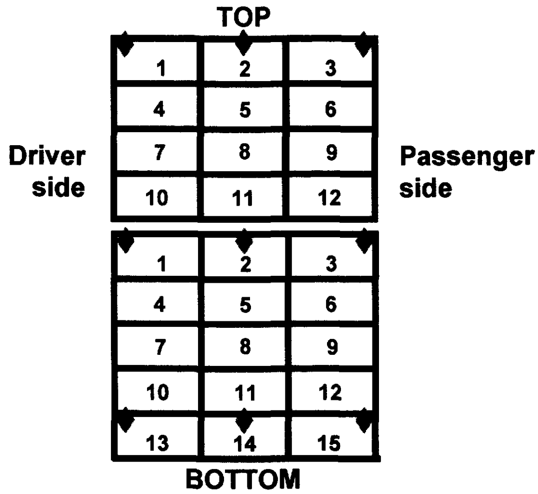

Figure 4.2. Crates within each module were numbered. When viewing the stack of modules from the back of the trailer, crate 1 was positioned on the driver side of the vehicle. The diamonds represent logger placement. Within a stack of modules, loggers were placed in three rows of crates: the top row of both the top module (nearest the roof) and bottom module (centre of stack), as well as in the bottom row of the bottom module (nearest the floor).

Upon arrival at the processing plant, the broiler transport vehicle was driven into the live receiving area located adjacent to the shackling equipment where the modules were unloaded. Data loggers were retrieved and the recorded data was downloaded.

Data from the broiler transportation journeys were sorted according to ambient temperature, with each temperature classification having different vent and curtain configurations. Temperature group 1 (T1) consisted of trips performed in temperatures below -16°C. Temperature groups two (T2), three (T3), four(T4) and five (T5) were conducted in the temperature ranges -15.9°C to -6.0°C, -5.9°C to 5.9°C, 6.0°C to 15.9°C, and above 16°C, respectively. Through all journeys conducted in T1, T2 and T3, both curtains on the trailer were lowered and fastened to the floor of the trailer. The headboard and tailboard vents remained closed; therefore, the eight vents along the roof of the trailer were the only vents manipulated in these temperature categories. In T4, all eight roof vents were open and the headboard and tailboard vents were closed; however, tarping strategy was adjusted to provide additional ventilation. Generally, both curtains were raised and all roof vents were open during transportation in warm weather (T5). The headboard and tailboard vents were occasionally opened to maximize airflow through the trailer and due to rainfall, one of the tarps was lowered for an individual journey.

4.2.4 AET Classification

For each journey, the mean relative humidity and temperature data for each crate were considered and the corresponding AET zone was calculated (Mitchell and Kettlewell, 1993; see Figure 2.2). The percentage of crates from individual journeys that fell within each AET zone was tabulated and pooled according to ambient temperature classification. Crate temperatures below 6°C were classified as potentially dangerous (PD), whereas temperatures between 6°C and 15°C were considered to fall within the safe zone (S), regardless of humidity. The remainder of the temperature-humidity combinations from the crates fell within the alert (A) or danger (D) zones.

During cold weather transportation (T1 and T2), data loggers positioned near air inlets did not provide accurate results, as the humidity sensors did not function in the cold temperatures. Because the tarps were lowered, moisture accumulated within the load and saturated the data loggers situated in areas other than the inlets. AET zone classification for journeys completed in T1 and T2 was based on recorded mean crate temperature and the assumption that RH ranged from 80% to 95%.

4.2.5 Statistics

The MEANS procedure of SAS was used to calculate mean crate temperature and mean temperature lift, and the corresponding standard deviation and range of values. The REG procedure of SAS was the regression analysis used to determine if mean crate temperature could be predicted by ambient temperature when the trailer curtains were in an open or closed configuration.

4.3 RESULTS

Table 4.2 summarizes the 27 broiler journeys monitored. Journey length, ambient temperature, average crate temperature and range of temperatures in monitored crates, and the corresponding mean temperature lift values are listed beginning with the broiler journey conducted in the coldest ambient temperature. The temperature values are averages for the entire trip and do not incorporate any changes in vent configuration that may have occurred during the journeys. The outdoor temperature ranged from –27.2°C to 21.9°C and the average journey length was 175 min, with the trips ranging from 140 to 240 min (Table 4.2). Mean temperature lift was calculated as the difference between average ambient temperature and average crate temperature. In the coldest journey monitored, mean temperature lift was 35.3°C with a range of 17.4 to 53.4°C. The average temperature lift from the journey with the warmest outdoor temperature was 2.3°C with a range of 0.5 to 4.9°C (Table 4.2). These data demonstrate that at higher ambient temperatures, with both tarps raised, there was less thermal variation throughout the trailer as compared to studies conducted under colder conditions with both tarps lowered.

Table 4.2. Journey summary listed according to mean ambient temperature

		Crate temperature		Temperature lift[1]			Crate RH	
Journey length	Ambient temp.	Mean	Range	Mean	Range	Ambient RH	Mean	Range
(min)	(˚C)	(˚C)	(˚C)	(˚C)	(˚C)	(%)	(%)	(%)
190	-27.2	8.1	-9.8 to 26.2	35.3	17.4 to 53.4	NA[2]	NA	NA
155	-20.7	0.9	-10.3 to 25.4	24.5	10.4 to 46.1	NA	NA	NA
190	-20.6	3.8	-13.7 to 20.9	21.5	6.9 to 41.5	NA	NA	NA
190	-12.9	4.1	-6.8 to 20.6	17.0	6.1 to 33.5	NA	NA	NA
150	-12.7	5.4	-4.3 to 18.3	18.1	8.4 to 31.0	NA	NA	NA
170	-10.5	6.7	-4.3 to 19.4	17.2	6.2 to 29.9	NA	NA	NA
185	-9.7	6.2	-4.3 to 21.1	15.9	5.4 to 30.8	NA	NA	NA
240	-9.1	9.3	-1.7 to 25.6	18.4	7.4 to 34.7	NA	NA	NA
155	-6.6	6.1	-1.8 to 18.4	12.7	4.8 to 25.0	NA	NA	NA
165	-5.8	9.4	0.5 to 22.6	15.2	6.3 to 28.4	NA	78	48 to 96
145	-5.0	8.6	0.2 to 22.1	13.6	5.2 to 27.1	NA	72	34 to 90
170	-0.9	11.4	2.7 to 24.8	12.3	3.6 to 25.7	88	65	27 to 90
180	-0.1	11.5	4.2 to 22.1	11.6	4.3 to 22.2	NA	72	45 to 93
200	2.8	14.3	7.6 to 24.9	11.5	4.8 to 22.1	62	44	12 to 64
165	2.8	14.0	6.5 to 24.3	11.2	3.7 to 21.5	64	47	13 to 74
175	2.9	13.9	6.4 to 23.9	11.0	3.5 to 21.0	73	54	20 to 76
155	7.2	12.6	8.6 to 18.8	4.3	1.4 to 11.6	61	50	18 to 68
205	7.9	15.9	11.1 to 23.3	8.0	3.2 to 15.4	89	64	35 to 90
165	11.8	17.1	12.8 to 21.6	5.3	1.0 to 9.8	30	30	10 to 79
205	12.4	17.3	14.0 to 22.4	4.9	1.6 to 10.0	58	50	20 to 70
190	12.8	16.6	14.1 to 21.0	3.8	1.3 to 8.2	38	52	14 to 74
195	13.5	17.6	15.0 to 21.2	4.1	1.5 to 7.7	74	60	27 to 81
160	14.8	18.1	15.7 to 21.5	3.3	0.9 to 6.7	79	75	53 to 92
160	14.9	17.9	15.7 to 21.4	3.0	0.8 to 6.5	53	64	23 to 84
180	17.5	21.8	18.6 to 24.7	4.3	1.1 to 7.2	46	36	14 to 51
140	17.7	20.5	18.4 to 23.6	2.8	0.7 to 5.9	71	64	28 to 83
175	21.9	24.2	22.4 to 26.8	2.3	0.5 to 4.9	24	33	11 to 45

[1]Temperature lift = crate temperature – ambient temperature.
[2]NA = data not available.

As expected, ambient temperature affected the average crate temperatures on the broiler trailers (Figure 4.3). The linear relationship between ambient temperature and mean temperature of the crates was stronger when the tarps were raised ($R^2 = 0.90$; $y = 0.69x + 8.54$) in comparison to when they were lowered ($R^2 = 0.62$; $y = 0.35x + 11.29$). This is a reflection of the variable vent configuration and the impact of imperfect sealing of the tarps at lower temperatures, in contrast to the more uniform and unrestrictive ventilation configurations at higher temperatures.

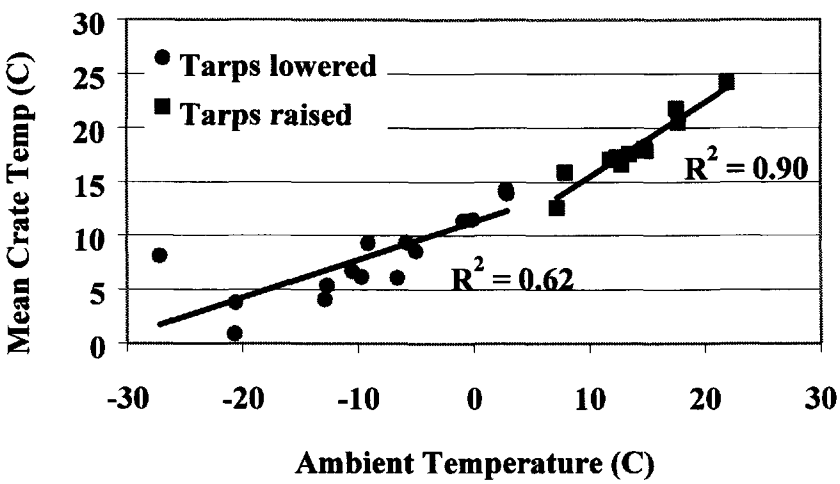

Figure 4.3 Linear relationship between ambient temperature (°C) and mean crate temperature (°C) over the entire trailer for trips conducted with both tarps raised or both tarps lowered.

4.3.1 AET Classification

The percentage of crates from individual journeys that fell within each AET zone was calculated and pooled according to ambient temperature classification (Table 4.3). Ambient temperatures below -16°C showed the highest proportion of crates with potentially dangerous (PD) temperature-humidity combinations (61.0%), followed by those in the temperature ranges -15.9°C to -6.0°C and -5.9°C to 5.9°C. This was expected in cold conditions, as unintentional air inlets on trailer units with both tarps lowered allowed cold air to penetrate along the floor and back end of the trailer. Occasional frost accumulation on birds located in these areas was observed upon arrival at the processing plant. Due to thermal core development, cold weather transportation resulted in 13.0% and 10.0% of crates classified in the alert zone when ambient temperatures were below -16°C, and between -15.9°C and -6.0°C, respectively. Under the same ambient temperature classifications, 23.7% and 39.0% of crates recorded conditions in the safe zone.

Table 4.3. The effect of ambient temperature on apparent equivalent temperature (AET) zone classification

	AET zone classification (%)			
Ambient temperature	PD[1]	S[2]	A[3]	D[4]
< -16.0 °C	61.0	23.7	13.0	1.3
-15.9 °C to -6.0 °C	51.8	39.0	10.0	0.3
-5.9 °C to 5.9 °C	15.4	78.4	5.9	-
6.0 °C to 15.9 °C	-	85.0	15.0	-
> 16.0 °C	-	56.3	43.7	-

[1]PD = potentially dangerous zone, crate temperatures below 6°C.
[2]S = safe zone, no risk to birds.
[3]A = alert zone, moderate stress responses.
[4]D = dangerous zone, severe stress responses.

As the temperature approached 0°C, 78.4% of the crates fell within the safe zone. The moderate temperature range of 6.0°C to 15.9°C had 85.0% of the crates in the safe zone and the remaining fraction in the alert zone. As the ambient temperature extended beyond this range, a higher percentage of crates fell into the alert classification (Table 4.3). The greatest potential for the development of conditions that can induce severe stress responses in birds due to high temperature and high humidity combinations lies within the two coldest temperature groups. The percentage of crates in the danger zone was 0.3% and 1.3% for ambient temperatures within -15.9°C to -6.0°C and less than -16°C, respectively.

4.4 DISCUSSION

With the use of an artificial chicken, Webster et al. (1993) determined that when ambient temperature was between 7 and 18°C, feathered broilers subject to minimal air movement could be transported in thermal comfort. During the 28 commercial broiler journeys used to collect these data, ambient temperature ranged from 3.0 to 24.0°C. Mitchell et al. (1997) suggested that if birds were dry, they could be transported when the outdoor temperature is as low as -4°C. However, if feather wetting occurred and significantly altered the thermoregulatory capabilities of the birds, ambient temperatures as high as 6°C could induce hypothermia in the transported broilers. In fact, when birds were sprayed with a fine mist and exposed to a temperature of -4°C in a climate chamber for 3 hours, there was a 14.2°C reduction in body temperature (Mitchell et al., 1997). Wetted birds transported in cool ambient temperatures can exhibit extreme hypothermia. Unfortunately, there are minimal data regarding transportation when ambient temperatures are much below -4°C. In this investigation, ambient temperatures ranged from -27.2°C to 21.9°C. It is apparent that there are considerable challenges faced when transporting broilers in Saskatchewan or in areas with a similar climate.

Ambient temperatures below -16°C showed the highest proportion of crates with potentially dangerous (PD) temperature-humidity combinations (61.0%), followed by the temperature ranges -15.9°C to -6.0°C and -5.9°C to 5.9°C. It was expected that ambient temperatures below -16°C would have the greatest proportion of crates in the potentially dangerous AET zone classification because unintentional air inlets on trailer units with both tarps lowered allowed cold air to penetrate along the floor and back end of the trailer. However, it is unlikely that 60% of all birds on the trailer were exposed to a potentially dangerous thermal environment. Because data loggers were clipped to the outside edges of the exterior crates within a row of crates being monitored, the data gathered by these loggers does not represent the conditions experienced by all 22 to 26 chickens in the monitored crates. In fact, the recorded data may pertain to only two or three birds in closest vicinity to the loggers.

In contrast, lowered curtains during cold weather transportation restricted airflow distribution, providing the opportunity for high crate temperatures to develop in the core of the trailer in conjunction with high humidity levels. The greatest potential for the development of conditions that can induce severe stress responses in birds due to high temperature and high humidity combinations fell within the two coldest temperature groups. Observations of wet birds, particularly in the middle of the modules and core of the trailer, suggested that the moisture produced from bird respiration and the low ventilation rate were primary factors responsible for the high humidity conditions in the core of the trailer. Efforts to prevent chilling by controlling air movement and water infiltration must be taken, yet at the same time adequate ventilation must be provided to prevent excess temperatures from developing on the trailer.

Several recommendations can be suggested to improve the trailer conditions for the broilers during cold weather transportation. Because curtain use influences air flow through the trailer (Kettlewell et al., 1993), truck drivers should be aware of the curtain and bungee cord condition. If the bungee cord used to secure the tarp has lost its elasticity, it should be replaced, and other methods of securing the tarp should be investigated. However, air must enter the passively ventilated trailers somewhere. If the curtains are secured too tightly, they will restrict airflow and create an unfavourable environment for the birds, particularly during transportation in extremely cold weather. Perforated curtains that can be firmly fastened to the trailer and still allow air entry may be an alternative.

Although bird respiration is the most significant contributor to humidity on the trailers, modules and crates should be dry before transporting birds under winter conditions. Once unloaded, trailer units are washed in the live receiving area of the plant and immediately taken out of the facility. In cold temperatures, the modules and crates do not dry, and therefore, water freezes to the equipment. Birds loaded into these containers produce enough heat to melt the ice and this moisture may contribute to the compromising conditions encountered in cold weather transport (Mitchell et al., 1997). No measurements were taken to estimate the amount of water frozen to the modular transportation equipment during journeys conducted in cold ambient temperatures, and compared to bird respiration, the volume may be diminutive. However, by drying the trailer equipment, an element contributing to on-board humidity can be eliminated.

During warm weather transportation, passively ventilated transport trailers provided acceptable on-board thermal conditions, provided that the vehicle remained in motion. Based on AET zone classification, transportation when ambient temperatures were above 6°C was least stressful for the birds. However, caution should be taken as ambient temperatures exceed 16°C due to the increased proportion of crates in the alert zone. Opening the front and rear trailer vents resulted in slightly cooler and more homogeneous temperatures, which would be advantageous during hot weather. High ambient temperatures during transportation may be hazardous when the broiler carriers are stationary, as the heat and moisture produced by the birds is not effectively dissipated, thereby creating the potential for dangerously high air temperature and humidity combinations to develop within the crates. Truck stoppage during the transit period should be kept short to avoid the possibility of hazardous thermal developments. Webster et al. (1993) suggested that on an enclosed transport vehicle, either stationary or in motion, the ambient temperature would have to be between 7°C and 8°C for a feathered bird to remain thermally comfortable during transportation. Under other situations, the broilers would experience a degree of hyperthermia or hypothermia at some point during their journey. Therefore, real-time temperature sensors placed within the load may be useful for monitoring conditions during periods when the vehicle is stationary.

Following warm weather transportation, observations of panting birds were made upon arrival at the processing plant after the trailer had been immobile for several minutes. Bird condition was very dry at the processing plant, so the likelihood of high temperature and high humidity conditions developing concurrently would require additional time. Lairage facilities capable of providing adequate air circulation while birds await processing would be of benefit.

In conclusion, the poultry industry relies on transporting birds from the production site to a processing facility and faces a considerable challenge when transporting broilers to market. As indicated by the AET values tabulated in this study, Saskatchewan birds sent to market are subject to thermal stress in transit, whether it be heat stress or cold stress. In conjunction with the temperature, humidity in the trailer compromises the on-board environment by lowering the effective temperature during cold weather journeys and increasing the effective temperature when transporting broilers in warm weather. Data gathered by loggers on the outside edge of the load was useful and meaningful, but suggested additional broiler transportation research should concentrate on a more accurate reflection of the temperature-humidity status of the micro-environment around birds situated throughout the trailer.

5.0 INVESTIGATION OF HORIZONTAL AND VERTICAL TEMPERATURE AND HUMIDITY GRADIENTS ON TRAILERS TRANSPORTING MARKET-AGE BROILERS IN SASKATCHEWAN: PART II, THE EFFECT OF VENT CONFIGURATION

5.1 INTRODUCTION

This is the second paper describing an investigation of the temperature and relative humidity conditions within transportation trailers carrying market-age broilers in Saskatchewan. Part I (Chapter 4) contained the individual journey data, the effects of curtain configuration and the AET birds were exposed to when transported.

Understanding the pressure distribution on the outside surface of the trailer and the effect of the dense packing inside the trailer are useful in interpreting the temperature and humidity data collected from these units. It also provides a better appreciation of the air flow patterns within the transport trailer. The pressure distribution over the surface of the trailer is characteristic of blunt, sharp-edged bodies (Götz, 1987). The headboard of the trailer has a positive pressure that is highest near the top leading edge of the trailer and decreases down the headboard. Therefore, an opening in the headboard will act as an air inlet. Flow separation occurs at the leading edge on the top of the trailer and at the leading edges of the sides of the trailer, and causes large negative pressures on the top and sides of the trailer near the front (Hoxey et al., 1996), which declines towards the back of the trailer. Because the largest negative pressure occurs on the top of the trailer near the front, open vents in this area will act as exhaust outlets for the trailer and openings at the rear of the trailer will act as air inlets. This pressure differential drives air movement from the back to the front of the trailer, such that the direction of airflow in a moving broiler carrier is the same as the direction of motion (Baker et al., 1996). The bird-laden modules cause a significant obstruction to air movement within the load and limit air mixing within the trailer. With the tarps down, air may short circuit between vents on the roof or between openings at the bottom of the tarp and vents in the roof directly above. For these reasons, laden broiler transporters may experience heterogeneous airflow distribution and inadequate ventilation.

Data from preliminary studies on Saskatchewan broiler transportation demonstrated that passive ventilation on tightly tarped transport trailers, while allowing birds to maintain body temperature, produced a heterogeneous distribution of airflow and consequently, less than optimum temperate and humidity conditions (Chapter 3). Paradoxical heat stress was encountered and air entered the trailer from unintentional openings, creating the potential for cold stress to occur for birds positioned in areas of air entry. In addition, wet birds and the accretion of frost on the modules and crates suggested that birds located outside the core of the trailer were subject to more adverse conditions during cold weather transportation.

Based on those results, subsequent data collection was required to comprehensively quantify the temperature and relative humidity conditions on broiler carriers under a range of environmental conditions, as opposed to cold weather conditions exclusively. Due to the forward movement of air on passively ventilated trailers, it was expected that temperature recordings would increase from the tailboard to the headboard of the trailer. It was hypothesized that vent configuration would influence the temperature distribution on the trailers and that birds located in the trailer core would experience warmer temperatures than birds crated near the trailer edges.

5.2 MATERIALS AND METHODS

Twenty-seven broiler journeys were monitored between November 2000 and October 2001 to comprehensively quantify the horizontal and vertical temperature and humidity gradients established within the 16 m transportation vehicles used by the Saskatchewan broiler industry. Vehicular configuration and module and crate dimensions were described in Chapter 3, whereas, the crate locations for logger placement were detailed in Chapter 4. Continual recording of temperature and relative humidity was achieved using FlashLink data loggers (DeltaTRAK, Inc., Pleasanton, CA, 94566, USA) that were calibrated by the manufacturer and programmed to record data at one-minute intervals. The range for the internal temperature sensor was -40°C to 66°C with the accuracy being ±1°C, while the operating humidity range was 10% to 100% RH with the accuracy being ±5% when the recordings were between 20% and 90% RH.

In a modular stack, vertical temperature gradients were determined by placing loggers in each of the top, middle and bottom rows of crates; whereas, horizontal gradients were recorded in each of these rows by placing loggers in the centre of the middle crate and at the extreme edges of the outside crates (Figure 5.2). Figures 5.1 and 5.2 illustrate how the modules on the truck and the crates within the modules were labeled.

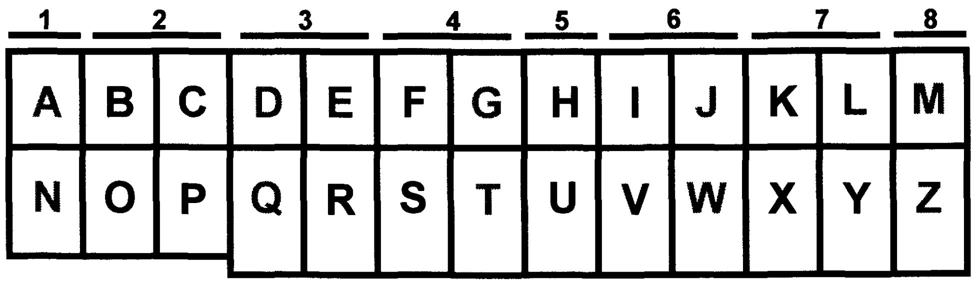

Figure 5.1. This drawing represents the lateral view of a 16 m broiler transport trailer used in Saskatchewan. Modules were labeled alphabetically from the front of the trailer and the numbered solid lines above the trailer indicate vent location on the roof. Loggers were placed in evenly distributed stacks of modules, as indicated by the red letters: A/N, D/Q, G/T, J/W and M/Z.

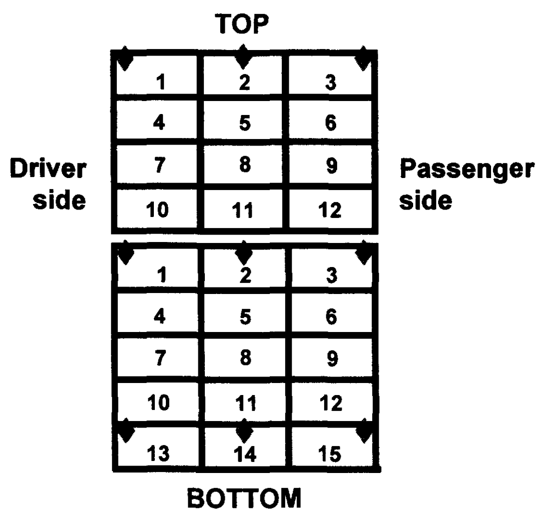

Figure 5.2. Crates within each module were numbered. When viewing the stack of modules from the back of the trailer, crate 1 was positioned on the driver side of the vehicle. The diamonds represent logger placement. Within a stack of modules, loggers were placed in three rows of crates: the top row of both the top module (nearest the roof) and bottom module (centre of stack), as well as in the bottom row of the bottom module (nearest the floor).

After the journeys were complete, the data loggers were retrieved and the recorded information was downloaded. An example of the crate temperatures recorded by loggers during a warm weather trip is shown in Figure 5.3. Values are from module D in the row of crates (D1-D3) nearest the roof. In the first 15 minutes, temperatures in all three crates decreased as the heat accumulated during loading was dissipated with vehicle movement. The increase and decrease in temperature following the initial 15-minute period appears unstable. However, if the change in ambient temperature for that broiler transportation journey is examined (Figure 5.4), it becomes obvious that the crate temperatures are reflecting shifts in the ambient conditions.

The environmental data used for the analysis was based on the observation that the in-crate temperature normalized during transportation, generally within 20 minutes of departure from the broiler-rearing site (Figures 5.3 and 5.4). This observation allowed the collection of additional data as two or three ventilation configurations could be tested during the same journey. Following a 30-minute stabilization period for each vent configuration, mean crate temperature and humidity were calculated by taking the average of the 15 subsequent recordings, thus creating a 15-minute data period.

Data were grouped according to the ambient temperature under which the journeys were performed, with the temperature categories being T1: < -16°C, T2: -15.9 to -6.0°C, T3: -5.9 to 5.9°C, T4: 6.0 to 15.9°C, and T5: >16°C. The journeys were further sorted based on vent configuration and curtain arrangement. Through all journeys conducted in T1, T2 and T3, both curtains on the trailer were lowered and the front and rear vents remained closed. The eight vents along the roof of the trailer were the only vents manipulated in these temperature categories. In T4, all eight roof vents were open and the headboard and tailboard vents were closed; however, tarping strategy was adjusted. Generally, both curtains were raised and all roof vents were open during transportation in warm weather (T5). The headboard and tailboard vents were occasionally opened, and due to rainfall, one of the tarps was lowered for an individual journey.

The MEANS procedure of SAS was used to calculate mean crate temperature and mean temperature lift, and the corresponding standard deviation and range of values. The REG procedure of SAS was used to determine the polynomial equation that best described mean temperature lift as a function of open vent area when journeys were conducted with both trailer curtains in a closed configuration.

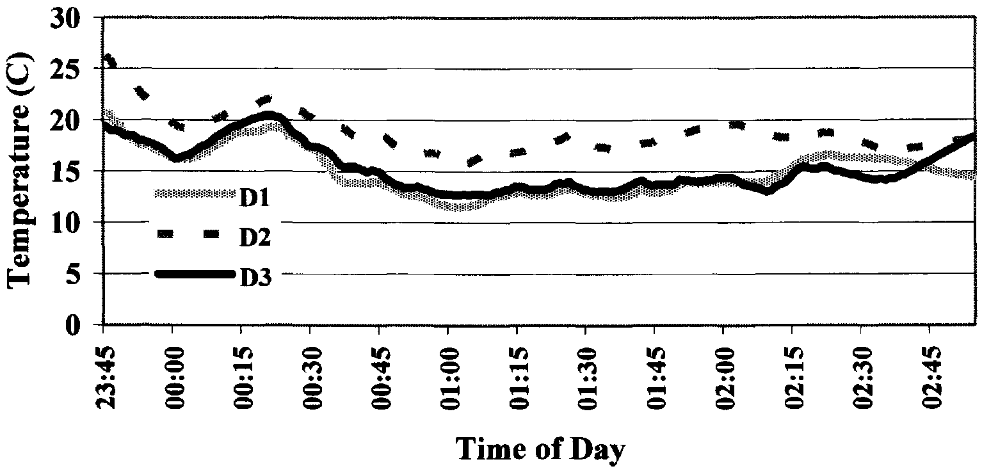

Figure 5.3. Crate temperatures (°C) from module D recorded by data loggers for the duration of a warm weather journey. Crate D2 is located in the middle of crates D1 and D3. Temperatures initially decline as vehicle movement dissipates accrued heat. Crate temperatures reflect changes in the ambient temperature.

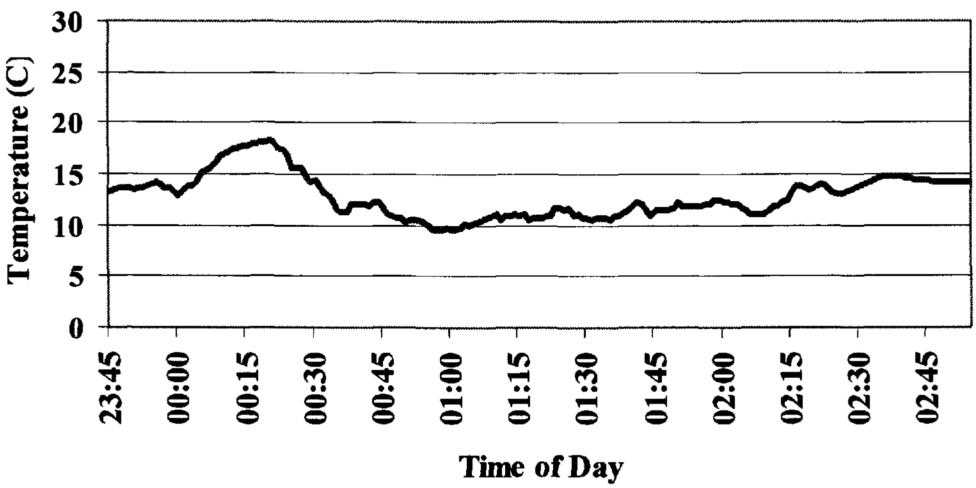

Figure 5.4. Ambient temperature (°C) from the warm weather journey that the crate temperatures in Figure 5.3 were extracted. Crate temperatures mimic changes in the ambient temperature.

5.3 RESULTS

All figures displaying the effect of ambient temperature and vent and curtain configuration on in-crate temperatures are located in Appendix B. Each figure follows an identical format: temperature (°C) is displayed on the y-axis and stack location is on the x-axis. The front stack location corresponds to modules A/N, followed by stacks D/Q, G/T (middle stack location), J/W and M/Z (back stack location). In each figure set, figure A represents crate temperatures from the top row of crates in a stack and is identified as ROOF (i.e. crates A1, A2 and A3 from the front stack location); figure B denotes crate temperatures from the middle row of crates in a stack and is labeled CENTRE (i.e. crates N1, N2 and N3 from the front stack location); and figure C depicts crate temperatures from the bottom row of crates and is named FLOOR (i.e. crates N10, N11 and N12 from the front stack location). Blue bars identify crates on the driver side of the trailer; whereas burgundy and beige shaded bars represent crates in the middle and passenger side of the trailer, respectively. The number of replications (n) and ambient temperature (T_a) under which the journey(s) were performed are indicated. The mean crate temperatures according to vent configuration for journeys conducted in T1, T2 and T3 are shown in Table 5.1; whereas the average crate temperatures according to curtain and headboard and tailboard vent configuration for journeys monitored in T4 and T5 are shown in Table 5.2.

General trends were obvious for most trips. Within a row of crates, the middle crate was warmer than those from the driver and passenger sides of the trailer. With minor exceptions, crate temperatures from both sides of the trailer unit located in the same row of crates were comparable.

It must be emphasized that the temperature and humidity conditions measured in this study may not reflect the conditions for the entire crate and therefore the conditions imposed on all birds. For example, the data loggers placed in the driver and passenger side crates were located on the outside perimeter of the crate and exposed to the most adverse cold weather conditions. Bird density and crowding within the crate are also expected to have influenced the microenvironment the birds experienced.

5.3.1 Adjustment of Roof Vents for T1, T2 and T3

Vents located on the roof of the trailer were adjusted for trips monitored in ambient conditions below 6°C (T1, T2 and T3). Open vent area affected temperature lift and the summarized data are shown in Table 5.3. The curvilinear response is best described by the equation $y = 2.62x^2 - 14.03x + 28.77$, $R^2=0.85$ (Figure 5.5). As open vent area increased from $0.18m^2$ to $2.0m^2$, there was a strong negative relationship between vent area and temperature lift. However, once the vent area exceeded $2.0\ m^2$, the degree of temperature lift plateaued (Figure 5.5). This information indicates that air exchange can be controlled somewhat by the area of vent opening, particularly when adjustments are made to the front roof vents.

Table 5.1. Mean crate temperatures according to vent configuration for journeys conducted in temperature groups 1, 2 and 3

	T1 crate temp (°C)			T2 crate temp (°C)				T3 crate temp (°C)			
Crate	1,5[1]	1	5	1-8	1,2	1,5,8	1	1-8	1-6	1-4	1,2,5,6
A1	7.7	8.5	17.0	12.0	13.5	9.1	4.0	17.4	23.6	20.8	19.9
A2	17.8	11.5	22.2	18.3	19.2	16.2	7.7	23.1	25.5	23.6	22.8
A3	6.3	-1.1	16.3	13.7	12.9	10.1	6.5	19.4	16.4	21.1	14.5
N1	10.9	8.6	11.4	16.8	17.3	10.7	0.3	20.0	25.9	24.7	19.3
N2	-5.2	-7.2	14.8	11.6	11.0	5.4	-2.0	16.2	21.6	15.0	18.8
N3	5.5	0.4	10.5	15.4	17.0	12.3	5.9	22.3	21.6	24.7	20.1
N10	1.0	-2.9	2.1	8.9	6.7	0.9	-6.8	12.6	23.6	18.6	14.2
N11	-11.3	-14.4	3.3	11.4	4.5	0.3	-6.1	13.9	22.6	16.3	11.0
N12	1.9	-8.7	2.2	11.5	4.4	-1.1	-5.4	16.0	21.7	21.5	15.1
D1	6.2	11.3	12.0	4.2	2.4	8.8	10.1	14.0	12.7	12.2	7.8
D2	20.9	25.2	21.4	11.0	9.1	17.3	22.0	21.2	19.0	17.0	20.6
D3	6.0	9.5	13.2	4.9	0.5	12.1	10.0	14.9	14.1	11.6	13.2
Q1	5.4	8.8	12.3	7.7	12.4	6.7	9.4	13.9	14.7	13.1	11.0
Q2	19.5	22.0	18.9	15.6	18.8	17.7	19.9	24.8	22.0	24.0	24.4
Q3	5.6	5.1	13.8	7.9	11.1	12.9	8.5	16.2	13.3	14.7	13.5
Q13	-5.5	-5.4	-3.4	2.2	0.0	-4.3	-5.0	10.3	17.0	12.7	7.1
Q14	0.1	0.1	-4.5	6.7	4.5	0.0	-0.6	12.2	15.2	15.1	8.4
Q15	0.0	-8.6	-4.1	3.2	0.7	-1.6	-6.2	10.8	8.7	14.6	5.0
G1	6.7	7.1	8.4	-1.1	4.3	5.0	9.8	8.1	8.1	6.4	9.7
G2	17.9	23.4	14.1	2.9	5.8	12.4	19.2	15.2	13.6	11.3	20.1
G3	8.8	9.7	7.3	-0.9	3.7	9.2	7.1	8.3	7.6	4.9	12.8
T1	5.1	10.5	6.2	5.5	12.5	7.6	6.8	11.7	10.7	10.5	7.8
T2	17.5	24.1	17.6	11.3	17.8	16.5	17.8	21.1	19.7	18.2	20.6
T3	5.0	10.7	12.8	6.7	11.6	8.7	8.0	13.7	12.2	12.8	13.2
T13	-5.3	-7.9	-7.4	5.5	2.3	-2.9	-9.1	9.6	11.1	9.1	4.5
T14	8.9	7.1	2.3	12.3	12.0	4.6	6.3	18.6	19.0	20.6	13.1
T15	-5.7	-7.5	-6.4	2.9	1.8	-0.3	-4.1	10.0	11.0	11.0	5.4
J1	-8.8	2.9	6.2	3.9	11.1	-0.7	6.1	7.3	8.2	5.9	5.7
J2	1.9	9.3	8.7	7.9	12.1	2.5	13.3	11.7	10.2	8.7	7.7
J3	-7.1	-2.6	6.5	2.4	5.1	-0.6	4.7	8.2	7.8	5.5	4.9
W1	-2.8	2.7	2.9	4.9	10.2	3.1	3.7	10.7	10.9	9.9	6.6
W2	9.3	13.2	15.6	13.6	17.4	9.3	14.7	17.2	14.6	13.9	15.1
W3	1.3	6.5	9.3	5.1	10.3	6.1	7.4	11.3	10.6	12.2	7.4
W13	-4.1	-5.5	1.6	0.3	-0.4	-2.8	-5.4	7.6	9.3	8.4	3.5
W14	3.9	6.3	1.8	10.5	8.8	7.5	5.4	15.5	17.0	16.8	11.4
W15	-2.8	-8.1	-1.0	0.7	0.9	-2.0	-4.9	8.6	8.5	9.6	3.9
M1	-10.5	-7.9	0.5	2.2	0.0	-3.9	-2.9	5.8	6.9	6.0	5.2
M2	-5.1	4.6	5.7	5.5	10.5	2.0	10.1	12.3	13.7	8.8	12.2
M3	-11.0	-7.3	-2.1	-0.1	0.4	-2.5	0.0	6.0	8.5	7.4	3.6
Z1	-7.4	-5.4	0.4	0.3	1.3	-1.6	-2.7	6.0	6.9	5.9	2.8
Z2	-2.4	0.4	4.2	7.2	9.5	1.5	0.8	12.4	11.2	10.8	7.2
Z3	-4.1	-3.7	1.4	0.9	3.1	-2.3	3.3	5.7	7.0	4.9	3.2
Z13	-9.8	-11.4	5.2	-0.6	-1.4	-3.6	-3.5	5.4	6.6	4.9	1.8
Z14	-1.6	-0.9	4.5	4.5	7.2	1.7	3.8	10.9	10.2	12.1	7.3
Z15	-9.1	-9.2	-4.5	0.8	-1.2	-4.6	-1.0	5.7	6.0	8.3	3.5

[1]Indicates the roof vents opened during data collection. Both curtains were lowered and headboard and tailboard vents were closed for all journeys conducted in T1, T2 and T3.

Table 5.2. Mean crate temperatures according to curtain and front and rear vent configuration for journeys conducted in temperature groups 4 and 5

	T4 crate temp (°C)				T5 crate temp (°C)		
Crate	D↓P↓[1]	D↑P↑	D↓P↑	D↑P↓	↑↑,FRcl[2]	↑↑,FRop	↑↓,FRcl
A1	15.7	17.7	18.8	20.3	22.8	20.3	27.1
A2	24.1	18.7	22.7	22.5	23.4	19.3	28.1
A3	19.5	17.4	20.8	20.8	22.8	19.8	28.3
N1	22.5	19.1	21.4	20.3	22.9	20.7	26.9
N2	24.8	18.6	23.4	21.3	23.3	20.2	27.9
N3	21.5	18.1	21.6	22.6	23.0	20.3	29.3
N10	21.5	15.9	20.3	17.5	22.2	19.7	25.9
N11	25.3	16.9	19.7	18.2	21.9	19.3	24.3
N12	19.8	14.5	16.9	20.7	21.5	18.9	30.0
D1	14.9	14.8	16.9	13.9	19.7	17.0	22.9
D2	22.3	16.8	18.1	18.6	22.2	20.1	26.1
D3	20.6	14.6	14.6	19.8	20.1	17.3	25.4
Q1	14.8	14.4	17.8	13.8	19.7	17.0	23.1
Q2	22.6	15.8	18.7	18.1	21.5	19.1	25.7
Q3	21.5	14.4	14.3	20.8	20.3	17.5	27.8
Q13	17.2	18.1	17.3	18.7	23.4	21.3	28.8
Q14	18.1	18.4	20.2	18.8	25.0	22.0	27.6
Q15	16.8	16.5	19.6	19.0	23.7	20.7	26.5
G1	13.8	15.0	16.2	13.7	19.9	17.2	23.1
G2	18.8	17.3	17.9	18.1	23.8	20.8	26.2
G3	14.7	14.4	14.7	18.0	19.8	16.7	24.6
T1	12.9	13.5	17.0	14.4	19.6	16.9	22.2
T2	21.7	16.5	17.5	18.3	22.3	19.2	26.6
T3	17.6	14.1	13.7	19.4	20.3	17.3	27.2
T13	13.7	16.4	17.5	14.0	21.0	18.3	23.7
T14	23.9	18.6	22.3	21.2	23.8	20.5	29.0
T15	15.3	14.2	14.4	18.2	21.0	18.0	25.7
J1	15.6	15.3	17.6	13.8	20.1	17.6	23.8
J2	15.2	15.4	16.7	19.3	22.4	19.3	27.5
J3	15.3	14.1	13.9	18.9	20.3	17.3	27.4
W1	13.8	14.6	17.4	13.0	19.9	17.0	23.0
W2	17.9	15.7	17.3	16.5	22.2	18.6	27.5
W3	14.7	14.1	13.2	17.6	20.0	17.1	28.0
W13	14.3	14.7	17.4	14.3	18.4	15.7	22.5
W14	18.5	15.1	18.0	17.0	21.7	18.1	27.9
W15	11.0	13.7	13.2	17.9	19.4	14.7	27.0
M1	12.7	14.7	14.7	15.2	20.0	17.6	25.0
M2	15.9	14.9	16.9	17.4	21.1	17.7	24.7
M3	12.2	13.2	14.7	15.5	19.6	16.9	23.0
Z1	12.6	14.0	15.7	14.7	20.2	17.6	24.1
Z2	15.4	15.6	17.8	18.3	22.2	18.0	25.5
Z3	11.9	14.0	14.3	14.9	20.1	17.0	22.7
Z13	12.9	15.5	16.3	18.1	21.7	19.6	24.9
Z14	15.3	17.1	18.5	18.1	22.5	21.2	25.0
Z15	12.3	15.8	15.6	15.1	21.8	19.2	22.9

[1]D = driver side curtain, P = passenger side curtain, ↓ = curtain lowered, ↑ = curtain raised.

[2]↑↑ = both curtains raised, ↑↓ = driver side curtain raised and passenger side curtain lowered, FRcl = front and rear vents closed, FRop = front and rear vents opened.

Table 5.3. Effect of roof vent opening on crate temperature and temperature lift during journeys conducted when ambient temperature was below 6°C

		Crate temperature (°C)				Temperature lift (°C)			
Open vent(s)	Area (m^2)	Mean	SD[1]	Min.[1]	Max.[1]	Mean	SD	Min.	Max.
5/2[2]	0.18	6.7	7.7	-7.4	22.2	29.6	7.7	15.5	45.1
1	0.29	3.2	9.5	-14.8	27.6	21.7	10.0	4.2	49.2
1,5	0.64	1.8	8.9	-13.5	23.2	22.5	8.9	7.0	44.1
1,2	0.86	7.6	6.6	-5.5	22.5	17.6	6.7	5.0	31.7
1,5,8	0.93	4.5	6.5	-4.6	17.7	16.0	6.5	6.9	29.2
1,2,5,6	1.78	10.8	6.5	-0.3	24.9	14.3	6.6	3.7	30.7
1-4	2.00	13.0	6.2	2.4	26.4	10.0	6.2	-0.6	23.4
1-6	2.92	13.9	6.0	4.6	26.5	10.9	6.0	1.6	23.5
1-8	3.78	11.6	6.4	-4.8	27.3	12.6	5.8	1.4	28.4

[1]SD = standard deviation; Min. = minimum; Max. = maximum.

[2]Vents 1 and 8 were 1.22 m x 0.235 m; vent 2,3,4,6 and 7 were 2.43 m x 0.235 m; vent 5 was 1.50 m x 0.235 m; 5/2 designates that only the back half of the 5th vent was open.

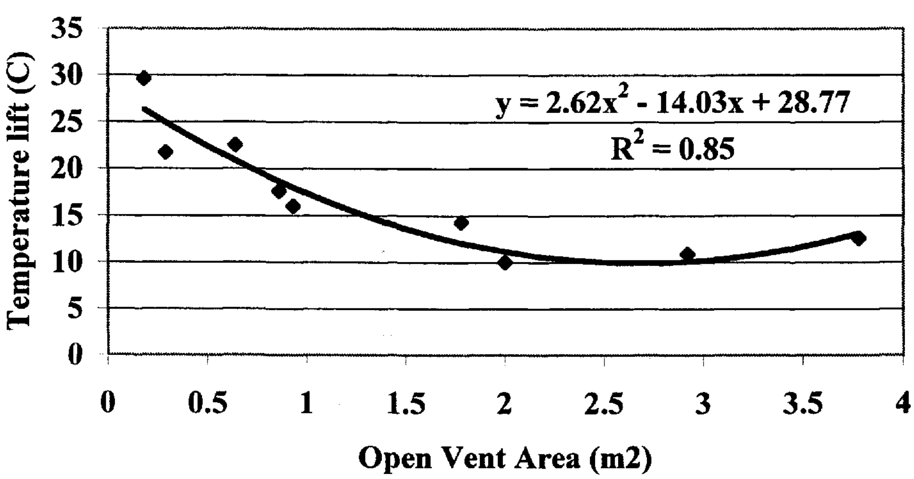

Figure 5.5. Relationship between mean temperature lift (°C) and open vent area (m^2) when journeys were conducted with both curtains lowered.

5.3.2 Temperature Group 1 (T1 = <-16.0°C)

A total of three trips were monitored in T1. On two occasions vents 1 and 5 were opened initially; however, the fifth vent was closed midway through the trip, leaving only the first vent open. The third trip was conducted with the back half of the fifth vent open and all remaining roof vents closed. No changes in vent configuration were incorporated into this trip.

One of the general findings included air being exhausted from the trailers through the roof vents, as indicated by observations of escaping steam. In addition, temperatures at the floor of the trailer for all stack locations were very low, as were the temperatures at the back of the trailer from the roof, centre and floor positions (Table 5.1). The curtains on the trailer units were difficult to seal in these areas, and as a consequence, very cold air infiltrated the load. As seen in the preliminary study, the highest temperatures were found in the middle and upper front sections (A2, D2, G2, Q2 and T2) of the trailer. This thermal core development occurred due to the distance from areas of air entry and the natural forward movement of air on the load. Information was also obtained from comparing the vent configurations.

Vents 1 and 5 open (Appendix B – Figure B1, 2 replications, T_a: -20.7, -20.6°C)
Temperatures at the centre and floor of the front stack indicated that air entered in this area (N2 and N11), likely through a warped headboard vent, due to the positive pressure in this region. Again, points of air entry during cold weather transportation resulted in cold crate temperatures and indicated that sealing the vents on the headboard of the trailer may be of benefit in this circumstance.

Vent 1 open (Appendix B - Figure B2, 2 replications, T_a: -20.7, -20.6°C)

Changing the vent configuration from having roof vents 1 and 5 open to only vent 1 open increased the temperature near the roof and centre of the stacks, but negatively influenced the crate temperatures closest to the trailer floor. The higher temperatures near the roof and centre of the stacks was likely the result of diminished airflow due to vent 5 being closed. Colder temperatures near the trailer floor suggested air entered through the bottom of the curtain, along the length of the trailer, and exited through the only open vent. Lower temperatures on the passenger side of the front stack (A3, N3 and N12) indicated the possibility of less adequate tarping compared to the driver side at the same locations or the influence of the wind during transportation.

Vent 5 open (Appendix B - Figure B3, no replication, T_a: -27.2°C)

Although similar, a different trailer than the one used for the preceding vent configurations was employed. In comparison to the former vent configurations, warmer temperatures were recorded in the roof and centre crates. The smaller vent opening ($0.18m^2$ vs. $0.29m^2$) and the more posterior location of the vent likely resulted in reduced airflow through the trailer due to the reduction of negative pressure at the vent location (Götz, 1987). As a result, higher temperatures were encountered. Crate temperatures across the roof decreased towards the rear of the trailer. This trend implied that air entered from the rear of the trailer and exited through the fifth vent. The temperatures at the centre of the stack followed the same trend with the exception of the first stack. The difference in the first stack location suggested that the front vents on this trailer were relatively well sealed. Cold temperatures at the floor of the middle stack (T13 and T15) suggested air was entering at this location and being drawn straight up, towards the open vent along the roof. Once again, air appeared to have taken the most direct path from entry to exhaust.

5.3.3 Temperature Group 2 (T2 = -15.9°C to -6.0°C)

Five trips were monitored in this temperature range. Again, because of changing vents midway through the trip, several vent configurations were studied. General observations in this temperature category were that the roof vents acted as points of air entry and escape. Roof temperatures became cooler and more variable as vent area increased. Temperatures along the trailer floor decreased when vent area was reduced. Details obtained from comparing the vent configurations are listed below.

Vents 1 to 8 open (Appendix B - Figure B4, 2 replications, T_a: -10.5, -6.6°C)
Variable temperatures across the roof of the trailer indicated that air entered and exited in an uncontrolled manner. The only areas experiencing temperatures below 0°C were the driver and passenger crates in the middle roof location (G1 and G3), the passenger side crate at the roof of the last stack (M3) and the driver side crate nearest the trailer floor in the last stack (Z13).

Vents 1 and 2 open (Appendix B - Figure B5, 4 replications, T_a: -12.7,-10.5,-9.7, -9.1°C)
The floor area of the front two stacks (N10-N12 and Q13-Q15) became colder once the back vents were closed, which suggested increased air flow through this area. Decreased temperatures in the roof of the second (D1-D3) and third stacks (G1-G3) compared to the first and fourth stacks supported the concept of coincidal air inlet and outlet vent areas.

Vents 1, 5 and 8 open (Appendix B - Figure B6, no replication, T_a: -12.9°C)
Temperatures at the roof of the last two stacks (J1-J3 and M1-M3) indicated that opening the eighth vent along the roof allowed cold air to enter not only through the tailboard of

the trailer but also through the eighth vent itself due to the low negative pressure at the back of the trailer. Again, temperatures in the first stack, at the centre (N1-N3) and floor (N10-N12) locations implied air entry from the headboard vents of the trailer. Generally, the conditions on the trailer floor were cold.

Vent 1 open (Appendix B - Figure B7, no replication, T_a: -12.9°C)

Colder temperatures throughout the front stack suggested air entered from the headboard vent and from the trailer floor and was drawn straight up, towards the open roof vent. Yet again, sealing the curtains to the headboard of the trailer and patching the hole in the headboard vent would be beneficial during cold weather transportation with the first roof vent open. Temperatures at the floor of the trailer for all stack locations, as well as the back of the trailer (roof, centre and floor), remained low, with the exception of the middle crate nearest the roof (M2).

5.3.4 Temperature Group 3 (T3 = -5.9°C to 5.9°C)

The following vent configurations were tested in T3: all vents (1-8) open (Appendix B - Figure B8, 7 replications, T_a: -5.8, -5.0, -0.9, -0.1, 2.8, 2.8, 2.9°C), vents 1 to 6 open (Appendix B - Figure B9, 2 replications, T_a: 2.8, 2.8°C), vents 1 to 4 open (Appendix B - Figure B10, 2 replications, T_a: -0.9, 2.9°C), and vents 1, 2, 5 and 6 open (Appendix B - Figure B11, 2 replications, T_a: -5.8, -0.1°C). In this moderate temperature range, all crate temperatures were above 0°C irrespective of the vent configuration (Table 5.1) and it is unlikely that low temperature would have an overly adverse effect on broiler chickens. The highest temperatures approached but did not exceed 26°C. With minor exceptions, temperature trends indicated that airflow was relatively uniform from the rear to front of the trailer.

5.3.5 Adjustment of Curtains and Front and Rear Vents

The degree of temperature lift was affected by tarp configuration and the data summarized for trips monitored above 6°C (T4 and T5) are shown in Table 5.4. The extent of air exchange in the trailer is directly related to tarp configuration with mean temperature lifts of 3.3, 5.7 and 9.6°C for curtains raised, one curtain raised and curtains lowered, respectively. With the curtains raised, closed or open front and rear vent configuration had little effect on the mean crate temperature (18.9°C and 18.6°C, respectively) and mean temperature lift values (3.3°C and 2.9°C, respectively).

Table 5.4. Effect of tarp positioning and front and rear vent status on crate temperature and temperature lift during journeys conducted when the ambient temperature was above 6°C

			Crate temperature (°C)				Temperature lift (°C)			
Tarp[1]	FRV[2]	n[3]	Mean	SD[4]	Min.[4]	Max.[4]	Mean	SD	Min.	Max.
DD	C	1	17.2	4.0	11.0	25.3	9.6	4.0	3.4	17.7
UU	C	9	18.9	4.5	6.9	28.2	3.3	2.0	0.0	11.4
UU	O	4	18.6	3.9	12.2	27.0	2.9	2.0	0.0	8.9
DU	C	2	17.4	2.8	12.1	24.2	5.8	2.9	1.3	13.9
UD	C	4	19.7	4.7	8.9	30.0	5.5	2.9	0.3	15.3

[1]Tarp configuration: DD = both down; UU = both up; DU = driver side tarp down, passenger side tarp up; UD = driver side tarp up, passenger side tarp down.
[2]Front and rear vent configuration: C = closed, O = open.
[3]n = number of journeys conducted.
[4]SD = standard deviation; Min. = minimum; Max. = maximum.

Nevertheless, possibly more important than the mean temperature lift is the maximum temperature lift (Table 5.4), which provides guidance regarding the potential for dangerously high temperatures particularly at the core of the trailer. The maximum temperature lift with both curtains retracted and the headboard and tailboard vents closed was 11.4°C, whereas the maximum temperature lift when the front and rear vents were open was 8.9°C (Table 5.4). This 2.5°C temperature difference suggests that opening the headboard and tailboard vents will facilitate more airflow through the trailer and may prevent conditions capable of causing heat stress from developing. Overall, these data support the regular practice of raising both curtains and opening the front and rear vents while transporting birds under warm ambient conditions.

5.3.6 Temperature Group 4 (T4 = 6.0°C to 15.9°C)

In this temperature range, all eight roof vents were open and the headboard and tailboard vents remained closed; however, tarping strategy was adjusted. Curtain configurations included both curtains lowered (Appendix B - Figure B12, no replication, T_a: 7.9°C), both curtains raised (Appendix B - Figure B13, 4 replications, T_a: 7.2, 12.4, 12.8, 13.5°C), or one curtain lowered (Appendix B - Figures B14 and B15, 2 and 3 replications for the driver tarp down and passenger tarp down, T_a: 7.2, 13.5°C and T_a: 7.9, 11.8, 12.4°C, respectively). Crate temperatures recorded within this temperature range were all moderate (Table 5.2) and unlikely to cause a negative impact on bird well being.

5.3.7 Temperature Group 5 (T5 = >16.0°C)

In general, tarps were raised and all roof vents were open during transportation in T5. The front and rear vents were closed (Figure B16, 3 replications, T_a: 17.5, 17.7, 21.9°C) or open (Figure B17, 2 replications T_a: 17.7, 21.9°C) and when required, one of the curtains was lowered. This was the case for one trip where rainfall prompted the truck driver to lower the passenger side curtain (Figure B18, no replication T_a: 17.5°C). The highest mean crate temperature on this trip was 30°C in crate N12 (Table 5.2). Crate temperatures in the monitored trips were uniform when both tarps were raised (Table 5.2). Opening the front and rear trailer vents resulted in slightly cooler and more homogeneous temperatures.

5.4 DISCUSSION

Horizontal and vertical temperature and humidity gradients were established during broiler transportation in Saskatchewan. Due to the effects of the lowered curtains, winter transportation of broilers in Saskatchewan presents a considerable challenge. On one hand, the birds must be protected from the freezing ambient temperature, but on the other hand, air exchange on the transport vehicle is required for removal of moisture and heat being produced by the birds and for provision of adequate levels of oxygen. Therefore, air circulation is required to provide for minimum ventilation rates. Although roof vents can be used to control air exchange to some degree, passive airflow of this type is difficult to estimate because of the influence of factors such as vent and inlet location, truck speed, prevailing winds and bird stocking density. Similarly, air does not enter the trailer in a planned fashion, but basically enters in response to pressure differentials on the moving vehicle and available openings (Hoxey et al., 1996). There are no planned inlets. Air enters primarily at the headboard, tailboard and bottom edges of the tarps as they are difficult to seal, through unintentional openings such as poorly sealed front vents, or through roof vents. In the case of roof vents, air entry is more likely to occur in vents near the back of the vehicle because of reduced exterior negative pressures on the trailer in this location compared to higher negative pressure at the front vents (Hoxey et al., 1996; Götz, 1987). Modules containing broilers block airflow and thereby influence the degree of ventilation that occurs in various sections of the trailer. The above factors create a complex thermal environment and a heterogeneous temperature distribution as characterized by cold areas near air inlets and poorly ventilated warm areas elsewhere.

Several recommendations were suggested to improve the trailer conditions for the broilers during cold weather transportation. Ensuring the headboard and tailboard vents are in good condition and properly sealed would enhance conditions in passively ventilated broiler transport vehicles. Under very cold conditions, points of air entry should not allow air to flow directly onto the birds. Therefore, other methods of securing the tarp, particularly for extremely cold weather, should be investigated. The possibility of equipping the trailer with an air mixing chamber capable of heating incoming air prior to bird exposure would benefit bird welfare, but may not prove to be economically feasible.

The use of smaller roof vents to control airflow and provide more uniform ventilation should be considered as open vent area affected mean temperature lift. Distribution of the vent openings over the front half of the vehicle should reduce the volume of air entering in proximity to the exhaust vent, thereby increasing the temperature at the floor level of the vehicle directly under the vents. During cold weather transportation, comparing average crate temperatures when the open vent area was $0.18m^2$ and $0.29m^2$ suggests that the size of the vent opening may impact the on-board transport conditions. Table 5.3 showed that a warmer mean crate temperature was recorded when the open vent area was reduced from $0.29m^2$ to $0.18m^2$ (3.2°C and 6.7°C, respectively). Developing a reference chart that could be used by live haul drivers that suggests the amount of open vent area appropriate for a range of cooler ambient temperatures would be a useful tool. Further investigations should be conducted to determine the effects of outfitting the passively ventilated broiler trailers with small vents distributed along the roof.

Since temperature is easy to measure and interpret, the installment of real-time temperature sensors inside the broiler trailers could be used to assist drivers such that vent adjustments could then be made according to the on-board conditions.

During warm weather transportation, passively ventilated transport trailers allowed for acceptable on-board thermal conditions, provided that the vehicle remained in motion. With the trailer curtains retracted, convective cooling reduced the effective temperature experienced by the birds and initiated moderate hypothermia at ambient temperatures as high as 6°C due to the increase airflow through the trailer (Mitchell et al., 1997). However, if the birds' feather covering was dry upon loading, which was the case in this study, cooling via conventional methods should not elicit a cold stress response from the birds. In addition, when ambient conditions dictate that one of the curtains be lowered, such as heavy rainfall from one direction, the headboard and tailboard vents should be opened to encourage airflow through the trailer, thus reducing the maximum temperature lift.

Overall, the Saskatchewan poultry industry is doing a reasonable job of transporting birds while operating under a variety of ambient conditions with a broiler transport system that allows little control besides the adjustment of trailer curtains and vents located on the roof, headboard and tailboard of the trailer. The United Kingdom has developed a mechanically ventilated trailer for transporting poultry to slaughtering facilities (SRI News, 1999). An on-board generator powers extraction fans controlled by a computer monitoring the micro-environment of the trailer such that transport conditions are consistently within the thermal comfort zone of the birds (Kettlewell and Mitchell, 2001). Engineering expertise would be required to investigate the possibility of renovating the current transportation trailers used in Saskatchewan with force-ventilation equipment.

6.0 BROILER MORTALITY ASSOCIATED WITH 26 TRANSPORTATION JOURNEYS CONDUCTED IN SASKATCHEWAN AND THE EFFECT OF FARM MANAGEMENT ON THE INCIDENCE OF BIRD DEATH

6.1 INTRODUCTION

Mortality occurring during the transportation of broilers from the farm to the processing plant is an economic and animal welfare concern and is typically reported as dead on arrival (DOA). The incidence of bird death varies by country, the number of processors surveyed, the data collection period, the sample size of the birds, and the catching method and transportation system used. Additional factors influencing broiler mortality levels include ambient conditions during loading and transportation, stocking density of the load, position on the broiler carrier, time in transit, the length of time birds are held in lairage and the quality of the environment while awaiting slaughter (Bayliss and Hinton, 1990). The effects of barn management and bird condition prior to transportation on broiler mortality during transport and lairage have not been well documented.

Apparent equivalent temperature (AET) for broilers is an index combining dry-bulb temperature and relative humidity to indicate the effective temperature broilers are exposed to in transit (Mitchell and Kettlewell, 1998). If the barn management was poor such that it resulted in wet litter, and consequently wet birds, broilers transported during cold ambient conditions would be at more at risk of cold stress due to a lower effective temperature when compared to broilers housed under dry litter conditions. Alternatively, misting birds prior to transportation may assist evaporative cooling during hot weather transportation thereby reducing a potentially dangerous, higher AET.

High atmospheric ammonia in broiler barns reflects substandard barn management and is generally an indication of excess litter moisture. Significant ammonia levels can negatively affect bird production, reflected particularly by reduced body weight and poorer feed conversion (Al Homidan et al., 2003). Further detrimental effects of excessive atmospheric ammonia include damage to the trachea, lungs, air sacs and the remainder of the respiratory tract, all of which can leave birds predisposed to transportation stressors. Temperature, ventilation, humidity, stocking density and bird age, as well as litter type, age and pH, are critical factors influencing ammonia production in barns and should be manipulated to maintain atmospheric ammonia levels below 25 ppm (MAFRI, 2002; Al Homidan et al., 2003).

Evidently, barn environment and the resulting bird condition can exaggerate or lessen the effective temperatures imposed on birds during transportation and therefore influence bird susceptibility to transportation associated death. In the United Kingdom, average broiler mortality occurring between loading and processing has been reported to range from 0.10% and 0.19% (Gregory and Austin, 1992; Warriss et al., 1992; Metheringham, 1996). Although this value seems negligible, it accounts for a loss in excess of 700,000 birds per annum. In comparison, 0.46% of birds slaughtered in Canada in 2002 were classified as DOA (CFIA), representing almost 3 million birds. In fact, poultry accounted for 99.3% of DOA animals from all slaughter animal classifications in Canada (CFIA). Saskatchewan, a Canadian prairie province, reported average mortality losses of 0.51% and 0.49% in 2000 and 2001, respectively (Lilydale Cooperative Ltd.). Clearly, there is a large discrepancy between bird mortality reported in the UK and Canada. An improvement in bird welfare and considerable economic savings for the

Canadian commercial poultry industry would result if broiler mortality could be reduced to those achieved in the UK.

Average journey length in the UK is approximately 3 h (Warriss et al., 1990; Warriss et al., 1992), yet the average distance traveled is roughly 30 km, suggesting that birds spend a significant portion of their journey on stationary vehicles that likely leads to compromising on-board thermal conditions due to a reduction of airflow. In contrast, commercial broiler barns in Saskatchewan are distributed throughout the province and there is a strong positive correlation between distance from the processing plant and journey length. The temperature extremes experienced in Saskatchewan pose the greatest challenge during transportation, especially during cold weather, as birds must be protected from the cold yet provided with adequate trailer ventilation (Chapters 3, 4, 5).

Although mortality is a valuable indicator of the effects a transportation system and lairage conditions have on the birds, there is a problem with the reported death losses. No distinction is made between birds dying during the transportation period and fatalities occurring while the birds are held in lairage, awaiting slaughter. In the UK, it has been suggested that the lairage period may be comparable to the journey time (Quinn et al., 1998) or possibly longer, depending on the processing schedule. No research is available describing lairage times in Canada.

This study was conducted to quantify the number of birds dying between the production site and arrival at the processing plant (DOA), and to differentiate DOA mortality from the total number of fatalities occurring between loading and shackling. Because bird losses after transportation are determined as the birds are being shackled, the total mortality occurring from the grow-out site to shackling is classified as dead on shackling (DOS) losses. In addition, the distribution of DOA birds was recorded and causes of DOA mortality were determined. The effects of barn management prior to transportation, ambient temperature, stocking density and journey time on DOA and DOS levels were also investigated.

6.2 MATERIALS AND METHODS

Between November 2000 and October 2001, barn environment and bird condition were assessed on twenty-six broiler production facilities prior to bird loading and transportation.

6.2.1 Barn Environment

Litter quality was evaluated according to areas of caking, depth of coverage and moisture content and subjectively recorded as good, moderate or poor. Litter in good condition had few areas of caking and covered the barn floor. It was also dry enough that it did not stick to footwear. In comparison, litter in poor condition had a high moisture content which caused widespread caking and stuck to footwear. Sections of bare floor were also considered a characteristic of poor litter quality.

In addition to litter scoring, two litter samples were collected for litter moisture analysis from 13 production sites. In each barn, one sample was taken from the main floor and the second sample was taken in proximity to the drinkers. Each litter sample was composed of ten sub-samples gathered from evenly dispersed areas of the barn. The drinker sub-samples were taken within 15 cm of the water lines, and the main floor sub-samples were collected at least 50 cm away from any drinker, feeder, doorway and heat source, or any component of the ventilation system. Litter samples were prepared for moisture analysis by placing the material into pre-weighed paper bags, re-weighing the bag and drying the sample at 55°C until no change in sample weight was noted (24 to 72 hours). Subsequently, the litter samples were analyzed for hygroscopic moisture (AOAC, 1990).

Atmospheric ammonia was determined using a Dräger apparatus (Drägerwerk Aktiengesellschaft Lübeck, Federal Republic of Germany). One ammonia reading was taken from the middle of each barn at bird height, avoiding areas near any element of the ventilation system.

6.2.2 Bird Condition

A visual evaluation of bird condition was made based on uniformity, leg problems, and cull birds, as well as feathering appearance and texture. Five lots of ten birds were subjectively assessed throughout the barn to give an indication of the overall bird condition and were summarized as good, moderate or poor. Characteristics of birds in good condition included no more than two birds with an obvious size difference, leg abnormality or wet and dirty feathers; whereas, characteristics of broilers in poor condition involved five or more broilers that were noticeably different in size, displayed a leg defect or had wet and dirty feathers.

6.2.3 Loading and Transportation

The broilers were reared until they attained an average body weight of approximately 1.83 kg (average flock weights ranged from 1.55 to 2.06 kg), which required between 36 and 41 days. Crews began catching broilers at 10 pm regardless of farm location and stocking density ranged from 22 to 26 birds per crate, or 7524 to 8892 birds per trailer. Once trailers were loaded, they traveled 200 km, on average, to

Wynyard, Saskatchewan for processing. The 16 m transport trailers were used for all journeys, with each trailer accommodating 26 Anglia Autoflow modules (Wortham Ling, Diss, Norfolk, England IP22 1SR). Figure 6.1 represents the lateral view of a 16 m trailer and Chapter 3 describes in detail the trailer, module and crate dimensions and characteristics. The modules, which were labeled alphabetically, each contained crates that were numbered for identification (Figure 6.2).

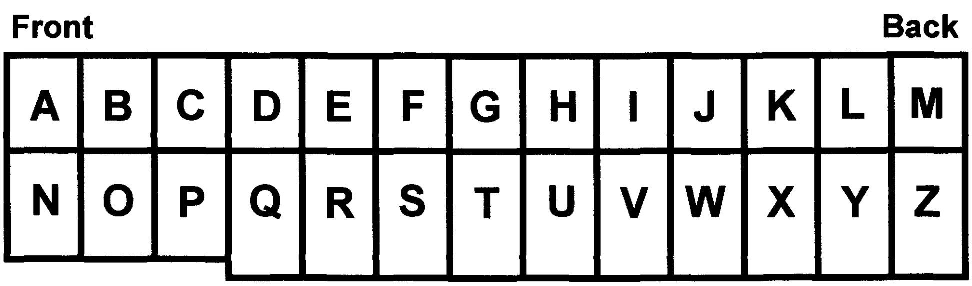

Figure 6.1. This drawing represents the lateral view of a 16 m broiler transport trailer used in Saskatchewan. Modules are labeled alphabetically from the front of the trailer.

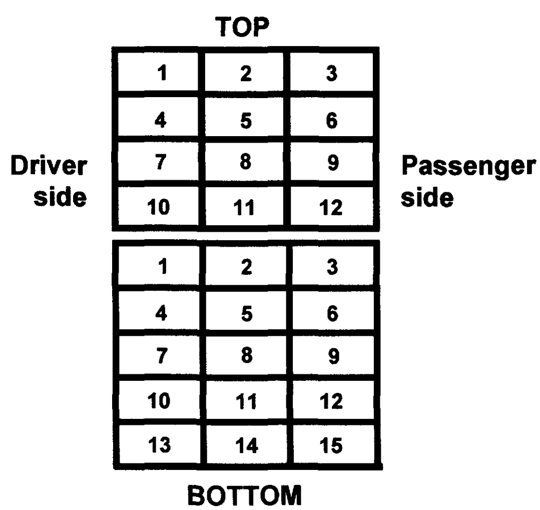

Figure 6.2. Crates within each module are numbered. When viewing the stack of modules from the back of the trailer, crate 1 is positioned on the driver side of the vehicle.

6.2.4 Broiler Mortality

Upon arrival at the processing plant, each trailer unit was driven directly into a live receiving shed adjacent to the slaughtering facility where the modules were immediately unloaded. Each crate was inspected for dead birds (DOAs), which were removed and identified to determine mortality distribution within the trailer. Canadian Food Inspection Agency (CFIA) inspectors completed bird necropsies and causes of death were categorized according to the most important contributing factors. These groupings included transportation itself, catching trauma, farm-related death, death resulting from the data collection method and additional losses not readily associated with those already listed.

Death losses associated with transportation characteristically showed no visible lesions and were typically caused by congestive heart failure, stress, collapse or suffocation. Mortality resulting from catching trauma included injuries and hemorrhages, such as dislocated or broken femurs, ruptured livers, crushed skulls and dislocated necks. Health of the flock prior to loading reflected upon farm management. Emaciation, cyanosis and disease conditions such as ascites, lung infection, pericarditis, and perihepatitis were all initiated during the grow-out period. Accidental bird death and mortality with no obvious association, such as birds loaded dead, were classified separately.

Plant reports obtained additional information including time of slaughter and the number of birds that died during lairage. From these records, the lairage period and DOS mortality were determined. The amount of time birds were in transit depended on the distance between the farm and the processing plant, while the lairage period depended on time of arrival at the abattoir and the time of slaughter. Mortality data were collected in conjunction with temperature and humidity characterization from broiler journeys conducted under a range of ambient temperatures (Chapter 4).

6.2.5 Statistics

Data were grouped according to the ambient temperature under which the journeys were performed, with the temperature categories being < -16°C, -15.9 to -6.0°C, -5.9 to 5.9°C, 6.0 to 15.9°C, and >16°C. The GLM procedure of SAS was used to analyse atmospheric ammonia and litter moisture levels according to ambient temperature, as well as DOA and DOS values according to ambient temperature, journey length and stocking density. Duncan's Multiple Range Test was applied to separate significantly different means ($P<0.05$). The REG procedure of SAS was used to determine if atmospheric ammonia levels affected broiler mortality.

6.3 RESULTS

6.3.1 Barn Environment and Bird Condition

The effects of ambient temperature on atmospheric ammonia are shown in Table 6.1. Average ammonia concentrations in the barns tended to be higher under cold weather conditions, but there was no relationship to DOA or DOS mortality.

Table 6.1. Effects of ambient temperature on atmospheric ammonia in broiler barns prior to shipping birds

	Ammonia reading (ppm)		
Ambient temperature	Mean	Minimum	Maximum
< -16.0 °C	25^{ab}	20	35
-15.9 °C to -6.0 °C	31^{a}	10	50
-5.9 °C to 5.9 °C	19^{ab}	9	43
6.0 °C to 15.9 °C	10^{b}	2	30
> 16.0 °C	7^{b}	4	9
SEM	2.9		

Bird condition and litter quality was recorded as good, moderate or poor, and categorized according to the ambient temperature. The assessment results in Table 6.2 show that the majority of flocks were in good condition and that all barns had good to moderate litter condition.

Table 6.2. The effects of ambient temperature on bird and litter quality

	No. of	Bird quality			Litter Quality		
Ambient temp.	trips	Good	Moderate	Poor	Good	Moderate	Poor
< -16.0°C	3	3	-	-	2	1	-
-15.9°C to -6.0°C	6	5	1	-	2	4	-
-5.9°C to 5.9°C	7	4	3	-	2	5	-
6.0°C to 15.9°C	8	5	2	1	5	3	-
> 16.0°C	3	2	1	-	3	-	-

Eight litter samples were taken when the ambient temperature was below 0°C, with the temperature ranging from -27.2°C to -0.1°C, and five samples were collected when the outdoor temperature was above 0°C, with the temperature ranging from 7.9°C to 17.5°C. As expected, litter moisture content around the water lines was higher than the main floor areas. The average moisture content for the samples collected near the water lines and from the main floor were 38.0% and 17.3%, respectively. The moisture content near the drinkers ranged from 22.7% to 49.4%; whereas the moisture from the main floor area samples ranged from 11.6% to 28.0%. Ambient temperature had no significant effect on the litter moisture content from the barns tested (Figure 6.3).

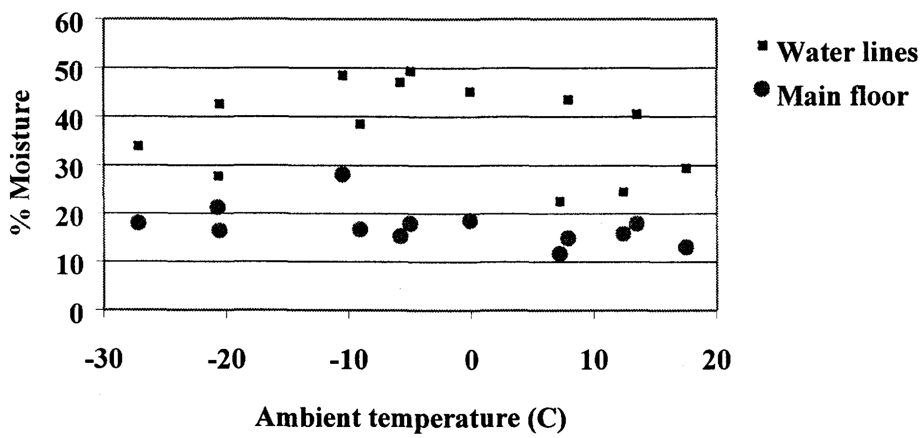

Figure 6.3. Effect of ambient temperature on litter moisture content (%) of litter samples from the main floor and in proximity to the watering lines.

6.3.2 Broiler Mortality

Death losses occurring during 26 broiler transportation journeys monitored under ambient temperatures varying from –27.2°C to 21.9°C are shown in Table 6.3. Average DOA and DOS mortality was 0.14% and 0.28%, respectively, with values ranging from 0.05% to 0.52% and 0.11% to 0.90%, respectively. Journey length varied from 140 to 240 min with the average time in transit being approximately 175 min, whereas the average lairage period was 230 min and varied from 165 to 310 min.

Table 6.4 reveals necropsy results from the DOA broilers. Birds with no visible lesions accounted for 34% of DOA mortality and were likely affiliated with transport conditions. Although the precise reason for death cannot be established due to the lack of symptoms, it is probable that a portion of these birds died of acute heart failure, also known as sudden death syndrome (Olkowski and Classen, 1997).

TABLE 6.3. Bird mortality immediately after transportation and at shackling, prior to slaughter

	Ambient temp. (°C)	Journey length (min)	Lairage (min)	DOA[1] (%)	DOS[2] (%)
	-27.2	190	190	0.15	0.24
	-20.7	155	225	0.52	0.90
	-20.6	190	235	0.15	0.37
	-12.9	190	210	0.17	0.25
	-12.7	150	240	0.10	0.26
	-9.7	185	205	0.05	0.31
	-9.1	240	165	0.16	0.56
	-6.6	155	245	0.11	0.20
	-5.8	165	230	0.22	0.41
	-5.0	145	270	0.15	0.17
	-0.9	170	245	0.12	0.24
	-0.1	180	205	0.12	0.13
	2.8	200	220	0.09	0.19
	2.8	165	185	0.12	0.20
	2.9	175	230	0.08	0.11
	7.2	155	275	0.11	0.23
	7.9	205	205	0.09	0.13
	11.8	165	245	0.13	0.28
	12.4	205	265	0.17	0.39
	12.8	190	185	0.10	0.12
	13.5	195	305	0.12	0.19
	14.8	160	310	0.09	0.28
	14.9	160	255	0.16	0.32
	17.5	180	220	0.09	0.23
	17.7	140	215	0.13	0.21
	21.9	175	235	0.11	0.25
Mean	1.1	176	231	0.14	0.28
SD	13.4	23	35	0.09	0.16

[1]DOA - birds arriving dead at the slaughtering plant.

[2]DOS – total birds dying between the production site and shackling, including both transportation and lairage periods.

TABLE 6.4. Necropsy findings from broilers found dead on arrival (DOA) after 26 journeys

Association[1]	Cause of death	# of birds	% of DOA[2]	% of DOA by association
Transportation	No visible lesions	97	34.0 ± 3.4	34.0
Catching-Influenced	Head trauma	66	23.2 ± 3.4	29.6
	Dislocated hip	13	4.6 ± 1.5	
	Liver hemorrhage	4	1.4 ± 0.8	
	Broken bones (culls)	1	0.4 ± 0.5	
Farm-Influenced	Ascites	52	18.2 ± 3.2	31.9
	Cyanosis	17	6.0 ± 1.8	
	Emaciated	12	4.2 ± 2.1	
	Infectious	10	3.5 ± 1.6	
Experimental[3]	Accidental	9	3.2 ± 1.9	3.2
Other		4	1.4 ± 0.8	1.4
	TOTAL	285	100.0	

[1]Cause of death is categorized according to the factor that was considered to have the greatest impact on bird mortality.
[2]Mean ± standard error of the mean.
[3]Death due to trauma during data collection.

Bird mortality linked to catching trauma (29.6%) included fractured skulls, as well as dislocated hips, liver hemorrhaging and broken bones caused by rough handling. Birds found with badly dislocated hips or broken bones were culled if found alive while collecting bird mortality. Farm associated mortality included several birds that were emaciated upon necropsy. Over 18% of DOA mortality was attributed to ascites, and cyanosis was observed in 6% of DOA birds. Infectious diseases including air sacculitis, pericarditis, peritonitis, hepatitis, enteritis and Marek's disease, were identified in 3.5% of dead birds. There was accidental mortality resulting from the method of DOA collection (3.2%), and no obvious association was noted for a small number of dead birds (1.4%), including birds that were loaded dead and were autolytic.

Time in transit did not affect DOA mortality in this study (Table 6.5); however, there was a limited range in transportation length and few journeys performed in the shortest and longest categories of journey length.

The incidence of DOA and DOS mortality was influenced by ambient temperature and stocking density. Journeys were grouped into five temperature categories as shown in Table 6.6. DOA and DOS percentages were significantly higher when the ambient temperature was below –16°C. However, the three trials monitored under the coldest temperatures showed considerable variability in DOA mortality (Table 6.7), with bird losses being 0.15% for two journeys and 0.52% for the remaining trip.

Stocking density for each journey was 22, 23, 24 or 26 birds per crate contingent primarily upon the number of birds being transported from each farm. Bird losses were significantly higher (0.52 and 0.90%, respectively) when the stocking density was 26 birds per crate compared to other stocking levels (Table 6.8). However, there was only one journey completed at this stocking level.

TABLE 6.5. Effect of transportation on the percentage of dead on arrival (DOA) broilers

Journey length (min)	# of journeys	DOA (%)
120-145	2	0.14
150-175	12	0.15
180-205	11	0.12
210-240	1	0.16

TABLE 6.6. The effect of ambient temperature on broiler mortality

Ambient temp. (°C)	# of trips	DOA[1] (%)	DOS[2] (%)
< -16.0	3	0.27^{a}	0.50^{a}
- 15.9 to - 6.0	5	0.12^{b}	0.31^{ab}
- 5.9 to 5.9	7	0.13^{b}	0.21^{b}
6.0 to 15.9	8	0.12^{b}	0.24^{b}
> 16.0	3	0.11^{b}	0.23^{b}

[a,b]Means in the same column without common subscripts differ significantly.

[1]DOA - birds arriving dead at the slaughtering plant.

[2]DOS - total birds dying between the production site and shackling, including both transportation and lairage periods.

TABLE 6.7. Necropsy findings for broilers found dead on arrival (DOA) at the processing plant for three cold weather journeys (< -16.0°C)

	Number of DOA birds		
Cause of death	Cold journey 1 (-27.2°C)	Cold journey 2 (-20.6°C)	Cold journey 3 (-20.7°C)
Ascites	3	0	18
Cyanosis	1	0	1
Dislocated hip	0	1	3
Head trauma	0	4	4
No visible lesions	7	7	18
Other	1	0	2
Journey DOA (%)	0.15	0.15	0.52

TABLE 6.8. The effect of stocking density on broiler mortality

Stocking density (birds/crate)	# of trips	DOA[1] (%)	DOS[2] (%)
22	13	0.13[a]	0.26[a]
23	1	0.16[a]	0.32[a]
24	11	0.11[a]	0.24[a]
26	1	0.52[b]	0.90[b]

[1]DOA - birds arriving dead at the slaughtering plant.
[2]DOS - total birds dying between the production site and shackling, including both transportation and lairage periods.

DOA mortality was distributed throughout the trailer. If mortality from the center stack of modules (modules G and T) was divided in half and added to the front and back halves of the trailer, these sections had 53.0% and 47.0% of DOA birds, respectively. The respective bird mortality across the entire top and bottom tiers of modules was 47.7% and 52.3%. The occurrence of DOA mortality was slightly higher among crates on the driver side of the vehicle (37.2%) compared to the center and passenger side crates (30.9% and 31.9%, respectively). The number of dead birds collected from the individual modules for all journeys varied from no birds to as many as six dead birds. Overall, the lowest level of total mortality occurred in module C (6 birds representing 2.1% of DOA mortality) while the greatest mortality transpired in module E (17 birds representing 6.0% of DOA mortality). In the three journeys with ambient temperatures below –16°C, 14.3% of DOA birds were located in the bottom three modules at the back of the trailer, which is slightly higher than the 11.5% expected if death losses were evenly distributed in all 26 modules. Location of DOS mortality was not available.

6.4 DISCUSSION

Average DOA mortality (0.14%) from these journeys, which reflected bird losses occurring during the transportation period only, was less than the Saskatchewan plant's average bird losses of 0.51% and 0.49% for 2000 and 2001, respectively (Lilydale Co-operative Ltd), and comparable to values cited in studies conducted in the UK (Bayliss and Hinton, 1990; Warriss et al., 1992; Metheringham, 1996). However, DOA values from the UK and those recorded by the processing plant in Saskatchewan did not differentiate between birds dying in transit and total mortality loss, including birds dying during the lairage period. Hence to make a valid comparison, the dead on shackling (DOS) values from this study must be considered. Mean DOS mortality (0.28%) remained lower than the Saskatchewan processor's annual DOA levels for 2000 and 2001, but was higher than DOA levels reported from the UK which ranged from 0.10% to 0.19% (Gregory and Austin, 1992; Warriss et al., 1992; Metheringham, 1996).

The broilers from these journeys were shackled within 165 to 310 min of arrival at the slaughtering facility and were among the first to be processed. Therefore, these journeys are representative of short holding periods at the plant. Due to the standardized loading time for farm sites regardless of distance from the plant, trailers not participating in the study would have had lairage periods extending beyond what were recorded. If the trial journeys are characteristic of DOA losses experienced for all trailers unloaded immediately into the live receiving area as opposed to the trailers held off-site, there is considerable potential to reduce bird losses through scheduling changes. The annual DOS losses for the Saskatchewan plant in 2000 and 2001 were approximately 0.5%. Scheduling catching times to coincide with when birds are required for slaughter could potentially save approximately 0.35% of the broilers that are processed annually. This research emphasizes the importance of short lairage periods under good environmental conditions. In fact, the Ministry of Agriculture, Fisheries and Food (MAFF) in the United Kingdom recommended birds are killed immediately upon arrival at the processing plant and that when it is required, lairage should not exceed two hours in length. Further investigation of the effects of extended lairage on DOS mortality under a variety of thermal conditions is necessary.

Although classified differently, the causes of DOA mortality are similar to those published by Bayliss and Hinton (1990) who found that stress and suffocation, catching and transportation, and pathological lesions were responsible for 40%, 35% and 25% of DOA mortality, respectively. In the present study, transportation stress was associated with 34% of DOAs. Catching trauma represented 29.6% of birds dying in transit and implied that more care during the catching process, especially when closing module drawers, would assist in reducing DOA mortality. Over 18% of DOA mortality was attributed to ascites, a chronic form of heart failure affected by bird management and barn conditions (Olkowski and Classen, 1997; Zuidhof et al., 1997). Similarly, cyanosis is linked to chronic heart failure (Olkowski et al., 1999) and was observed in 6% of DOA birds. Death associated with infectious disease would have been the result of processes initiated prior to transportation, as would all other causes of death in the farm-association category; however, the cumulative effects of transportation and its associated stressors could have caused death for birds predisposed to disease. Culling birds with farm associated disease conditions prior to shipping is not always possible because individual birds are difficult to single out in large commercial barns. Experienced catching crews will not load emaciated birds, but other disease conditions are too difficult to distinguish due to catching conditions, low light intensity and a lack of diagnostic ability.

In this study, ambient temperatures below -16°C significantly increased DOA and DOS levels. However, there was variability in DOA levels during cold weather transportation. A larger portion of ascitic birds and birds showing no visible lesions were identified in cold journey 3 suggesting that factors such as farm management and management of the trailer units on specific journeys can affect bird mortality. In fact, cold journey 3 was the only journey conducted with a stocking level of 26 birds per crate. This particular trip was performed when the mean ambient temperature was -20.7°C (Table 6.3) and it is possible that behavioural responses by the birds to the cold temperature were restricted due to their proximity to neighbouring birds (Nicol and Scott, 1990; Weeks and Webster, 1997). The two additional journeys performed when the ambient temperature was below -20°C had stocking densities of 24 birds per crate and reduced bird losses. Although these results implied the effect of load density on broiler mortality is related to ambient conditions, stocking density effects are also dependent on vent configuration of the trailer, bird size, travel distance and journey length (CARC, 2001). These mortality results also implied that cold ambient temperatures during broiler transportation do not necessarily translate to elevated death losses, as two of the three cold weather journeys had 0.15% DOAs.

Warriss et al. (1992) reported that with journeys in the UK lasting less than 4 h, DOA mortality was 0.16%, whereas journey lengths over 4 h showed an 80% increase in mortality (0.28%). The survey did not incorporate the time birds were held in lairage with journey length but did suggest that birds spent a substantial part of their journey on stationary vehicles. In comparison, Saskatchewan broiler transporters cover greater distances and are in motion for the entire journey length, with the exception of rest stops for the drivers. Although few journeys were performed in the shortest and longest categories of journey length, DOA mortality in this study was not affected by time in transit. Since the microenvironment of the transportation vehicles in transit remains relatively stable (Chapter 5), it appears likely that moderate transportation times should not have a major effect on death loss.

With respect to location of bird mortality on transport vehicles, Mitchell et al. (1997) proposed that a combination of cold air entering and moving over the birds, in conjunction with wetting caused by the introduction of road spray, likely lead to elevated mortality levels (36% of DOA birds) in the back-bottom module of the lorry used for transporting broilers in the United Kingdom. The latter half of the lorry contained 75% of the mortality, whereas 60% of the DOAs were located across the entire bottom tier of the modular stacks (Mitchell et al., 1997). This trend is likely related to the curtain configurations on the broiler carriers, as the curtains do not reach the floor of the trailer, leaving space for the ingress of water and road grit to occur.

In Saskatchewan, the open sided broiler transporters are covered with retractable solid curtains that are fastened to the floor with a bungee cord. However, the bungee cord is elastic in nature and the curtains are not attached to the tailboard or headboard of the trailer. Due to the pressure distribution along the trailer (Götz, 1987; Hoxey et al., 1996) and the unfastened curtains along the tailboard, the potential for moisture infiltration to happen simultaneously with air entry at high velocity exists at the back of the broiler carrier. During cold weather transportation, elevated levels of DOA birds might be expected in the three lower level modules at the back of the trailer due to this occurrence. This was not the case for the journeys monitored, as DOA birds were distributed throughout the trailer.

Although the focus of the mortality analysis was on birds dying in transit, adverse transport conditions could have affected birds dying during the lairage period. The trailers used in this study were immediately driven into the processor's live receiving area, which was equipped with a space heater. However, additional trailers not used in the study were parked away from the processing plant, until birds were required for slaughter. During mild weather, the trailers were parked outdoors with the curtains retracted and if the temperature climbed, the curtains were used as shades. Under winter conditions, the trailers were parked in a simple shed, which offered some protection from the elements, but had no heating or ventilation. In this study, birds sheltered immediately after cold weather transportation and held in a heated area prior to slaughter did not have high mortality levels. By altering the catching schedule to coincide with the processing shifts, the lairage period prior to processing could be shortened. Due to poorly ventilated lairage facilities, the thermal conditions can present additional strain on birds already exposed to transportation stressors (Quinn et al., 1998); therefore, a heated and well-ventilated holding area for birds awaiting processing would be beneficial.

Good bird condition prior to transportation is essential and is highly influenced by barn management. The barns visited in this study were well managed and contained birds in good condition; nonetheless, on-farm conditions can influence the impact that transportation-associated stressors have on birds. Atmospheric ammonia level is an indicator of barn management and is influenced by temperature, ventilation rate, humidity, stocking density and bird age, as well as litter type, age and pH. Typically, high ammonia is an indication of excess litter moisture, which can consequently compromise bird condition. The tendency for high ammonia concentrations to occur during cold ambient conditions likely reflects lower ventilation rates used during these periods to conserve heat inside the barns. Interestingly, the highest average and maximum ammonia levels (31 and 50 ppm, respectively) were not recorded during the trips conducted in the coldest ambient temperatures, but when the outdoor temperature was slightly warmer and between -15.9 to -6.0°C. Even when the ambient temperature was 7.2°C for a single journey, 30 ppm atmospheric ammonia was recorded in the barn prior to transportation.

It has been suggested that ammonia be maintained below 25 ppm such that the birds' respiratory systems, body weight and feed conversion is not compromised (MAFRI, 2002; Al Homidan et al., 2003). The American Conference of Governmental Industrial Hygienists has recommended for humans that the time weighted average exposure limit for ammonia be 25 ppm and the short term exposure limit be 35 ppm (CCOHS, 2005). In this study, several ammonia readings taken from inside the broiler barns exceeded these recommended limits for humans during an eight hour working shift, and to compound the circumstances, the birds remain in the barn environment until they are marketed. It can be argued that high ammonia levels are usually encountered only towards the end of the grow-out cycle and that the readings taken in this study may have been higher because the ventilation rate was reduced prior to loading. Because only one atmospheric ammonia measurement was taken from each production site, it is not indicative of the cumulative effects ammonia can have on bird welfare and productivity. Atmospheric ammonia in chicken barns can predispose birds to transportation stress and should be managed accordingly.

Although the broilers in this study were found to be clean and dry prior to loading, birds with existing disease will be more susceptible to transport stressors, as will damp birds, particularly in cold weather transportation. The litter was dry upon assessment, reflecting appropriate barn management for the production sites. Proper drinker management, and adequate barn heating and ventilation are on-farm factors that will ensure birds are loaded onto the trailer units in dry condition. Suitable barn and bird management will remove the barn environment prior to transportation as one of the immediate factors influencing transportation related broiler mortality

In summary, the procedure of catching broilers at the farm site, transporting them to the processing plant and storing the birds in lairage can all affect bird mortality. Consequently, it is important that the quality of management and the environment during the entire process be adequate to ensure satisfactory animal husbandry and product quality.

7.0 GENERAL CONCLUSIONS

Although the four initial journeys monitored in Saskatchewan were conducted in cold ambient conditions, temperature trends throughout the trailer were similar to those previously recorded on broiler carriers transporting birds in warmer ambient temperatures (Kettlewell et al., 1993). Thermal heterogeneity developed as the air moved from the back to the front of the trailer, creating cold spots in areas of air entry and thermal loads at the core of the trailers. Because the air inlets and outlets were not defined, the airflow distribution pattern on the trailers was complex.

In addition to temperature gradients established along the trailer, gradients also developed across the trailer. Observations of wet birds and frost accumulation on the crates and modules positioned near the curtains, in addition to reduced crate temperatures in the region, indicated that birds outside the trailer core were likely subject to a colder microenvironment and suggested that during cold weather transportation, conditions away from the trailer core may be drastically different.

Horizontal and vertical temperature and humidity gradients were monitored during additional broiler journeys conducted in Saskatchewan when ambient temperatures ranged from -27.2 to 21.9°C. Due to the effects of the lowered curtains, winter transportation of broilers in Saskatchewan presents a considerable challenge. On one hand, the birds must be protected from the freezing ambient temperature, but on the other hand, air exchange on the transport vehicle is required to prevent heat stress in the thermal core, for removal of moisture and heat being produced by the birds and for provision of adequate levels of oxygen. Therefore, air circulation is required to provide for minimum ventilation rates. Although roof vents can be used to control air exchange to some degree, passive airflow of this type is difficult to estimate because of the influence of factors such as vent and inlet location, truck speed, prevailing winds and bird stocking density. Similarly, air does not enter the trailer in a planned fashion, but basically enters in response to pressure differentials on the moving vehicle and available openings (Hoxey et al., 1996). There are no planned inlets; therefore, air enters primarily at the edges of the curtains (rear, bottom and front) as they are difficult to seal, through unintentional openings (poorly sealed front vents) or through roof vents. In the case of roof vents, entry is more likely to occur in vents near the back of the vehicle because of reduced exterior negative pressures on the trailer in this location (Hoxey et al., 1996; Götz, 1987). Modules containing broilers block airflow and thereby influence the degree of ventilation that occurs in various sections of the trailer. The above factors create a complex thermal environment and a heterogeneous temperature distribution resulting from cold areas near air inlets and poorly ventilated warm areas. In contrast, during warm weather transportation, passively ventilated transport trailers provide acceptable on-board thermal conditions, provided that the vehicle remained in motion.

AET zone classifications showed the highest proportion of crates with potentially dangerous (PD) temperature-humidity combinations (61.0%) at ambient temperatures less than -16.0°C due to cold air penetration along the floor and back end of the trailer, However, it is unlikely that such a high percentage of birds on the trailer were exposed to a potentially dangerous thermal environment. Because data loggers were clipped to the outside edges of the exterior crates within a row of crates being monitored, the recorded data may pertain to only two or three birds in closest vicinity to the loggers.

Transportation when ambient temperatures were above 6°C was least stressful for the birds. However, caution should be taken as ambient temperatures exceed 16°C due to the increased proportion of crates in the alert zone. Opening the front and rear trailer vents resulted in slightly cooler and more homogeneous temperatures, which would be advantageous during hot weather. High ambient temperatures during transportation may be hazardous when the broiler carriers are stationary, as the heat and moisture produced by the birds is not effectively dissipated, thereby creating the potential for dangerously high crate temperature and humidity combinations to develop.

Recommendations to improve the trailer conditions for the broilers during cold weather transportation included monitoring bungee cord condition, ensuring the headboard and tailboard vents are in good condition and properly sealed, drying the trailer equipment after washing, shortening trucker rest stops during the transit period, and installing real-time temperature sensors in problem areas of the trailer for monitoring purposes. Limiting rest periods during the transportation period and opening headboard and tailboard vents to reduce the maximum temperature lift were suggested improvements for warm weather transportation. Lairage facilities capable of providing adequate air circulation at bird level while broilers await processing would also be beneficial.

A differentiation was drawn between birds dying in transit and total mortality loss, including birds dying during the lairage period. Mean dead on arrival (DOA) and dead on shackling (DOS) mortality was 0.14% and 0.28%, respectively, which was markedly lower mortality than the Saskatchewan processor's annual bird losses for 2000 and 2001. Although the broilers in this study were well managed and found to be clean and dry prior to loading, birds exposed to poor barn conditions will be more susceptible to transport stressors. Appropriate barn and bird management will remove the barn environment prior to transportation as one of the immediate factors influencing transportation related broiler mortality.

In conclusion, the poultry industry relies on transporting birds from the production site to a processing facility and faces a considerable challenge when transporting broilers to market. As indicated by the AET values tabulated in this study, Saskatchewan birds sent to market are subject to thermal stress in transit, whether it be heat stress or cold stress. In conjunction with the temperature, humidity in the trailer compromises the on-board environment by lowering the effective temperature during cold weather journeys and increasing the effective temperature when transporting broilers in warm weather. Data gathered by loggers on the outside edge of the load was useful and meaningful, but suggested additional broiler transportation research should concentrate on a more accurate reflection of the temperature-humidity status of the micro-environment around birds situated throughout the trailer. Overall, the Saskatchewan poultry industry is doing a reasonable job of transporting birds while operating under a variety of ambient conditions with a broiler transport system that allows little control besides the adjustment of trailer curtains and vents located on the roof, headboard and tailboard of the trailer.

Subsequent to this research, the Lilydale processing plant in Wynyard, Saskatchewan, has made several changes to their live-haul practices. The simple live haul shed adjacent to the shackling line where the trailers proceeded after transportation was replaced with a larger building and equipped with ventilation controls. Additionally, the loading times have been scheduled to coincide with processing so that birds are not held in lairage for extended periods. Consequently, broiler mortality has diminished (Bartoshewski, personal communication).

7.1 FUTURE RESEARCH

Fine-tuning the broiler transportation system currently used in Saskatchewan would be most feasible. New methods of securing the trailer curtains to the floor, particularly for extremely cold weather, should be investigated. With the curtains lowered, open roof vent area affected mean temperature lift; hence, developing a reference chart that could be used by live haul drivers that suggests the amount of open vent area appropriate for a range of cooler ambient temperatures would be a useful tool. Further investigations should be conducted to determine the effects of outfitting the passively ventilated broiler trailers with small vents distributed along the roof.

In addition, a comprehensive investigation of the temperature gradients that develop across the trailer during transportation is required. Data gathered by loggers on the outside edge of the load was useful and meaningful, but suggested additional broiler transportation research should concentrate on a more accurate reflection of the temperature-humidity status of the micro-environment around birds situated throughout the trailer. Under very cold conditions in Saskatchewan, points of air entry should not allow air to flow directly onto the birds. The possibility of equipping the trailer with an air mixing chamber capable of heating incoming air prior to bird exposure would benefit bird welfare, but may not prove to be economically feasible.

The United Kingdom has developed a mechanically ventilated trailer for transporting poultry to slaughtering facilities (SRI News, 1999; Kettlewell and Mitchell, 2001). The modified trailer houses an on-board generator that powers extraction fans controlled by a computer. The computer monitors the micro-environment of the trailer such that transport conditions are within the thermal comfort zone of the birds (Kettlewell and Mitchell, 2001).

Research further investigating the characteristics of the passively ventilated broiler trailers used in Saskatchewan has already begun. Agriculture and Bio-resource engineer, Dr. Trever Crowe, has received funding from the Natural Sciences and Engineering Research Council (NSERC) to extend the engineering components of this study and to investigate the possibility of renovating the current transportation trailers used in Saskatchewan with force-ventilation equipment.

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APPENDIX A

TABLE A1. Rectal temperatures (°C) from broilers located in crate 5 of modules A, F, U and Z from journey 1

		A5			F5			U5			Z5	
Bird	T1[1]	T2[2]	ΔT[3]	T1	T2	ΔT	T1	T2	ΔT	T1	T2	ΔT
1	40.5	40.7	0.2	40.1	41.4	1.3	40.7	40.7	0.0	40.5	40.1	-0.4
2	40.4	40.1	-0.3	40.4	40.5	0.1	40.5	41.4	0.9	40.7	40.8	0.1
3	40.3	40.4	0.1	40.3	41.1	0.8	40.8	40.8	0.0	40.4	41.2	0.8
4	40.4	40.8	0.4	40.5	40.8	0.3	40.5	40.8	0.3	40.7	40.3	-0.4
5	40.3	40.5	0.2	40.1	40.3	0.2	40.8	40.7	-0.1	40.7	40.8	0.1
6	40.3	40.7	0.4	40.9	41.3	0.4	40.0	40.7	0.7	40.4	41.1	0.7
7	40.4	40.7	0.3	40.4	41.3	0.9	40.8	40.9	0.1	39.9	39.7	-0.2
8	40.5	40.9	0.4	40.8	40.9	0.1	40.5	40.3	-0.2	40.9	41.3	0.4
Mean	40.4	40.6	0.2	40.4	41.0	0.5	40.6	40.8	0.2	40.5	40.7	0.1
SD	0.1	0.3	0.2	0.3	0.4	0.4	0.3	0.3	0.4	0.3	0.6	0.5

[1]T1 = Rectal temperature prior to transportation.
[2]T2 = Rectal temperature after transportation.
[3]ΔT = Change in rectal temperature.

TABLE A2. Rectal temperatures (°C) from broilers located in crate 1 or 2 of modules C, I, K and Q from journey 2

		C2			I1			K2			Q2	
Bird	T1[1]	T2[2]	ΔT[3]	T1	T2	ΔT	T1	T2	ΔT	T1	T2	ΔT
1	40.8	40.4	-0.4	40.9	40.1	-0.8	40.8	40.8	0.0	40.3	40.9	0.6
2	40.7	41.1	0.4	40.5	40.0	-0.5	41.1	40.9	-0.2	40.5	41.1	0.6
3	40.5	40.7	0.2	40.3	40.3	0.0	41.4	40.7	-0.7	40.9	40.9	0.0
4	40.3	40.8	0.5	40.4	39.9	-0.5	40.5	40.7	0.2	40.9	41.2	0.3
5	40.3	40.5	0.2	40.8	41.1	0.3	41.7	40.8	-0.9	40.9	41.1	0.2
6	40.1	40.0	-0.1	39.8	39.7	-0.1	41.3	40.8	-0.5	41.1	40.8	-0.3
7	40.9	40.9	0.0	40.4	40.8	0.4	40.9	40.8	-0.1	40.3	40.1	-0.2
8	41.1	40.7	-0.4	40.0	40.0	0.0	40.7	40.3	-0.4	40.1	40.7	0.6
Mean	40.6	40.6	0.0	40.4	40.2	-0.2	41.1	40.7	-0.3	40.6	40.9	0.2
SD	0.3	0.3	0.3	0.4	0.5	0.4	0.4	0.2	0.4	0.4	0.3	0.4

[1]T1 = Rectal temperature prior to transportation.
[2]T2 = Rectal temperature after transportation.
[3]ΔT = Change in rectal temperature.

TABLE A3. Rectal temperatures (°C) from broilers located in crate 2 of modules D, H, I and Q from journey 3

		D2			H2			I2			Q2	
Bird	T1[1]	T2[2]	ΔT[3]	T1	T2	ΔT	T1	T2	ΔT	T1	T2	ΔT
1	39.8	40.4	0.6	40.0	39.0	-1.0	40.4	39.9	-0.5	39.9	39.9	0.0
2	40.0	40.5	0.5	40.1	39.5	-0.6	40.0	39.8	-0.2	40.5	40.5	0.0
3	40.0	39.9	-0.1	39.8	39.1	-0.7	40.3	39.2	-1.1	40.5	40.4	-0.1
4	40.1	40.3	0.2	38.4	33.1	-5.3	39.8	38.3	-1.5	40.1	40.7	0.6
5	40.3	40.4	0.1	40.1	39.8	-0.3	39.9	39.2	-0.7	40.1	40.3	0.2
6	40.0	40.5	0.5	40.1	39.6	-0.5	39.9	38.5	-1.4	40.3	40.5	0.2
7	39.6	40.1	0.5	39.8	39.4	-0.4	40.1	39.9	-0.2	39.9	40.8	0.9
8	40.1	40.4	0.3	40.4	40.3	-0.1	40.0	38.3	-1.7	40.5	40.8	0.3
Mean	40.0	40.3	0.3	39.8	38.7	-1.1	40.1	39.1	-0.9	40.2	40.5	0.3
SD	0.2	0.2	0.2	0.6	2.3	1.7	0.2	0.7	0.6	0.3	0.3	0.3

[1]T1 = Rectal temperature prior to transportation.
[2]T2 = Rectal temperature after transportation.
[3]ΔT = Change in rectal temperature.

TABLE A4. Rectal temperatures (°C) from broilers located in crate 2 of modules A, D, I and Q from journey 4

		A2			D2			I2			Q2	
Bird	T1[1]	T2[2]	ΔT[3]	T1	T2	ΔT	T1	T2	ΔT	T1	T2	ΔT
1	40.7	39.7	-1.0	39.8	39.7	-0.1	40.1	40.0	-0.1	39.7	38.8	-0.9
2	40.5	39.9	-0.6	40.9	40.4	-0.5	39.9	39.4	-0.5	40.1	39.5	-0.6
3	40.7	39.9	-0.8	40.1	40.1	0.0	39.8	37.6	-2.2	40.1	39.4	-0.7
4	40.1	40.0	-0.1	39.9	40.1	0.2	40.7	39.6	-1.1	40.8	39.9	-0.9
5	40.3	40.3	0.0	40.0	39.7	-0.3	40.5	39.9	-0.6	40.1	39.1	-1.0
6	40.1	40.0	-0.1	40.1	39.7	-0.4	39.8	38.1	-1.7	40.4	38.8	-1.6
7	41.1	40.9	-0.2	40.0	39.8	-0.2	40.1	39.6	-0.5	40.3	39.6	-0.7
8	39.9	40.3	0.4	40.3	40.0	-0.3	40.0	39.1	-0.9	40.9	40.4	-0.5
Mean	40.4	40.1	-0.3	40.1	39.9	-0.2	40.1	39.2	-1.0	40.3	39.4	-0.9
SD	0.4	0.4	0.5	0.3	0.3	0.2	0.3	0.9	0.7	0.4	0.5	0.3

[1]T1 = Rectal temperature prior to transportation.
[2]T2 = Rectal temperature after transportation.
[3]ΔT = Change in rectal temperature.

APPENDIX B

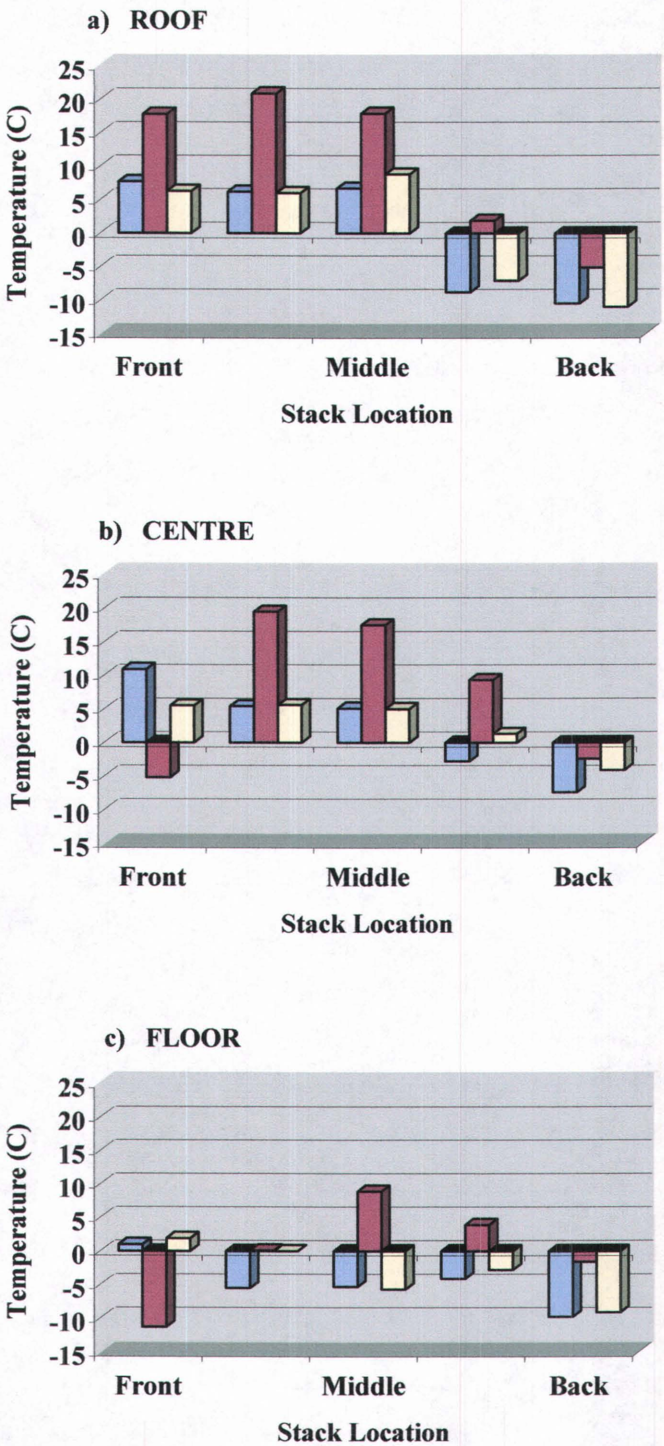


Figure B1. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was below -16.0 C, both tarps were lowered, front and rear vents were closed, and roof vents 1 and 5 were open (n = 2; Ta = -20.7, -20.6 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

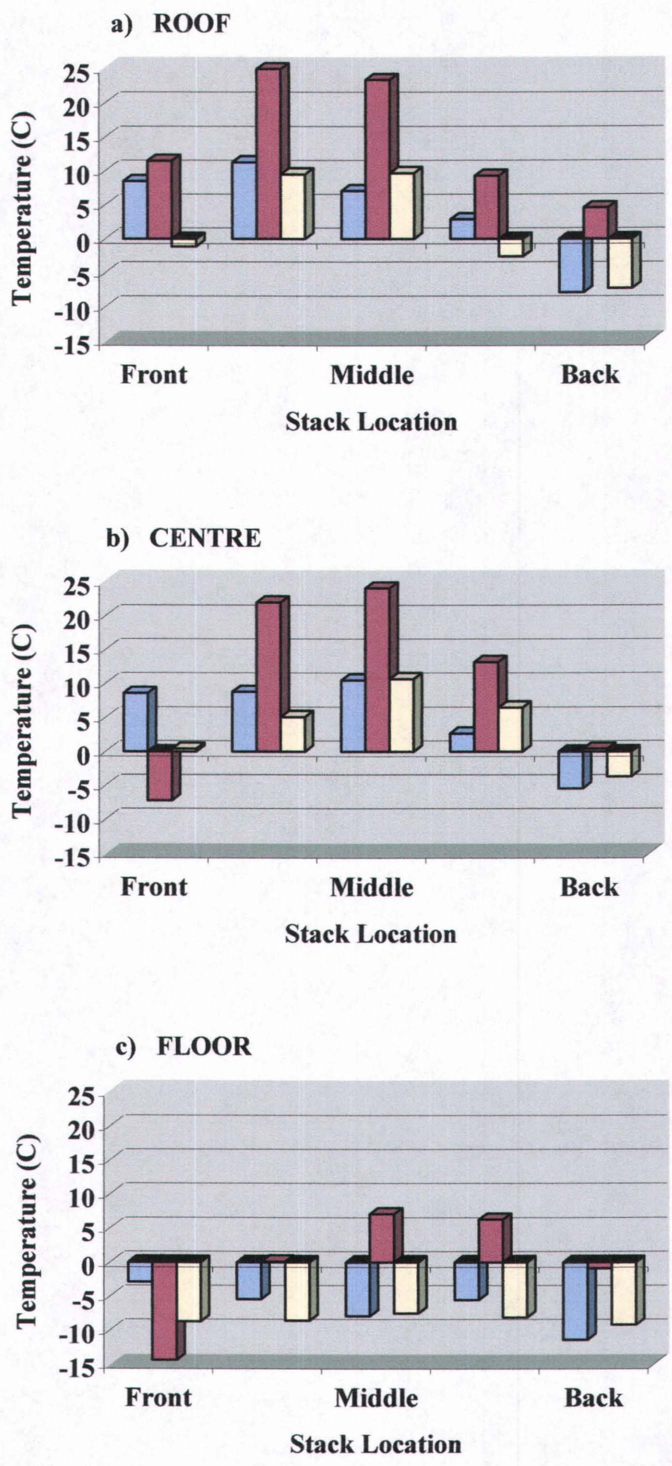


Figure B2. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was below -16.0 C, both tarps were lowered, front and rear vents were closed, and roof vent 1 was open (n = 2; Ta = -20.7, -20.6 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

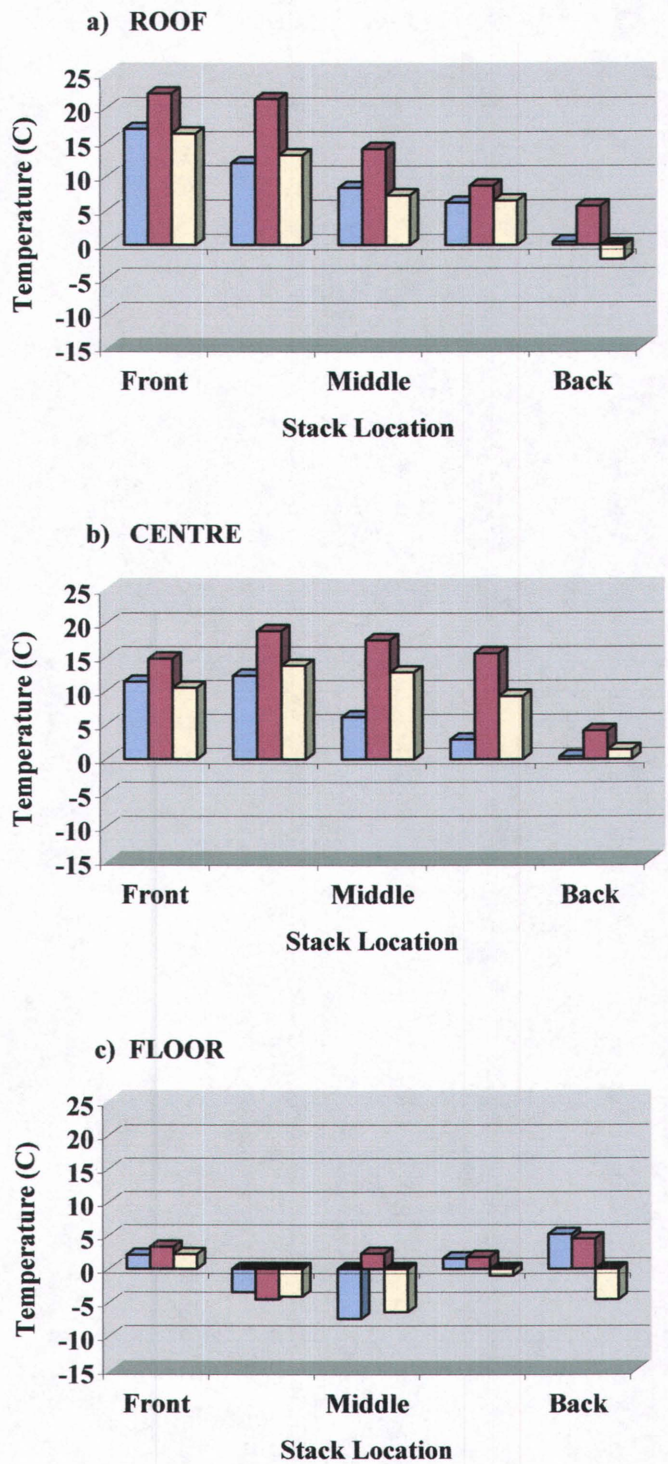


Figure B3. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was below -16.0 C, both tarps were lowered, front and rear vents were closed, and only the back half of roof vent 5 was open (n = 1, Ta = -27.2 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

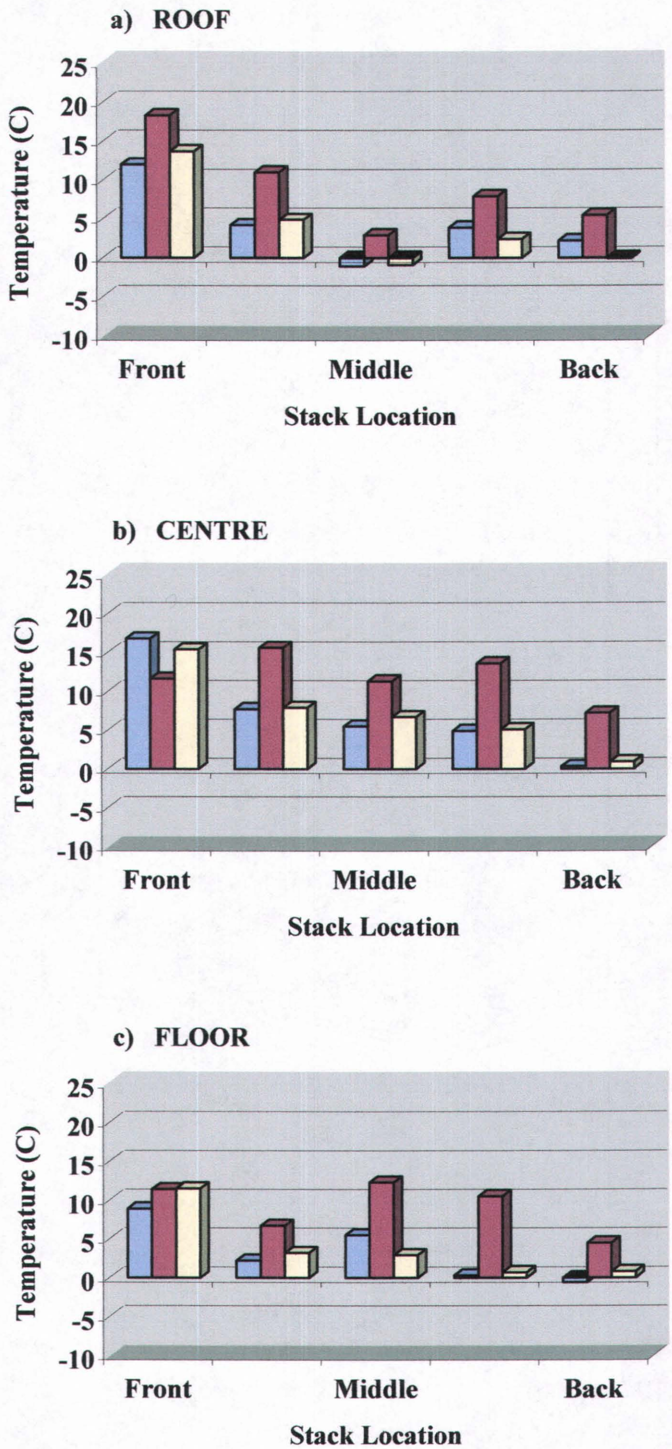


Figure B4. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was -15.9 to -6.0 C, both tarps were lowered, front and rear vents were closed, and all roof vents (1-8) were open (n = 2; Ta = -10.5, -6.6 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

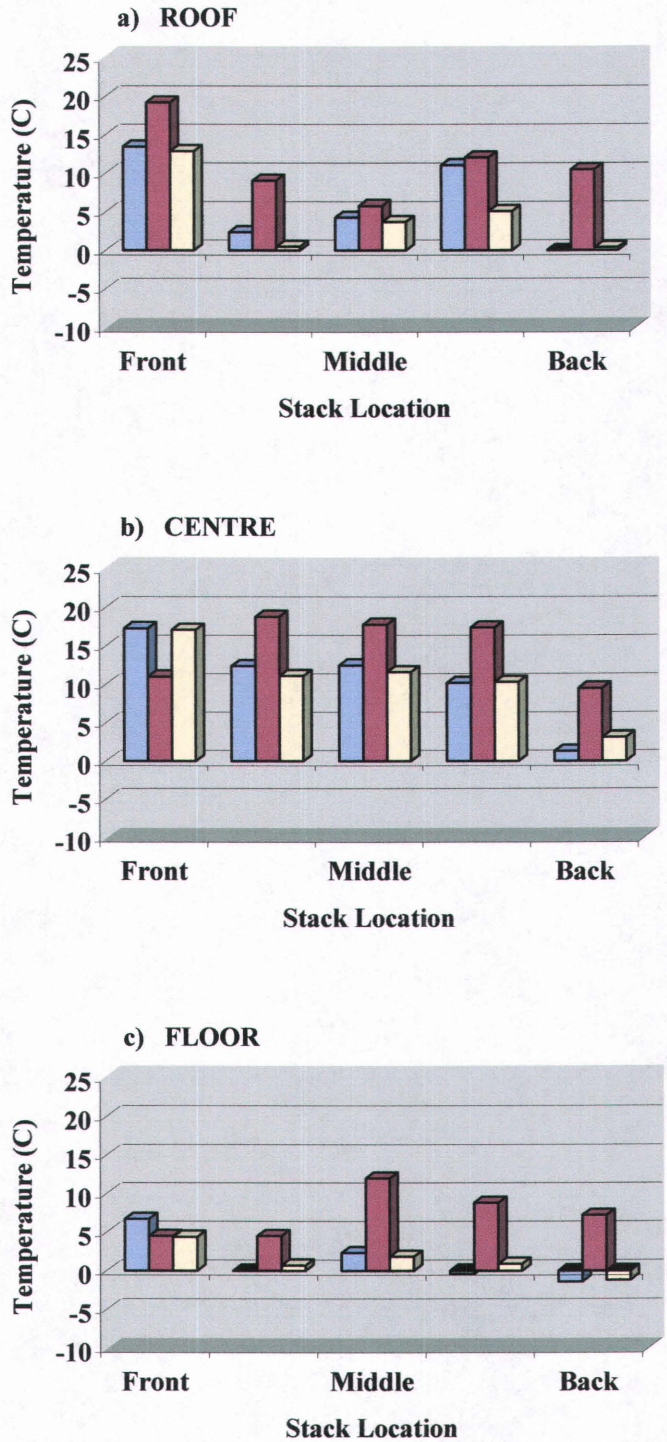


Figure B5. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was -15.9 to -6.0 C, both tarps were lowered, front and rear vents were closed, and roof vents 1 and 2 were open (n = 4; Ta = -12.7, -10.5, -9.7, -9.1 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

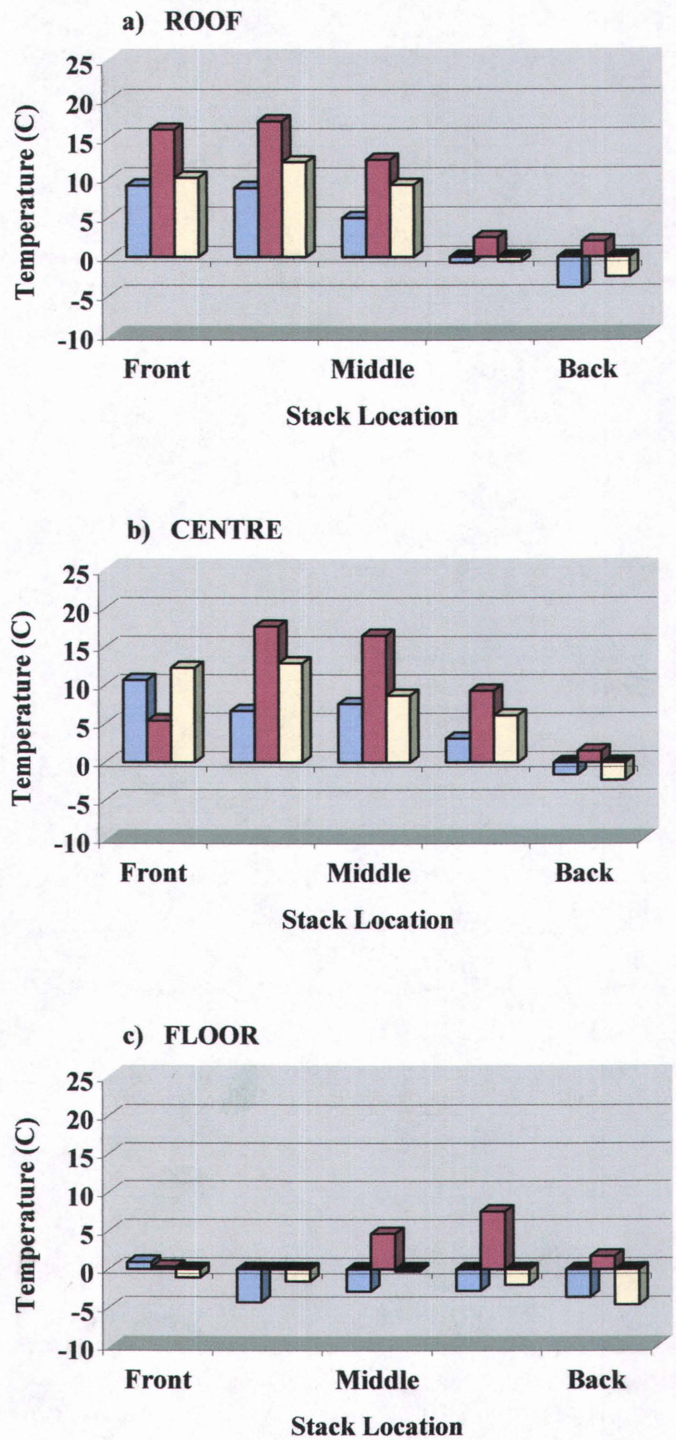


Figure B6. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was -15.9 to -6.0 C, both tarps were lowered, front and rear vents were closed and roof vents 1, 5, and 8 were open (n = 1; Ta = -12.9 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

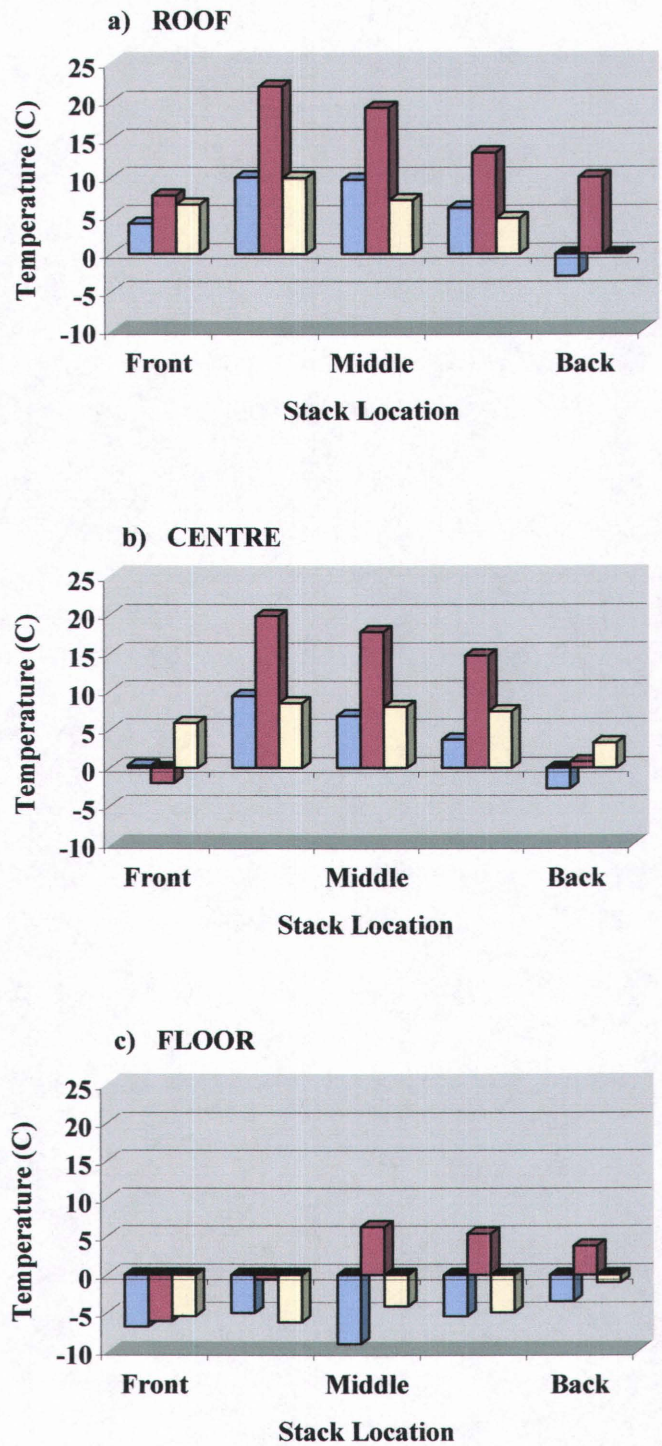


Figure B7. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was -15.9 to -6.0 C, both tarps were lowered, front and rear vents were closed and roof vent 1 was open (n = 1; Ta = -12.9 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

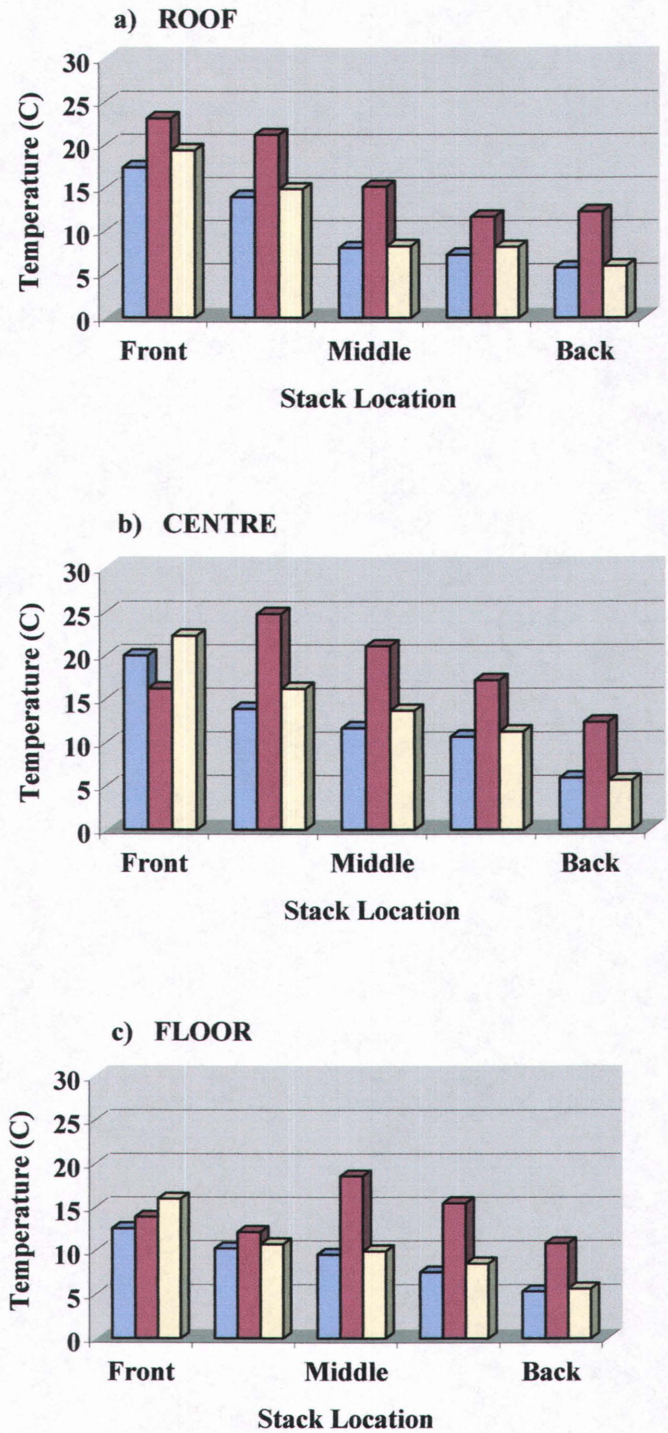


Figure B8. Crate temperature recorded in different stack locations from journeys completed when ambient temperature ranged from -5.9 to +5.9 C, both tarps were lowered, front and rear vents were closed and all roof vents (1-8) were open (n = 7; Ta = -5.8, -5.0, -0.9, -0.1, 2.8, 2.8, 2.9 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer

Driver Middle Passenger

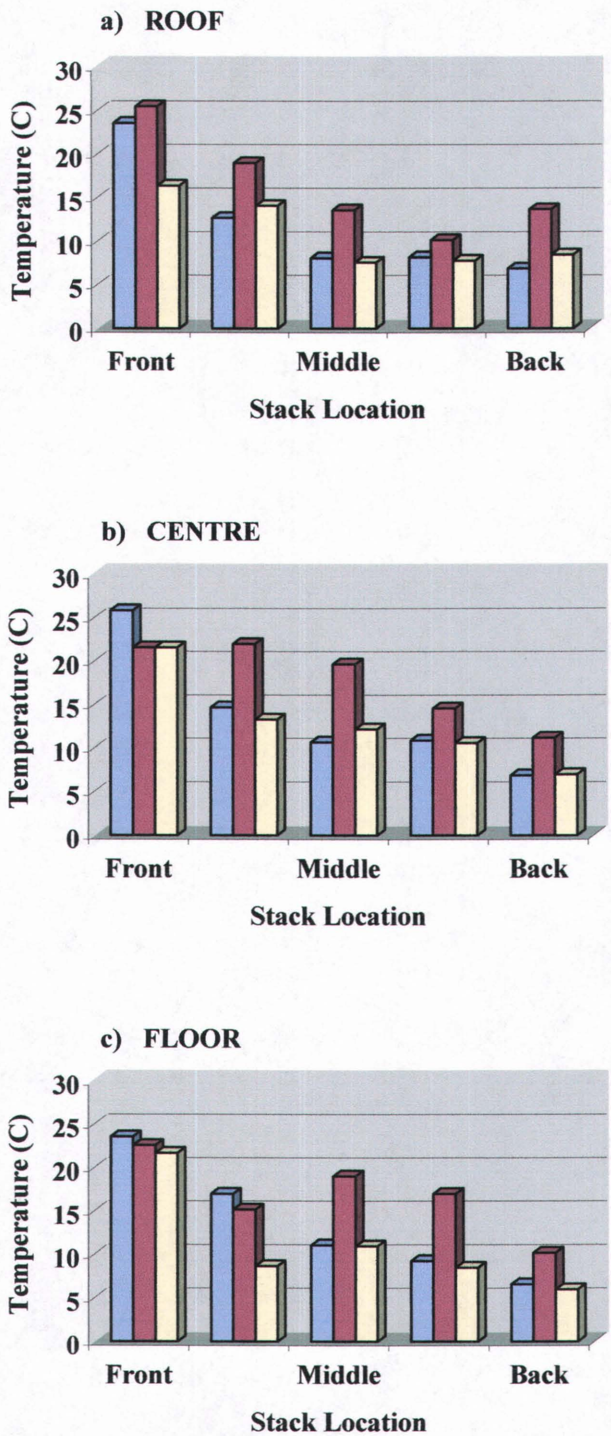


Figure B9. Crate temperature recorded in different stack locations from journeys completed when ambient temperature ranged from -5.9 to +5.9 C, both tarps were lowered, front and rear vents were closed and roof vents 1 to 6 were open (n = 2; Ta = 2.8, 2.8 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

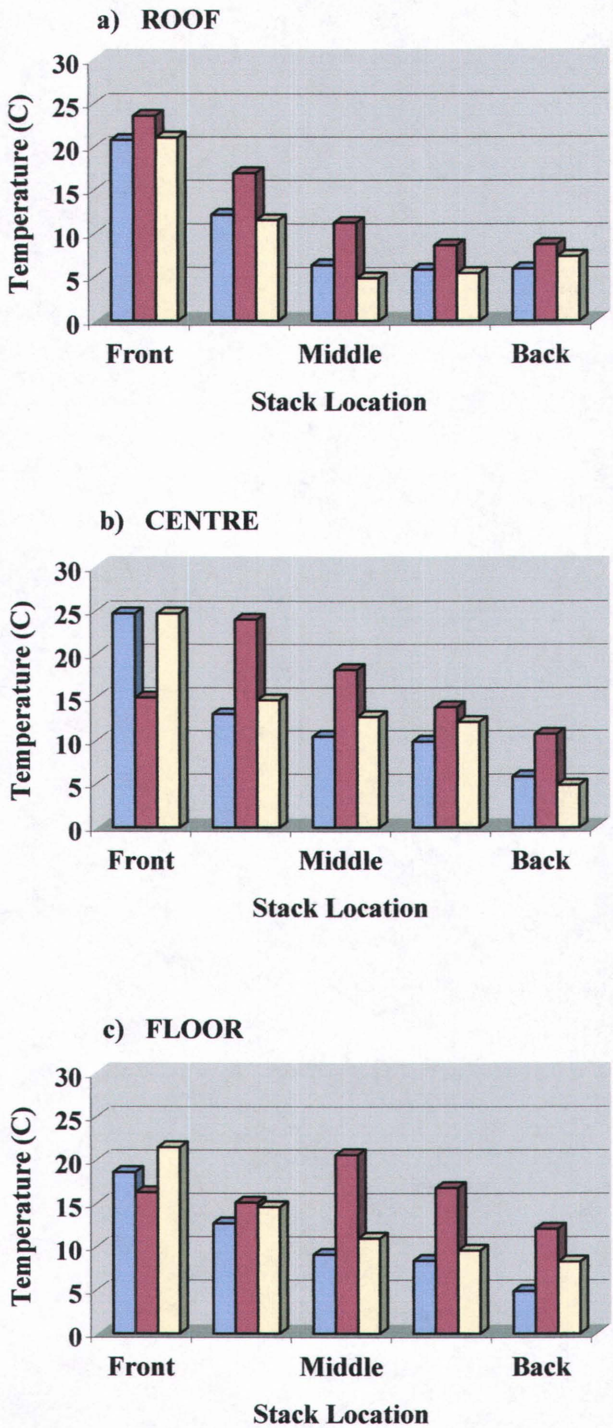


Figure B10. Crate temperature recorded in different stack locations from journeys completed when ambient temperature ranged from -5.9 to +5.9 C, both tarps were lowered, front and rear vents were closed and roof vents 1 to 4 were open (n = 2; Ta = -0.9, 2.9 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

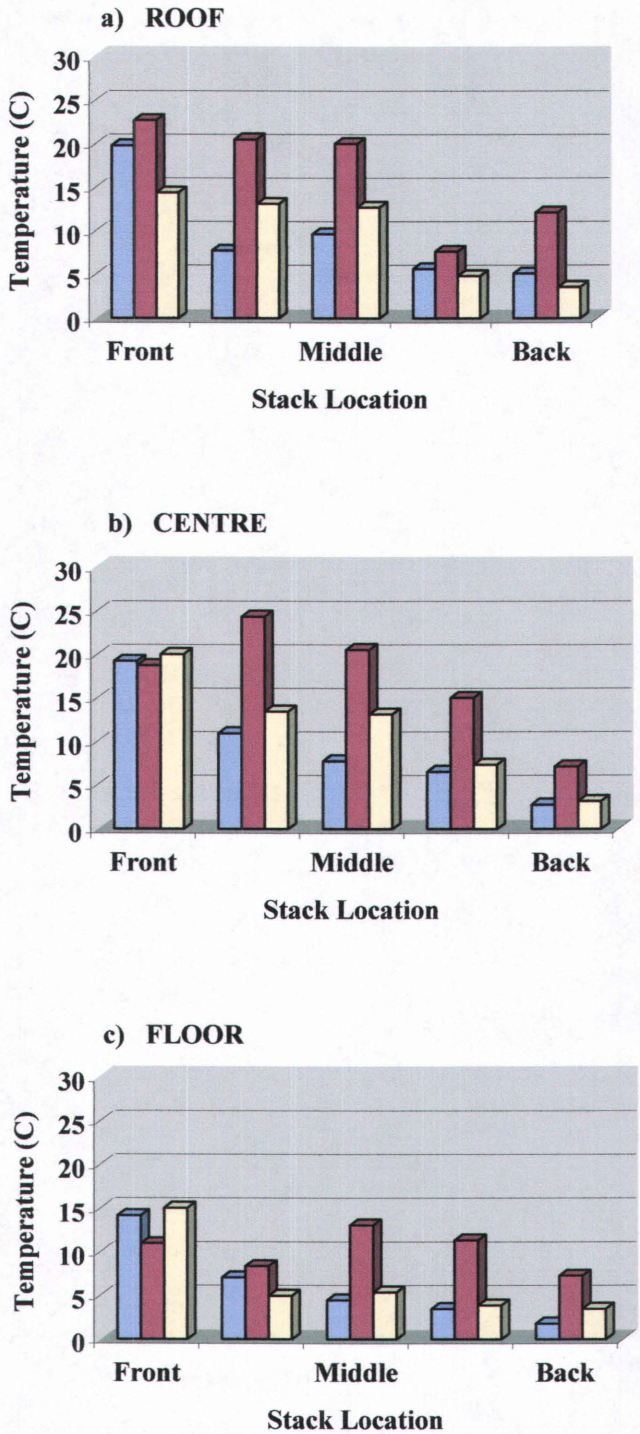


Figure B11. Crate temperature recorded in different stack locations from journeys completed when ambient temperature ranged from -5.9 to +5.9 C, both tarps were lowered, front and rear vents were closed and roof vents 1, 2, 5 and 6 were open (n = 2; Ta = -5.8, -0.1 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

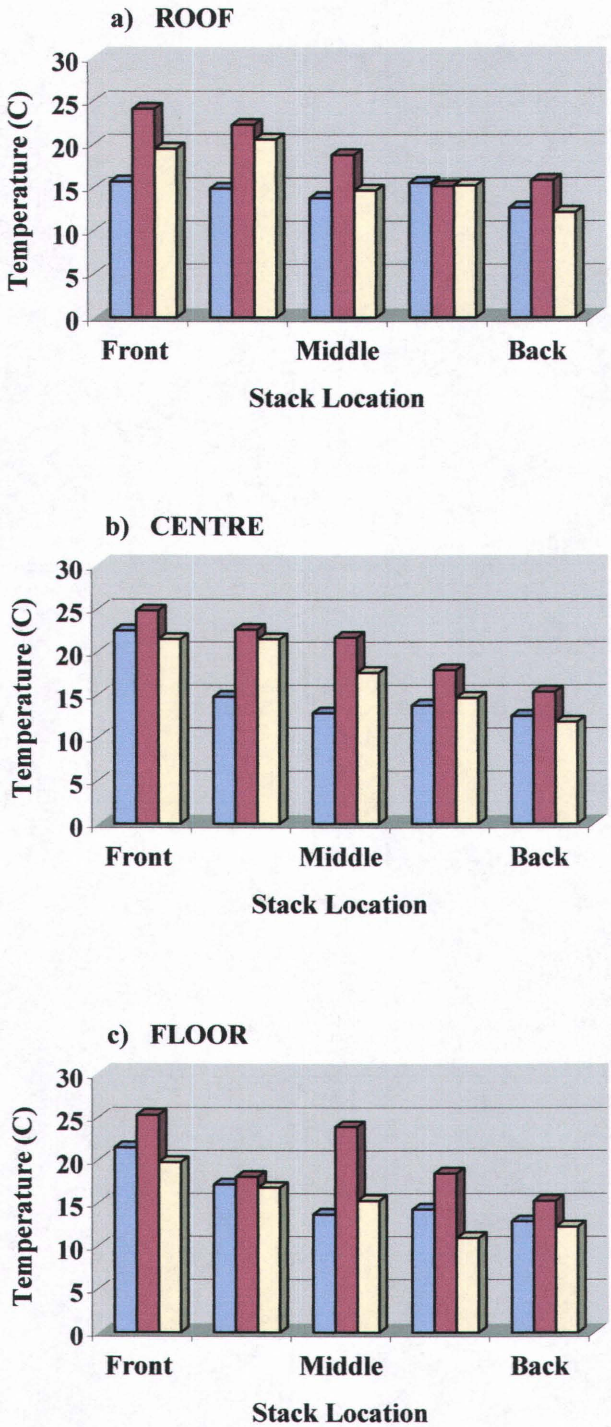


Figure B12. Crate temperature recorded in different stack locations from journeys completed when ambient temperature ranged from 6.0 to 15.9 C, front and rear vents were closed, all roof vents were open and both curtains were lowered (n = 1; Ta = 7.9 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

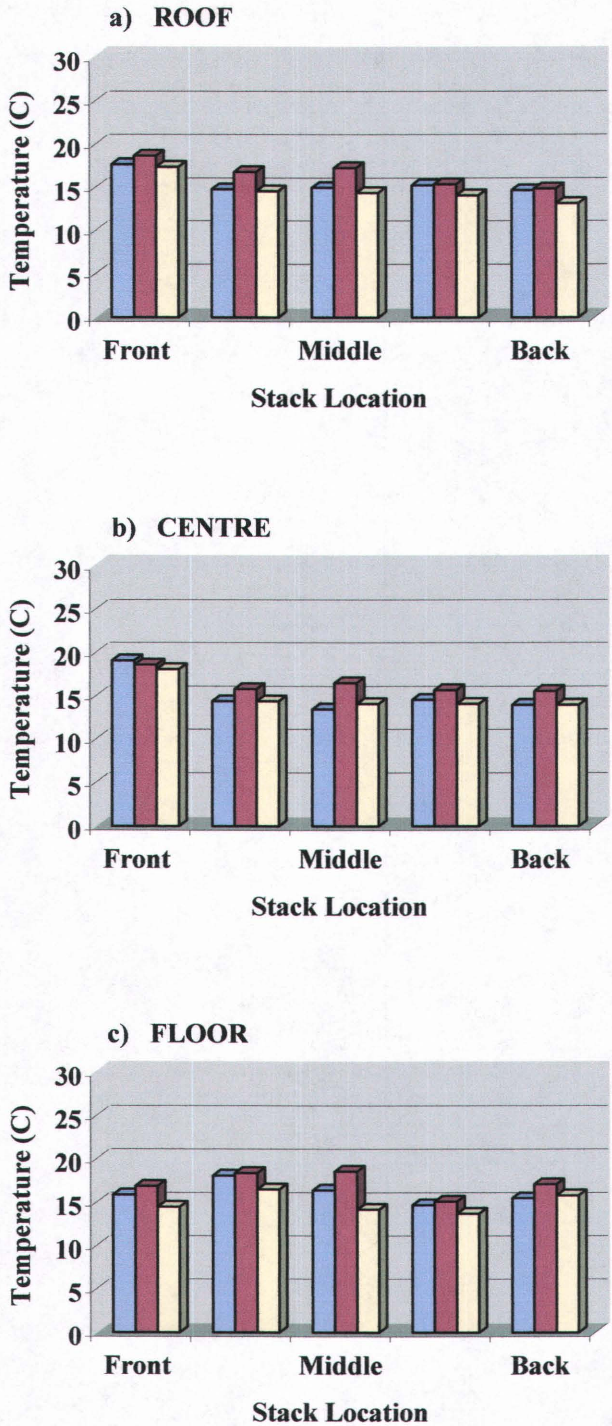


Figure B13. Crate temperature recorded in different stack locations from journeys completed when ambient temperature ranged from 6.0 to 15.9 C, front and rear vents were closed, all roof vents were open and both curtains were raised (n = 4; Ta = 7.2, 12.4, 12.8, 13.5 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

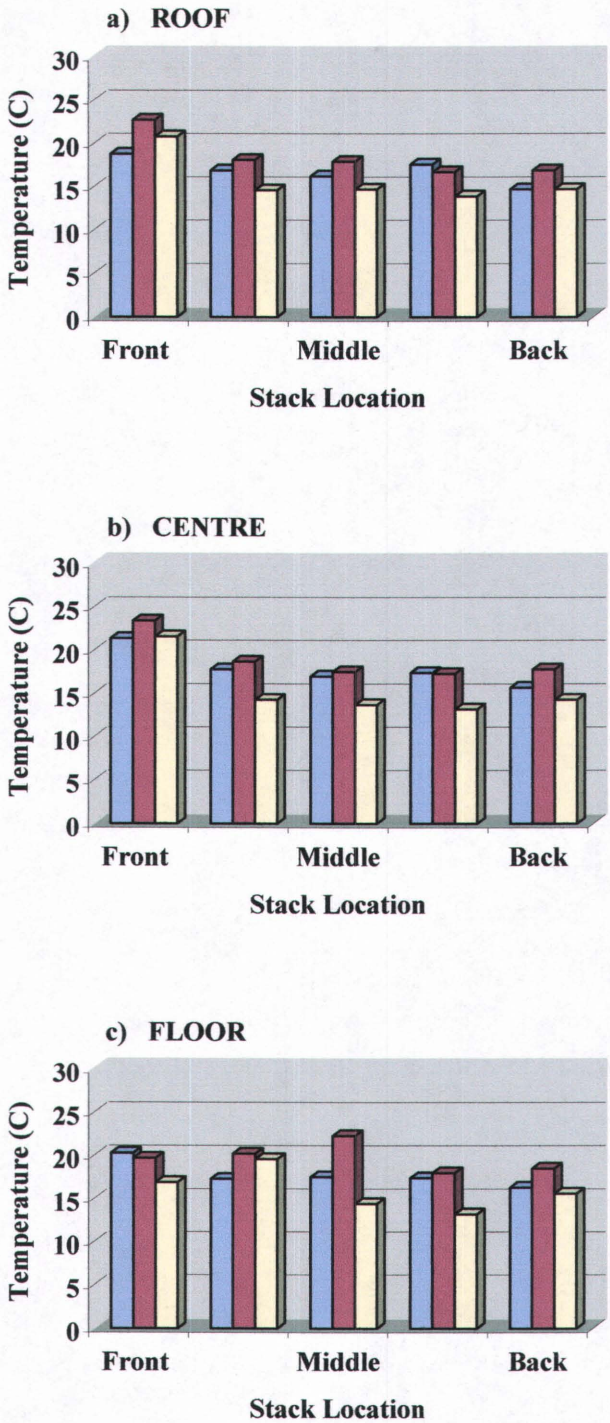


Figure B14. Crate temperature recorded in different stack locations from journeys completed when ambient temperature ranged from 6.0 to 15.9 C, front & rear vents were closed, all roof vents were open, the driver side curtain was down & the passenger side curtain was up (n = 2; Ta = 7.2, 13.5 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

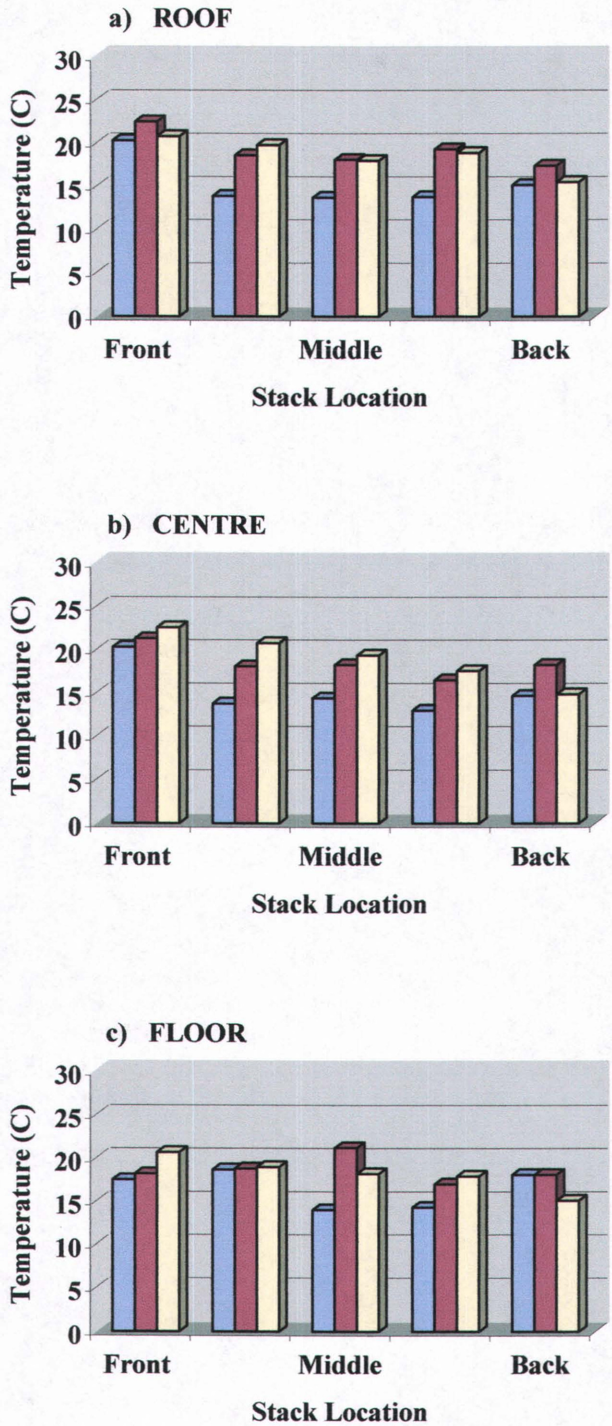


Figure B15. Crate temperature recorded in different stack locations from journeys completed when ambient temperature ranged from 6.0 to 15.9 C, front & rear vents were closed, all roof vents were open, the driver side curtain was up & the passenger side curtain was down (n = 3; Ta = 7.9, 11.8, 12.4 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver　Middle　Passenger

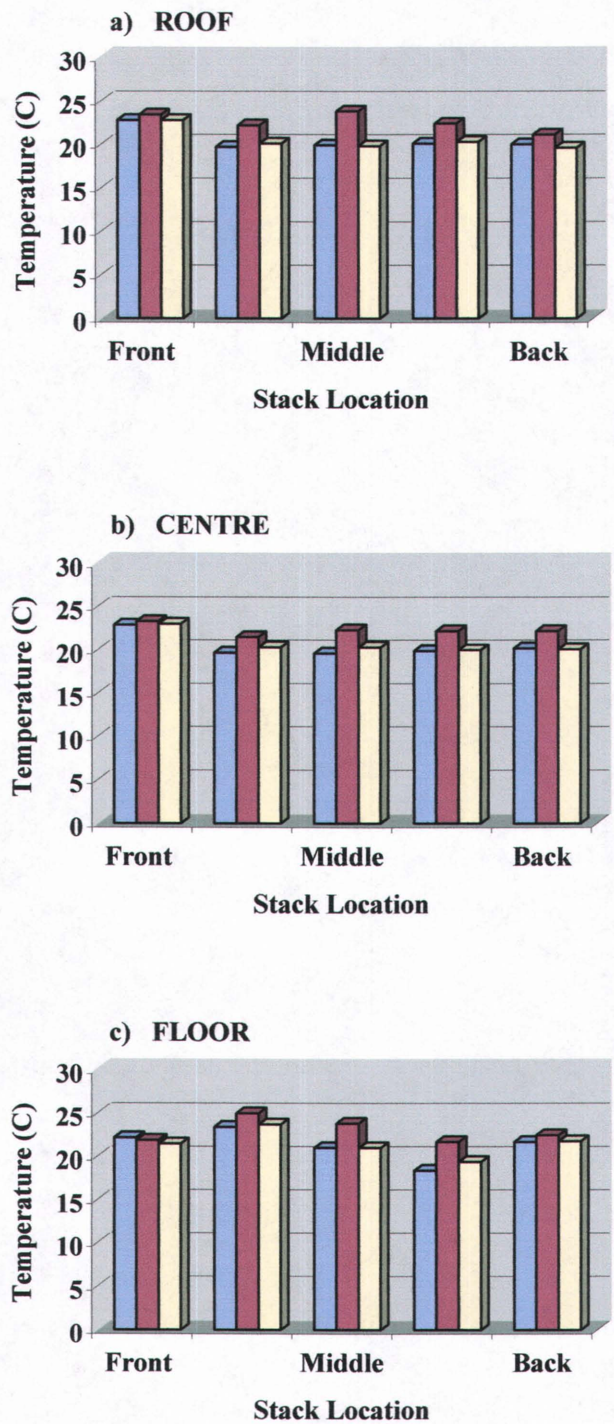
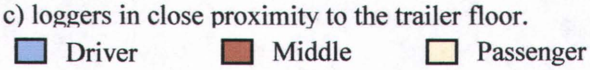


Figure B16. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was above 16.0 C, all roof vents were open, both curtains were raised and the front and rear vents were closed (n = 3; Ta = 17.5, 17.7, 21.9 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.



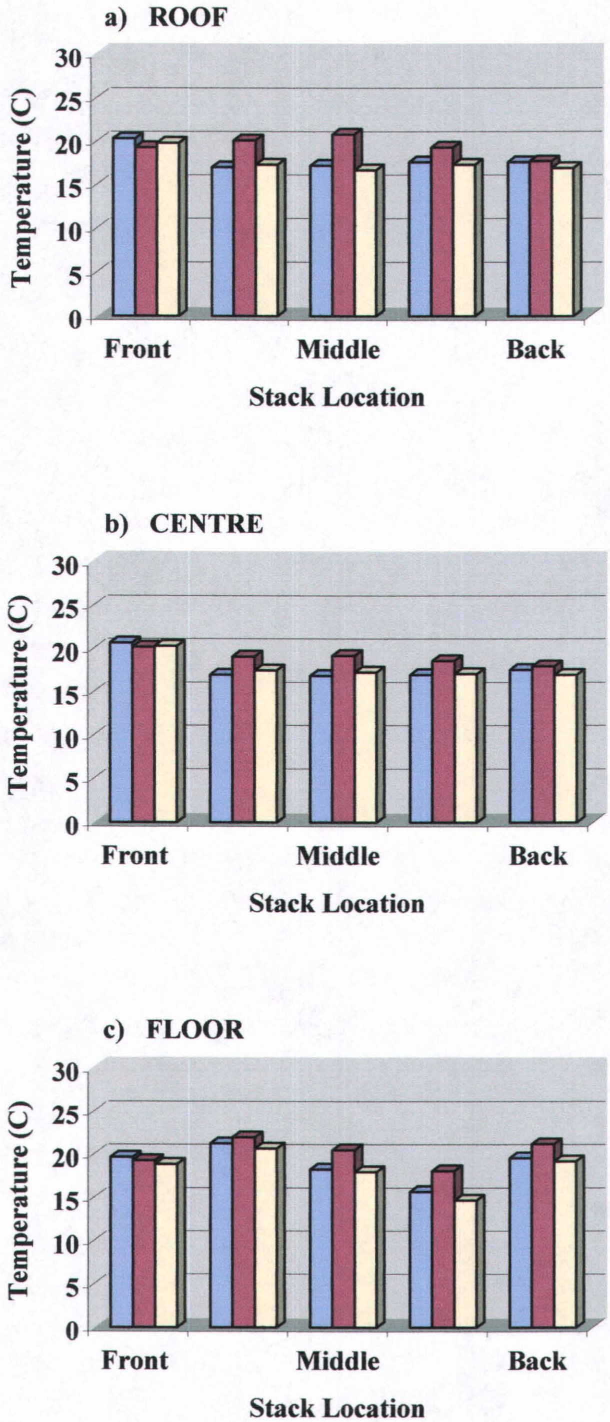


Figure B17. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was above 16.0 C, all roof vents were open, both curtains were raised and front and rear vents were open (n = 2; Ta = 17.7, 21.9 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer floor.

Driver Middle Passenger

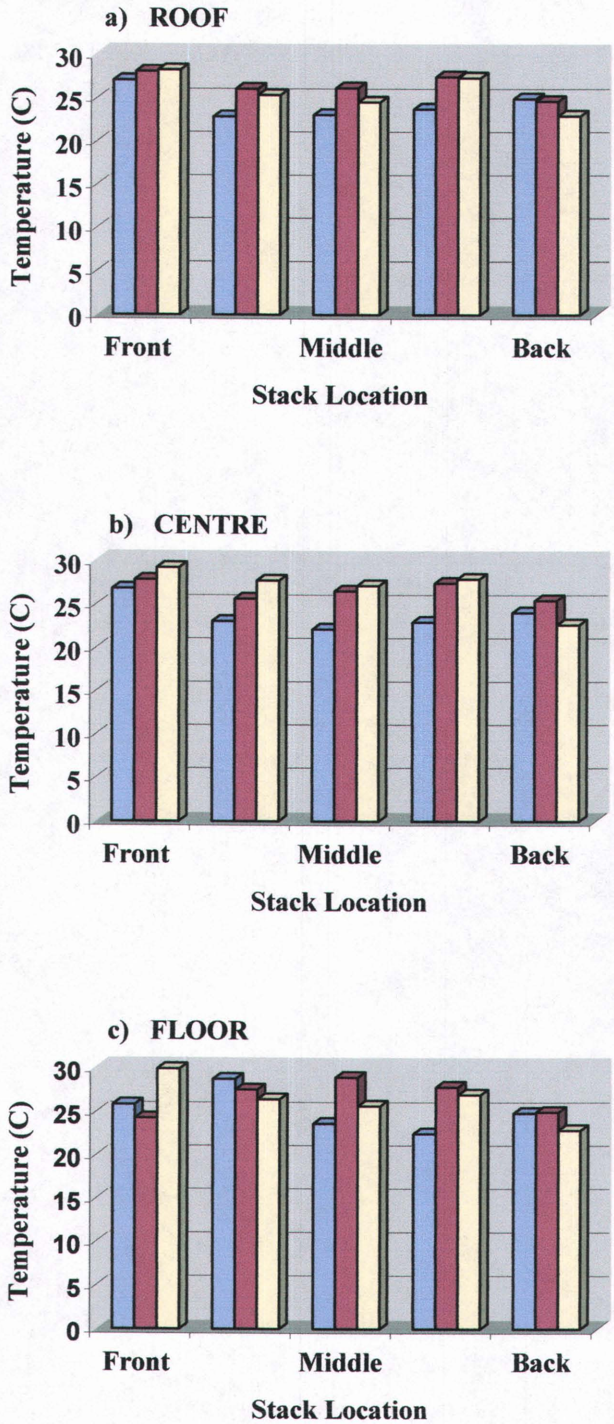


Figure B18. Crate temperature recorded in different stack locations from journeys completed when ambient temperature was above 16.0 C, all roof vents were open, front & rear vents were closed, the driver side curtain was raised & the passenger side curtain was lowered (n = 1; Ta = 17.5 C). a) loggers placed nearest the roof; b) loggers in the centre of the stack; c) loggers in close proximity to the trailer

Driver Middle Passenger