Characterization of the Thermal Environment during Transport of Commercial Broiler Chickens

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Characterization of the Thermal Environment during Transport of Commercial Broiler Chickens

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Abstract

Transport of commercial broiler chickens from the farm to the processing plant is perceived to compromise welfare under some circumstances. Research has been conducted using European standard equipment to characterize the environment experienced by poultry during broiler transport. In contrast no studies have been reported on the environment experienced by broilers under United States standard industry practices during transport. Moreover, microenvironment temperatures within industry trailers have not been reported.

The present study characterized the thermal micro-environment experienced by broiler chickens during transport across different seasons. The temperatures were influenced by temperature mitigation practices (plastic wrap, double side board, single side board, open side, and heat mitigation) and by ambient temperatures. Temperatures measured within transporters were found to have less variation compared to studies using other transport systems. Temperatures were found to decrease ($p=0.05$) for the second half of transport duration during low ambient conditions (-16.4 to 2.80 ^{0}C). For moderate ambient conditions (6.22 to 23.35 ^{0}C) significant ($p=0.05$) yet small (<2^{o}C) changes in temperature were seen. For transport within high ambient temperature ranges (29.05 to 40.14 ^{0}C) an increase ($p<0.05$) in temperature was seen from the first to second half of transport duration.

While temperature mitigation practices do provide improved thermal environments compared to that of ambient conditions, improvements are still needed. Further research is needed to develop new mitigation practices at high (29.05 to 40.14 ^{0}C) and low (-16.4 to 2.80 ^{0}C) ambient temperatures. Research is also needed to expand current indexes that consider the effects of temperature, humidity, air velocity, and duration to ensure welfare is not compromised by the transport environments experienced by poultry.

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Introduction

Concern for the welfare of poultry is of utmost importance to the poultry industry and the consumers it serves. Live haul (transport) of commercial broiler chickens from production to processing plants poses numerous challenges to ensure that welfare is maintained. One major challenge of transport is ensuring the thermal micro-environments experienced by broilers are maintained within ranges that do not compromise welfare. The following evaluations have taken the first step of understanding the micro-environments experienced during transport of commercial broiler chickens.

Chapter One

Literature Review

Under European industry practices the many factors influencing poultry transport have been evaluated. A system was developed to examine the environment experienced by broiler chickens during transit. This system is used to gain an understanding the physiological changes caused by transportation(Mitchell and Kettlewell, 1998). There is evidence that both environmental and deep body temperatures are influenced by transportation (Mitchell and Kettlewell, 1998). For example, birds were exposed to increased temperature during transportation due to inadequate ventilation to remove the generated body heat of the broilers (Mitchell and Kettlewell, 1998). A European industry standard broiler transporter was compared to a transporter modified for increased ventilation(Mitchell and Kettlewell, 1998). With increased ventilation, there were higher heterophil to lymphocyte ratios (0.3 vs 0.9) in birds at the core of the transport area (Mitchell and Kettlewell, 1998). Moreover, it was reported that a large proportion of birds experienced a lack of comfort throughout the transport vehicle due to high temperature and humidity (Mitchell and Kettlewell, 1998). Thus, the majority of birds were experiencing an adverse environment based on an index AET [θ*app. = T + (e/ã*) where è*app = AET, T = absolute temperature (K), e = water vapor pressure (mbar), ã* = corrected psychrometric constant (mbar K-1): ã* = ã (rv/rh), where rv = the resistance to water vapor transfer (sm-1) and rh = the resistance to heat transfer (sm-1)](Mitchell et al., 2001). It is-concluded that conditions are not conducive for bird comfort in transporters (Mitchell and Kettlewell, 1998). Both summer and winter conditions have been compared using European industry standard equipment (Mitchell and Kettlewell, 1998). Unexpectedly, similar conditions were observed in the center of the transporter based on the AET index (Mitchell and Kettlewell, 1998). A ten point plan was proposed for future research in the area of transportation of poultry (Mitchell and Kettlewell, 1998).

This plan is summarized as follows:

> *1) Characterize the transport process and environment under practical conditions. 2) Identify the major stressors imposed. 3) Identify appropriate indices of physiological stress. 4) Produce integrative, predictive models relating physiological stress response to quantified stressors ("dose-response curves"). 5) From the relevant physiological stress profiles determine the acceptable ranges and limits for the stressor. 6) Examine interactions among concurrent multiple stressors including summation or facilitation of effects. 7) Test laboratory derived models under "field conditions". 8) Design appropriate strategies for the alleviation or prevention of stress including the control of stressors within the prescribed ranges and limits. 9) Use the model to evaluate the effectiveness or success of the strategies. 10) Use this philosophy and approach as the scientific basis for recommendations for improvements in future vehicle and container design, transport practices and legislation*. (Mitchell and Kettlewell, 1998).

A study in Canada conducted in compliance with the 10 point plan found similar results discussed below under extremely low ambient temperatures (-7.1 ^{0}C to -28.2 ^{0}C) (Knezacek et al., 2010). As would be expected at these extremely low temperatures, birds located near tarp coverings on the outside of the transport coops experience a much cooler environment than those on the interior of the transport (Knezacek et al., 2010). Investigations of transportation at more mild temperatures showed no difference in temperature across the transport area (Kettlewell et al., 2000). However, there were differences in temperatures measured along the length of the transport but these were due to the use of an inlet system (Kettlewell et al., 2000). Birds had lower body temperatures when closer to the air inlets located in the center of the truck (Kettlewell et al., 2000).

In areas where poultry farms are not within a one hour of transport time to processing the focus has been placed upon the temperatures experienced during longer travel times (Mitchell and Kettlewell, 1998). Due to shorter transport time from the production to the processing plant managing temperatures broilers experience during transport has been seen as less important in the United States compared to Europe and Canada, (Ritz et al., 2005) These shorter trips, typically less than 2 hours, are also aided by the use of high volume broiler handling systems have also been shown to reduce the time required to load and unload a poultry live haul trailers (Shackelford et al., 1981). Due to these comparatively short transport and loading times, it has been suggested that the pre transport and holding conditions be of main concern for maintaining animal wellbeing (Ritz et al., 2005).

Under industry conditions, there is still the possibility of heat stress during transportation and loading, more so during warm weather (Ritz et al., 2005). The latter is especially the case for those birds in the back of the poultry house which can experience exposure to external warm air entering the house through the open door instead of through cooling pads Heat stress can also be induced by crowding of birds at the back of the house during catching (Ritz et al., 2005). For that reason, it was suggested that the most critical part of the live haul process is on the farm catching and the post trip holding at the processing plant (Ritz et al., 2005). While loading time in the live haul process has been greatly reduced using high volume transport equipment (Shackelford et al., 1981), improvement is still needed to further reduce the risk of overheating during warmer seasons before the transport leaves the farm (Ritz et al., 2005).

While wet conditions are reported to increase the potential hypothermia in low ambient conditions during transport (Hunter et al., 1999), misting in combination with forced air ventilation during the holding period was reported to reduce the incidence of PSE (Pale Soft and Exudative) breast meat in young chickens(Jiang et al., 2016).

Physiological Measures Used in Live Haul

Plasma concentrations of corticosterone (CORT) are considered an important indicator of stress (reviewed: Scanes, 2016). As might be expected, plasma concentrations of corticosterone (CORT) were higher after catching and crating of the birds (Vosmerova et al., 2010). Similarly, plasma concentrations of CORT in chickens handled in a standard catching manner were increased for 7 minutes after crating

(Voslarova et al., 2010). Plasma concentrations of CORT were reported unexpectedly to be decreased during transit (Vosmerova et al., 2010). However, plasma concentrations of CORT were elevated during trips over very long distances (130 km) and under summer conditions (Vosmerova et al., 2010). Other investigators have observed high plasma concentrations of CORT in broilers exposed to high frequencies of vibration for extended periods of time in transport simulations. (Carlisle and Mitchell, 1998). In another investigation there was no difference in plasma concentrations of corticosterone with feed withdrawal or holding except when crate stocking density was high (Delezie et al., 2007).

Plasma concentrations of metabolites are another useful index of stress. Using a simulated transport system, it was found that broilers exposed to low environmental temperatures (0^{o}C) had decreased blood concentrations of glucose compared to those at 20^{o}C (Dadgar et al., 2011). Similarly, birds in a -14 ^{o}C environment had lower plasma concentrations of glucose (Dadgar et al., 2011). In addition, there were elevated plasma concentrations of lactate together with a 57% increase in the occurrence of Dark Dry and Firm (DFD) meat (Dadgar et al., 2011).

Heat Stress

Heat stress is one of the main types of stress that can occur during live haul (Mitchell and Kettlewell, 1998). Increases have been measure in heterophil/lymphocyte (H/L) and basophil ratios for birds placed under heat stress during crating (Akşit et al., 2006). Heat stress grows in importance as genetic selection for increased body weight gains continue. Commercial broilers have been shown to have increased mortality at temperatures not effecting random bred lines (Berrong and Washburn, 1998). This increased growth at younger ages also increase the focus on heat stress. Broilers of the same age but differing size have shown differences in their ability to maintain deep body temperatures with the larger broilers having greater reactions to increase in ambient temperatures than that of smaller broilers (Deeb and Cahaner, 2001)

However not all broilers have the same reactions to heat stress. When comparing three different commercial broiler lines significant differences have been seen in production performance when placed under heat stress (Yalcin, 1992). In addition it has been found that broilers selected for optimal growth are less feed efficient under heat stress conditions (Deeb and Cahaner, 2001). While the majority of studies evaluate the performance measures many suggest the increased body size at younger ages increase heat stress risk (Yalçin et al., 2004; Akşit et al., 2006).

Many other factors also effect body temperatures of broilers. Activity levels of birds has been shown to increase body temperature as would be expected (Prinzinger, R., Preßmar, A., Schleucher, 1991). The levels of ventilation have also been reported to directly influence the body temperatures of broilers(Yahav et al., 2004). When broilers were exposed to conditions known to cause heat stress (35^{o}C) and varying ventilation rates body temperatures were significantly lower for those ventilated at 2 m/s compared to 0.8 m/s (Yahav et al., 2004). While the increase in ventilation from 0.8 to 2.0 m/s improved body temperatures a further increase to 3.0 m/s resulted in a negative water balance due to evaporative water loss (Yahav et al., 2004). Evaporative water loss is a key component of cooling for birds (Scanes, 2015). Birds are able to cool through evaporative water loss using 3 different forms. Respiratory water loss, when air taken in during respiration is heated it is also humidified before being expelled back into the environment (Yahav et al., 2004). Cutaneous water loss, where evaporation of water from the skin cools the bird (Scanes, 2015). Finally cloacal water loss, where evaporation of water within the cloaca (DeNardo et al., 2004). While evaporation is an effective way of cooling for birds its effectiveness is decreased during time of high humidity such as those experienced in the broiler production regions of the United States (Lin et al., 2005). This is due to a decreased ability of the bird to transfer heat from its body’s core to the skin for dissipation into the surrounding environment (Lin et al., 2005). This maybe in part to the reduced blood flow to feathered areas overall during heat stress while leg blood flow accounts for 30% of total blood flow that maybe compressed under the bird if it is not standing (Wolfenson, 1983)

During live haul it was reported that conventional heat mitigation during loading may not be effectively lowering the deep body temperature of broilers (Ritz et al., 2005) Any delays in the loading due to a late arrival of a transport after the initial load of birds has been removed from the house is seen as another high risk situation for the onset of overheating (Ritz et al., 2005). Should a delay occur, it was prescribed that the house be closed and evaporative cooling equipment use reinstated (Ritz et al., 2005). Overall heat stress is a critical factor to consider during live haul. Not only due the compromise of welfare but also the ability to reduce the quality of meat from broilers who have experienced heat stress (Sandercock et al., 2001)

Cold Stress

The exposure of chickens to low ambient temperatures is an important factor in live haul. Early work reported that the lethal low body temperature of chickens to be 22^{o}C to 24^{o} C for acute hypothermia (Sturkie, 1946). Acute hypothermia was induced by submerging chickens in different temperature water baths at low temperatures (6.0^{o}C to 11.6^{o} C) (Sturkie, 1946). The exposure to cold water baths induced violent shivering till the body temperature of the birds fell to 26^{o} C when the shivering decreased in severity. At this point respiration rates became irregular as the slowed till ceasing (Sturkie, 1946). Similarly chickens were placed in at 24^{o} C water bath for 1 hour when their body temperature had decreased to 31^{o}C to 32^{o} C. Water temperatures were increased to 27 ^{o}C at this time. The increased water temperature was shown to slow the decline in body temperature. When the water bath temperatures were raised chickens were able to survive for up to 44 hours in the hypothermic environment (Sturkie, 1946). While these are not similar to the conditions seen during live haul it can be concluded that birds have the ability to with stand hypothermia for long periods of time before death.

In studies employing laboratory conditions that simulated the environment experienced during transport, there were no increases in stress indicators when comparing air temperatures down to -4 ^{0}C (Hunter et al., 1999). However when exposed to intermittent misting, there were evidence of hypothermia at temperatures below 8 ^{0}C as birds deep body temperature decreased (-6.74$\pm$2.27^{o}C change from pretest deep body temperatures) (Hunter et al., 1999). Deep body temperatures were observed to decrease from pretest level by 7^{o}C over the first 90 minutes of exposure to -4^{o}C with intermittent misting. For the second 90 min of exposer deep body temperatures were lowered by 11.5^{o}C (Hunter et al., 1999). The same biphasic deep body temperature response was reported at 1.5 hours of exposure to 0^{o}C with intermittent misting, indicating the failure of thermoregulation (Hunter et al., 1999). The effect of misting during cold conditions shows such great effect due to water has 25 times greater conductance than that of air (Scanes, 2015)

It was reported when 5 week old broilers were exposed to -11^{o}C for 3 hours, 9% of broilers experienced lethal low core body temperatures. While birds of the same age exposed to -14^{o}C for 3 hours, 23% experienced lethal low core body temperatures (Dadgar et al., 2011). However this study examined broilers exposed to low temperatures held in individual compartments unable to huddle with other birds like those within industry live haul conditions (Dadgar et al., 2011) In a similar study using a tarp sided Canadian live haul system its was reported that at -5^{o}C 11% of broilers experienced hypothermic conditions. At -10^{o}C 55% of broilers experienced hypothermia yet at -15^{o}C only 44% experienced hypothermia within the live haul trailer (Strawford et al., 2011). This further demonstrates the variability within live haul micro environments from trip to trip (Strawford et al., 2011). Studies that characterized the temperatures within the Canadian live haul system have reported that the variability within each load to be large with areas reaching from 21.7^{o}C to -20.7^{o}C within a single trailer (Burlinguette et al., 2012). Considering the birds exposed to these temperatures it was estimated that 58% were exposed to temperatures below 0.8^{o}C(Burlinguette et al., 2012)

When considering cold stress in the live haul environment temperature, precipitation/humidity and air velocity are critical factors (Sturkie, 1946; Hunter et al., 1999; Knezacek et al., 2010; Dadgar et al., 2011). It has been demonstrated that acceptable range for the transport of broilers is greatly increased in dry conditions compared to those where precipitation is present (Sturkie, 1946; Hunter et al., 1999; Knezacek et al., 2010; Dadgar et al., 2011). Further the mitigation of cold stress could be advantageous beyond preventing DOA's and improving welfare but also guarding against the occurrence of Dark Firm and Dry (DFD) meat (Dadgar et al., 2012).

DOAs (Dead On Arrival) as a Quality of wellbeing Measure in Live Haul

Dead On Arrival (DOA) birds have also been used as an indicator of issues with transport conditions. A greater number of mortalities during live haul have reported in the lower tier of the transport vehicle than in other areas of the transport vehicle (Hunter et al., 2001). Across all configurations, locations within the transporter reaching 21 ^{o}C above ambient outside temperature have also higher mortality rates (Hunter et al., 2001). Other investigators have also found when ambient temperatures rise above 18^{0} C, there is a noticeable increase in DOA percentages (from 0.09% to 0.13%)(Warriss et al., 2005). This does not take into account any heat mitigation practices that may or may not be used (Warriss et al., 2005). Another investigation reported that many variables are related to DOA percentages (Chauvin- et al., 2011). This study reported that farm mortality, catching style, transport density and climate conditions influences the number of DOAs from 403 flocks(Chauvin- et al., 2011). Climate conditions of rain or wind were shown to be a risk ratio of 1.34 compared to the neither rain nor wind conditions.

Birds Size and Heat Production

Broilers ability to dissipate heat to the environment decreases as their body weight increases (Tao and Xin, 2003). This provides challenges to large broilers during transit during hot weather conditions (Warriss et al., 2005). As would be expected a greater challenge is placed upon smaller broilers during cold weather conditions to maintain body temperatures due to increase surface area per pound of body weight (Xin et al., 2002). This challenge is magnified if cool weather is combine with precipitation and increased wind speeds further reducing the insulation value of plumage (Nicol and Scott, 1990; Hunter et al., 1999).

Conclusion

Overall, transport systems that have been evaluated (European and Canadian) have shown to have highly variable micro environments within a single transporter(Mitchell and Kettlewell, 1998; Knezacek et al., 2010). Moreover, broilers within the micro environments reaching high (>18^{o} C) temperatures have shown to be at a greater risk of becoming DOA’s (Hunter et al., 2001; Warriss et al., 2005). While broilers exposed to precipitation at low ambient temperatures have been shown to be at risk of hypothermia reaching the point of death (Sturkie, 1946; Hunter et al., 1999; Dadgar et al., 2011). However no studies have evaluated the micro environment broilers experience during live haul under United States industry practices.

Chapter 2

Experienced Temperatures of Broiler in Commercial Transporters in the South Central United States

Introduction

There is an increasing recognition of the importance of welfare of poultry. This is coming from the poultry industry, activists and consumers. Concerns have been raised about the conditions that broilers may experience during “live haul”, the process of moving broilers from production to processing. There is, however, a lack of studies on this area examining conditions in the USA. One area of concern is the temperatures broilers are exposed to during the “live haul” process.

Prior to the 1970’s broilers around the world were transported in wooden or plastic coops. Coops would be carried from the broilers houses to the truck or trailer used for transport to processing. Once the truck arrived at processing, coops would then be unloaded by hand one at a time. As the demand of broilers rose in the need for more efficient live haul systems developed. The coopless live haul system was developed and adopted into the United States industry and is still used. This system uses modules (see figure 5) in place of wooden coops. Fork lifts move the modules to and from trailers during loading and unloading. During unloading no manual labor is needed as birds are removed by tilting the modules once they are removed from the trailer. The development of the coopless system was reported to reduce labor by 30% on the back dock of the processing plant alone (Shackelford et al., 1981) While this system was implemented within the U.S. industry other modified coop systems were developed and implemented in Europe.

It is hypothesized that environmental factors influence the climate broiler chickens are experiencing during transportation. Moreover, understanding the climate birds are experiencing will allow for focus on areas in need of improvement. While the environment experienced in European industry standard coop transport systems have been documented (Hoxey et al., 1996; Hunter et al., 2001; Kettlewell et al., 2001) in detail those of the industry standard module system in the United States of America have not been studied. The present studies examine the temperatures experienced by broiler chickens during transportation in the South Central Region of the USA.

Materials and Methods

Design

Monitoring protocols were designed to follow the 10 point plan proposed by Mitchell and Kettlewell (1998) for research and understanding of poultry transport temperatures. The focus of the current study was to characterize the temperatures experienced by broiler chickens during transportation at low, moderate, and high ambient temperatures. All studies were conducted in the Arkansas, Oklahoma and Missouri border region (185km radius from Fayetteville AR). To capture and record the temperatures experienced by broilers during transport from the farm to processing, 45 temperature loggers (DS1922L Thermochron, OnSolution Baulkham Hills, Australia and Hobo Pro V2 Temperature Data Logger, Onset Computer Corporation Bourne, MA) were placed in a 3 (bottom, middle, top) by 3 (left, center, driver) by 5 (1-5) grid (see figure 1). Temperature loggers were set to record the temperature every 30 seconds. Industry standard transport tractors and trailers (7.315 m long of differing manufacturers) were used. Trailers hauled industry standard 10 or 15 door high volume modules (47-3/4" wide; 95-3/4" long; 52" tall) (Bright Coop, Inc Nacogdoches, TX). A GPS unit (etrex 20, Garmin Olathe, KA) was also placed on the truck to enable accurate times to be reported for the beginning and end of transport period.

Integration into Industry Process

The two person research team would arrive at the processing plant up to 12 hours prior to the trip, where the modules would be off loaded from the trailer and outfitted with the temperature loggers. The modules were marked by location on the trailer to ensure proper relocation. Modules were reloaded on to the trailer in the opposite vertical orientation to that of the transport placement to lessen any artificial effect from increased loading time on the farm. The trailer was also marked using matching colored survey tape (Presco Products Sherman, TX) to ensure proper placement of modules along the length of the trailer. Trailers were then followed to the farm for loading. The outfitted trailer was observed at the farm to ensure that all modules were placed in the proper location. In the event of unforeseen circumstances or non-typical events (partial loads, truck break downs, or loading crew delays), data were excluded from consideration as they were considered as non- representative.

The standard loading process begins when the truck arrives on the farm with and the driver removes any securement devices from the empty modules. Once the truck is ready to be loaded the lift truck driver will remove the first top module and place it inside of the broiler house for the catch crew to load. While birds are placed in the first module by the catch crew the lift truck will return to the trailer for the first bottom module and place it in the house to be loaded with broilers by the catch crew. At this time the first loaded module is removed from the house and place it in the front bottom location of the trailer. From this point on loaded modules are removed from the house and empty modules are brought in. Once the transport is loaded the driver reattaches the securement devices to the modules and trailer before departing from the farm.

When the transport was unloaded at the processing plant the modules were once again off loaded and loggers were retrieved. After the loggers were collected they were returned to the laboratory where the collected data was downloaded and consolidated into Excel (Redmond, WA) spreadsheets. Ambient weather data during transport was collected from the nearest airport weather station.

Bird Size

Live haul of both large and small market weight broilers were included. It has been shown that under simulated cold transport conditions small broilers have higher heat loss to maintain body temperature (Watts et al., 2011). The most adverse low temperature transportation conditions were examined in small market weight broilers (1.67 kg). The most adverse high temperature transportation conditions were examined in heavy market weight broiler (3.63 Kg) during the summer months. Both market weights were also examined at moderate temperatures.

Different practices were employed by live haul managers to mitigate temperature effects depending upon the seasonal temperatures. In extremely cold conditions (-16.4 to 2.80 0C) plastic pallet wrap (see figure 2) was applied around each individual module after the birds were loaded into the module but before the module was loaded onto the transport. During cold weather conditions (-16.4 to 10.4 ^{0}C) two panels of fiberglass would be attached to the left and right side of the modules (Double Side Board) (see figure 3) attempting to cover 100% of each side. During mildly cool conditions (2.4 to 21.0 ^{0}C) one panel of fiber glass (Single Side Board) (see figure 4) was attached to the left and right side of the modules covering approximately 50% of the side. During mild conditions (19.3 to 29.1 ^{0}C) no modifications to the modules were made leaving the sides open to ventilation (see figure 5). For warm weather conditions (30.5 to 40.1 ^{0}C) heat mitigation strategies were employed by live haul managers. These practices included the use of single or multiple fans during the loading of the transport. Water was also applied to transport modules before and after loading as a common heat mitigation practice (see figure 6).

Analysis

28 trips from were included in the analysis. Trips were placed into 3 different categories based on ambient temperature. The high ambient temperature group ranged from 29.05 to 40.14^{o} C, moderate from 6.22 to 23.35^{o} C and low from -16.40 to 2.80^{o} C. Trips were also grouped by the different management practices used, plastic wrap, doubles side boards, single side boards, open, and heat mitigation. Further trips were divided into first half of trip and second half of trip temperature. Trips ranged from 23 to 125 minutes.

The ambient, first half of trip, and second half of trip temperatures were analyzed between each ambient grouping as well as each management grouping. Tukey's HSD test in JMP PRO 12® was used. First half and second half temperatures were also analyzed within each grouping. Matched paired analysis was carried out in JMP PRO 12®. For both analysis values were considered significant if $p<0.05$.

Figure 1. Depiction of an industry standard drop deck poultry trailer loaded with 20, 10 door modules.

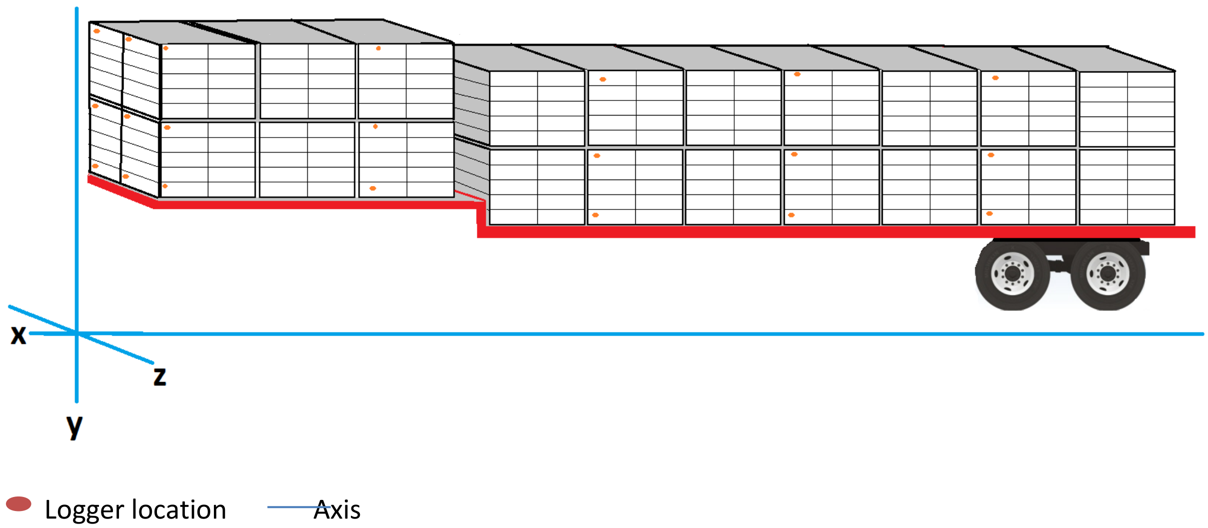

Figure 2. Modules during extremely cold conditions filled with small broilers wrapped with plastic and loaded on to a live haul trailer.

Figure 3. Double side boarded modules for reduced air flow in cold weather.

Figure 4. Modules have single side boards for reduced air flow in cool weather conditions.

Figure 5. Open sided modules for use in moderate temperatures and high temperatures.

Figure 6. A fan trailer equipped with spray nozzles used for heat mitigation while the trailer is being loaded on the farm.

Results and Discussion

As expected, differences ($p<0.05$) were seen between all ambient groupings (Table 1). Differences were also seen within each grouping. For the low ambient temperature trips, the temperature within the trailer for the first half of the trip was higher ($p<0.05$) than the temperature during the second half of trip (Table 2). This is likely due to the dissipation of the heat retained from the birds within the transporter during loading. The moderate ambient temperature group first half temperatures were higher (<0.05) than that of the second half. While differences were significant they were small, a mean difference of 0.17^{o}C (Table 2). This suggests that the environment within the trailers is near thermal neutral. Considering the high ambient group, the first half temperature was lower than the ambient temperature (Table 1). From the first half of transport to the second temperatures increased ($p<0.05$) toward ambient. This is due to the reduced effectiveness of heat mitigation practices over time.

Spanning all trips temperatures within the transporter moved closer to that of ambient from the first half of the trip to the second half of the trip. This suggests that adequate ventilation through the trailer during the transit. Transport areas with this range of temperatures have not been reported in the literature using the same transport systems (Ritz et al., 2005; Knezacek et al., 2010; Chauvin- et al., 2011).

Table 1. Air temperatures within trailers (see figure 1) holding broiler chickens at low, moderate, and high ambient temperatures.

	Ambient Temperature	First Half of Trip#	Second Half of Trip#	ANOVA p-value
Low	-5.27 $\pm$ 0.40^{c}	5.41 $\pm$ 0.38^{c}	4.22 $\pm$ 0.40^{c}	<0.001
Moderate	16.16 $\pm$ 0.37^{b}	19.15 $\pm$ 0.35^{b}	18.98 $\pm$ 0.36^{b}	<0.001
High	33.72 $\pm$ 0.38^{a}	30.53 $\pm$ 0.36^{a}	32.73 $\pm$ 0.28^{a}	<0.001

^{abc} Superscripts denote differences ($p<0.05$) within each column.
Low categorized were trips having average ambient temperatures from -16.4 to 2.80 ^{0}C.
Moderate ambient temperatures are trips from 6.22 to 23.35 ^{0}C.
High ambient temperatures trips are from 29.05 to 40.14 ^{0}C.
Duration ranged from 23 to 125 minutes first half transport is the average temperature for all measured locations (see figure 1) from the time of departure from the farm till half the duration of the transport time to the processing plant. The second half of transport is the average temperature of all measured locations within the transporter starting at the midpoint of the duration of trip from the farm to the processing plant.

Table 2. Evaluation of transport duration matched paired analysis at low, moderate, and high ambient temperatures

	Low	Moderate	High
First Half of Trip#	5.41^{a}	19.15^{a}	30.53^{b}
Second Half of Trip#	4.22^{b}	18.98^{b}	32.73^{a}
Mean Difference	1.19	0.17	-2.20
Std Error	0.14	0.07	0.09
N	362	464	323
P=	<0.0001	0.0083	<0.0001

^{ab} Superscripts denote differences ($p<0.05$) within each column.
Low categorized were trips having average ambient temperatures from -16.4 to 2.80 ^{0}C.
Moderate ambient temperatures are trips from 6.22 to 23.35 ^{0}C.
High ambient temperatures trips are from 29.05 to 40.14 ^{0}C.
Duration ranged from 23 to 125 minutes first half temperature is the average temperature for all measured locations (see figure 1) from the time of departure from the farm till half the duration of the transport time to the processing plant. The second half temperature is the average temperature of all measured locations within the transporter starting at the midpoint of the duration of trip from the farm to the processing plant.

For management groups all ambient temperatures were different ($p<0.05$). Trips where plastic was used (see figure 2) had statically similar temperatures for the first and second half of trip to that of double side board trips (Table 3). These were the only statistically similar temperatures observed when trips were compared by management group.

When considering first and second half temperatures within each group all showed significant differences. Plastic wrap, Double Side Boards, and Single Side Boards all decreased ($p<0.05$) from first to second half. Conversely, Open Sided and Heat Mitigation increased (<0.05) from the first half of trip to the second. While changes for Double Side Board, Single Side Board, and Open Sided were statistically significant, the differences were small ($<1.0^0$C). It can be assumed that the temperature within the trailers are near thermal neutral due to the small changes in temperature from first to second half of trip.

Table 3. Air temperatures within poultry trailers (see figure 1) using different management configurations (see figure 2-6)

Treatment	Ambient Temperature	First Half Temperature#	Second Half Temperature#	ANOVA p-value
Plastic Wrap	-5.63 ± 0.40^{e}	6.17 ± 0.38^{d}	4.92 ± 0.40^{d}	.001
Double Side Board	-2.80 ± 0.45^{d}	6.48 ± 0.44^{d}	5.54 ± 0.47^{d}	.001
Single Side Board	13.08 ± 0.32^{c}	16.65 ± 0.30^{c}	16.28 ± 0.32^{c}	.001
Open Sided	23.51 ± 0.45^{b}	25.01 ± 0.42^{b}	25.39 ± 0.44^{b}	.001
Heat Mitigation	34.39 ± 0.34^{a}	30.40 ± 0.33^{a}	32.76 ± 0.35^{a}	.001

[abcd] Superscripts denote differences ($p<0.05$) within each column.

Duration ranged from 23 to 125 minutes

Plastic Wrap ambient temperatures ranged from -15.8 to 2.8^{o}C

Double Side Board ambient temperatures ranged from -16.4 to 10.4 ^{0}C

Single Side Board ambient temperatures ranged from 2.4 to 21.0 ^{0}C

Open Sided ambient temperatures ranged from 19.3 to 29.1 ^{0}C

Heat Mitigation ambient temperatures ranged from 30.5 to 40.1 ^{0}C

First half temperature is the average temperature for all measured locations (see figure 1) from the time of departure from the farm till half the duration of the transport time to the processing plant. The second half temperature is the average temperature of all measured locations within the transporter starting at the midpoint of the duration of trip from the farm to the processing plant.

Table 4. Evaluation of transport duration matched paired analysis using different temperature mitigation methods

	Plastic Wrap	**Double Side Board**	**Single Side Board**	**Open Sided**	**Heat Mitigation**
First Half of Trip#	6.17^{a}	6.48^{a}	16.65^{a}	25.01^{b}	30.40^{b}
Second Half of Trip#	4.92^{b}	5.54^{b}	16.28^{b}	25.39^{a}	32.76^{a}
Mean Difference	1.25	0.93	0.37	-0.38	-2.36
Std Error	0.19	0.21	0.09	0.07	0.10
N	206	156	331	176	280
P=	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

^{ab} Superscripts denote differences ($p<0.05$) within each column.
Duration ranged from 23 to 125 minutes
First half temperature is the average temperature for all measured locations (see figure 1) from the time of departure from the farm till half the duration of the transport time to the processing plant. The second half temperature is the average temperature of all measured locations within the transporter starting at the midpoint of the duration of trip from the farm to the processing plant.
Plastic Wrap ambient temperatures ranged from -15.8 to 2.8^{o}C
Double Side Board ambient temperatures ranged from -16.4 to 10.4 ^{0}C
Single Side Board ambient temperatures ranged from 2.4 to 21.0 ^{0}C
Open Sided ambient temperatures ranged from 19.3 to 29.1 ^{0}C
Heat Mitigation ambient temperatures ranged from 30.5 to 40.1 ^{0}C

Table 5. Air temperature in modules holding broiler chickens during transportation and corresponding ambient air temperatures.

Treatment	**Adjusted R^2**	**P=**	**Degrees of freedom**
Plastic Wrap	0.850	0.017	4
Double Side Board	0.954	0.016	3
Single Side Board	0.813	0.001	7
Open Sided	0.802	0.068	3
Heat mitigation	0.530	0.039	6

Have you discussed Table 5? It is not appropriate to include a figure but not to discussion the results in the figure.

Conclusion

While low ambient trip experienced temperatures were higher than that of the ambient the temperature rises remained small. (Ritz et al., 2005). Low ambient temperatures were not as low as those reported by Knezacek and colleagues (2010) but air temperature on trailer? may be below comfort levels for broilers if considered using a comfort index. Trailer area temperatures never rose to elevated level of those reported in Canada (up to 27^{o}C) during cool/cold season transportation? (they did experience up to 35 C in summer) (Knezacek et al., 2010). Moreover the heat mitigation effects were shown to decrease over time. Temperatures within the trailers reached much higher levels than those reported in any previous US study. However the recorded temperatures within the trailers were greatly improved from ambient when heat mitigation was used.. While both extreme temperature mitigation practices were effective improvements are needed. Micro climates within the transport need to be understood as well as other factors influencing the live haul environment.

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Chapter 3

Characterization of Micro-environments within Commercial Broiler Transporters

Introduction

Understanding the temperatures broilers experience during transport allows managers to identify environmental conditions where mortalities are likely to increase and meat quality to be down-graded (Kannan et al., 1997). Moreover, there is a risk that overall welfare is compromised. There have been limited studies of poultry and their environment during transportation in the USA. Ritz and colleagues (2005) examined temperatures experienced during broilers in warm weather conditions. The temperatures recorded in 3 unidentified locations within the transport were lower than those within the house during loading. This lead to exclusion of transport temperatures from any further analysis (Ritz et al., 2005)

In contrast, there are multiple studies in Europe (Mitchell and Kettlewell, 1998; Kettlewell et al., 2000; Hunter et al., 2001). Under European industry standard coop transport systems, there is high variability of temperature within an individual transporter (Kettlewell et al., 2001; Knezacek et al., 2010; Richards et al., 2012). Knezacek et al (2010) colleagues investigated temperature using European coop style transporter in Canada(Knezacek et al., 2010). They reported minimum temperatures from 1.5^{o}C to -12.0^{o}C in different locations along the transporter over a single trip(Knezacek et al., 2010). Richards et al (2012) colleagues showed that end of lay hens within a single location on a transport experienced temperatures ranging from 13.8^{o}C to 33.5^{o}C.

There has not been an in depth characterization of the transport temperatures experienced by broilers in the US. The present studie examine the micro climate temperatures experienced by broiler chickens during transportation in the South Central Region of the USA. It is important to understanding the microclimates that occur throughout the transporter in order to ensure that current temperature mitigation practices are beneficial to the largest number of broilers.

Materials and Methods

Overall Design

The systems to monitor temperatures followed the 10 point plan proposed by Mitchell and Kettlewell (1998) for studying poultry transport temperatures. The focus of our study was to characterize the temperatures experienced by broiler chickens, in module micro-environments, during transportation. All studies were conducted in the Arkansas, Oklahoma and Missouri border region (185km radius from Fayetteville AR). To record the temperatures experienced by broilers during transport 45 temperature loggers (DS1922L Thermochron, OnSolution Baulkham Hills, Australia and Hobo Pro V2 Temperature Data Logger, Onset Computer Corporation Bourne, MA) were placed in a 3 (bottom, middle, top) by 3 (left, center, driver) by 5 (1-5) grid (see figure 1). Temperature loggers were set to record the temperature every 30 seconds. Industry standard transport tractors and drop deck trailers (12.92 m to 14.63 m long of differing manufacturers) were used. Trailers hauled industry standard 10 or 15 door high volume modules (1.21 m wide; 2.44 m long; 1.21 m tall) (Bright Coop, Inc Nacogdoches, TX). A GPS unit (etrex 20, Garmin Olathe, KA) was also placed on the truck to enable accurate times the beginning and end of transport period.

Method to Integrate Study into Industry Process

The two person research team would arrive at the processing plant prior to the trucks departure time, where the modules would be off loaded from the trailer and outfitted with the temperature loggers. The modules were marked by location to ensure proper relocation. Modules were reloaded on to the trailer in the opposite vertical orientation to that of the transport placement to lessen any artificial effect from increased loading time on the farm. The trailer was also marked using matching colored survey tape (Presco Products Sherman, TX) to ensure proper placement of modules along the length of the trailer. Trailers were then followed to the farm for loading. The outfitted trailer was observed at the farm to ensure that all modules were placed in the proper location. In the event of unforeseen circumstances or non-typical events (partial loads, truck break downs, or loading crew delays), data was excluded from consideration as they were considered non-representative.

Once the transport was unloaded at the processing plant the modules were once again off loaded and loggers were retrieved. After the loggers were collected they were returned to the laboratory where the data collected was downloaded and consolidated into Excel (Redmond, WA) spreadsheets. Ambient weather data was collected from the nearest airport weather station.

Influence of Bird Size in Design of the Studies

Small chickens (1.67 kg) were examined during winter conditions. Due to the lower metabolic heat production (Xin et al., 2002) and greater heat loss at low temperatures small broilers are thought to be at risk of mortality at low temperatures. Large chickens unlike small, have high metabolic heat production (Feddes et al., 1984). The most adverse high temperature transportation conditions were examined in heavy market weight broiler (3.63 Kg) during the summer months. Both small and large broilers were examined during moderate temperatures.

Industry practices to mitigate environmental temperatures

Different practices were employed by live haul managers to mitigate temperature effects depending upon the seasonal temperatures. In extremely cold conditions (-16.4 to 2.80 0C) plastic pallet wrap (see figure 2) was applied around each individual module after the birds were loaded into the module but before the module was loaded onto the transport. During cold weather conditions (-16.4 to 2.80 0C) two panels of fiberglass would be used to cover each side of the modules (Double Side Board) (see figure 3) attempting to cover 100% of the sides. During mildly cool conditions (2.4 to 21.0 ^{0}C) one panel of fiber glass (Single Side Board) (see figure 4) to cover the left and right side of the modules covering approximately 50% of the side. During mild conditions (19.3 to 29.1 ^{0}C) no modifications to the modules were made leaving the sides open to ventilation (see figure 5). For warm weather conditions (30.5 to

40.1 ^{0}C) heat mitigation strategies were employed by live haul managers. These practices included the use of single or multiple fans during the loading of the transport. Water was also applied via direct spray to transport modules before and after loading as a common heat mitigation practice (see figure 6).

Analysis

28 trips from were included in the analysis. Trips were placed into 3 different categories based on ambient temperature. The high ambient temperature group ranged from -29.05 to 40.14^{o} C, moderate from 6.22 to 23.35^{o} C and low from -16.40 to 2.80^{o} C. Trips were also grouped by the different management practices used, plastic wrap, doubles side boards, single side boards, open, and heat mitigation. Further trips were divided into first half of trip and second half of trip temperature. Trips ranged from 23 to 125 minutes.

The first half of trip and second half of trip temperatures were analyzed between ambient groupings as well as management grouping for each location along the 3 axes (Figure 1). Tukey's HSD test in JMP PRO 12® was used. First half and second half temperatures were also analyzed within groupings for each location along the 3 axes. Matched paired analysis was carried out in JMP PRO 12®. For both analysis values were considered significant if $p<0.05$.

Figure 1. Schematic of an industry standard drop deck poultry trailer loaded with 20, 10 door modules

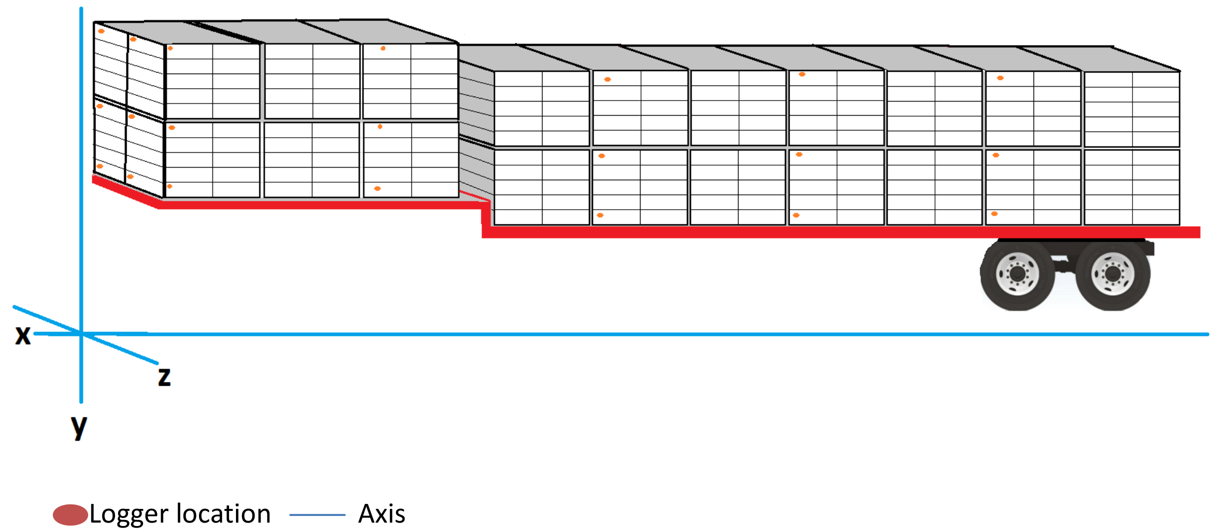


Figure 2. Modules after being loaded with broilers, wrapped with plastic and loaded on to the transporter. Plastic wrap is used only in extremely cold conditions (-15.8 to 2.8°C)

Figure 3. Double side boarded modules for reduced air flow in cold weather (-16.4 to 10.4 ^{0}C)

Figure 4. Industry standard drop deck poultry transport. Modules have single side boards for reduced air flow in cool weather conditions (2.4 to 21.0 ^{0}C).

Figure 5. Open sided modules for use in moderate temperatures and high temperatures (19.3 to 29.1 ^{0}C)

Figure 6. A fan trailer equipped with spray nozzles used for heat mitigation while the trailer is being loaded on the farm. **(**30.5 to 40.1 ^{0}C)

Results and Discussion

Impact of Low Ambient Temperature

For the low ambient trips (table 1) and considering first the Z axis (see figure 1), the temperature were highest in the middle, as would be expected due to sheltering from the ambient conditions. Temperatures were greater ($p<0.05$) in the center than the left. The temperature for the right location was no different from center or left. Observations were consistent for both the first and second half of the journey. After the birds were loaded in to the module, the module is loaded on to the transporter from the left side. It was observed that birds would congregate on the right side of the modules during loading in attempt to move away from the motion of the lift truck. Table 2 shows temperatures across the Z axis decreased ($p<0.05$) from the first to second half of the trip duration. The decrease in temperature from the first to second half of trip indicates that the heat produced by the broilers was not adequate to maintain the temperature within the trailer.

The Y axis (see figure 1) shows the temperature along the vertical axis of the trailer at low ambient temperatures. Lower temperatures ($p<0.05$) for this axis were recorded in the top of the trailers, compared to the bottom and middle locations. This was recorded for both the first and second half of trip. In some cases, in cold conditions when plastic wrap was used, small gaps between the top of the module and the edge of the plastic wrap would be present. This gap would increase in size throughout trips as the wrap was not able to withstand the wind.

Along the X axis (see figure 1), differences ($p<0.05$) were present between the 2nd and 3rd location for the first and second half of trip. The space created between modules on a drop deck trailer were observed to create an increased exterior exposure near location 2. Excluding location 4, temperatures were lower ($p<0.05$) for the second half of transport along the X axis. As the trailer is loaded on the farm heat produced by the loaded broilers raises the temperature within the modules. Once the trailer leaves the farm heat levels that increased during loading are quickly lowered. It was concluded that temperatures while improved from ambient were still in need of improvement to maintain optimum conditions under the most extreme conditions.

Table 1 Variation in air temperatures in modules containing broiler chickens during trips within the trailer at low ambient temperatures* across the trailer area (see Figure 1).

	First Half of Trip#	**Second Half of Trip#**
Z axis		
Left	4.1 ± 0.6^{b}	2.8 ± 0.6^{b}
Middle	7.0 ± 0.6^{a}	5.8 ± 0.6^{a}
Right	5.1 ± 0.6^{ab}	4.1 ± 0.6^{ab}
Y axis		
Bottom	5.9 ± 0.6^{a}	5.2 ± 0.7^{a}
Middle	7.0 ± 0.6^{a}	5.4 ± 0.6^{a}
Top	3.4 ± 0.6^{b}	2.2 ± 0.6^{b}
X axis		
1	5.7 ± 0.8^{ab}	3.7 ± 0.8^{ab}
2	3.8 ± 0.8^{b}	2.2 ± 0.8^{b}
3	7.8 ± 0.8^{a}	6.8 ± 0.8^{a}
4	5.3 ± 0.8^{ab}	4.8 ± 0.8^{ab}
5	4.4 ± 0.7^{b}	3.5 ± 0.8^{b}

[ab] Superscripts denote differences ($p<0.05$) within each column and axis.
*Low ambient trips includes those having average ambient temperatures from -16.4 to 2.80 ^{0}C. #Trip durations range from 60 to 125 minutes.
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant.

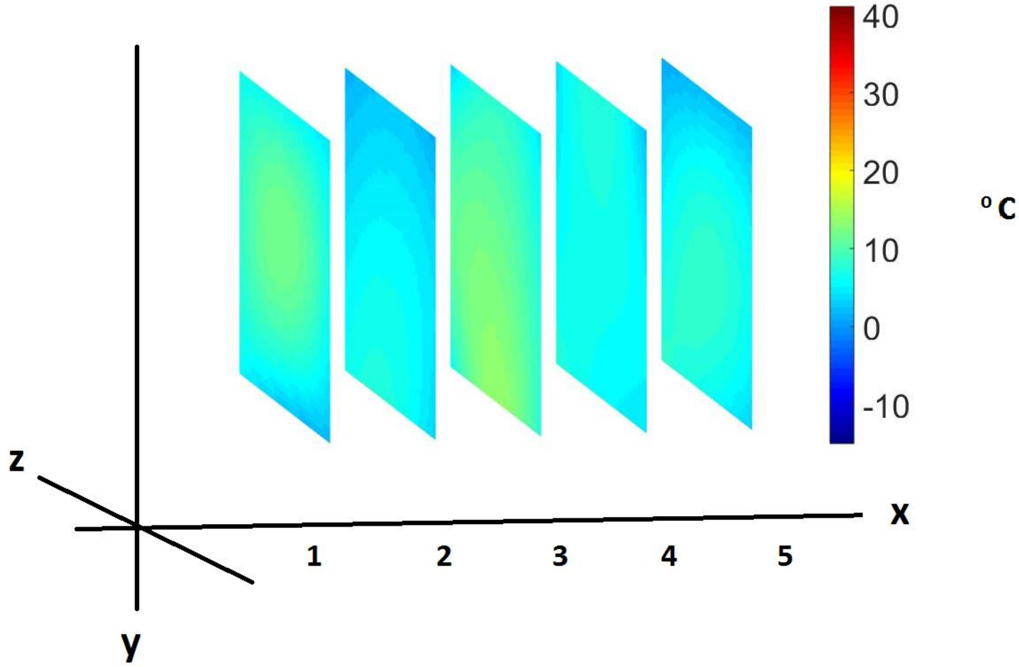
Table 2 Effect of trip duration on micro-environments matched paired analysis, comparison of temperatures for the first and second half of trip[#] at low[*] ambient temperatures across the trailer (see Figure 1.)

	Z axis			**Y axis**			**X axis**				
	Left	Middle	Right	Bottom	Middle	Top	1	2	3	4	5
First Half of Trip[#]	4.12[a]	6.98[a]	5.11[a]	5.86[a]	6.98[a]	3.38	5.74[b]	3.76[a]	7.79[a]	5.28	4.36[a]
Second Half of Trip[#]	2.81[b]	5.76[b]	4.10[b]	5.21[b]	5.35[b]	2.18	3.68[a]	2.19[b]	6.77[b]	4.81	3.48[b]
Mean Difference	1.33	0.27	1.00	0.65	1.64	1.21	2.06	1.58	1.02	0.47	0.88
Std Error	0.25	0.26	0.20	0.26	0.23	0.22	0.22	0.31	0.42	0.31	0.20
N	124	123	115	111	127	124	71	68	74	74	75
P=	<0.0001	<0.0001	<0.0001	0.015	<0.0001	<0.0001	<0.0001	<0.0001	0.018	0.136	<0.0001

[ab] Superscripts denote differences ($p<0.05$) within each column and axis.

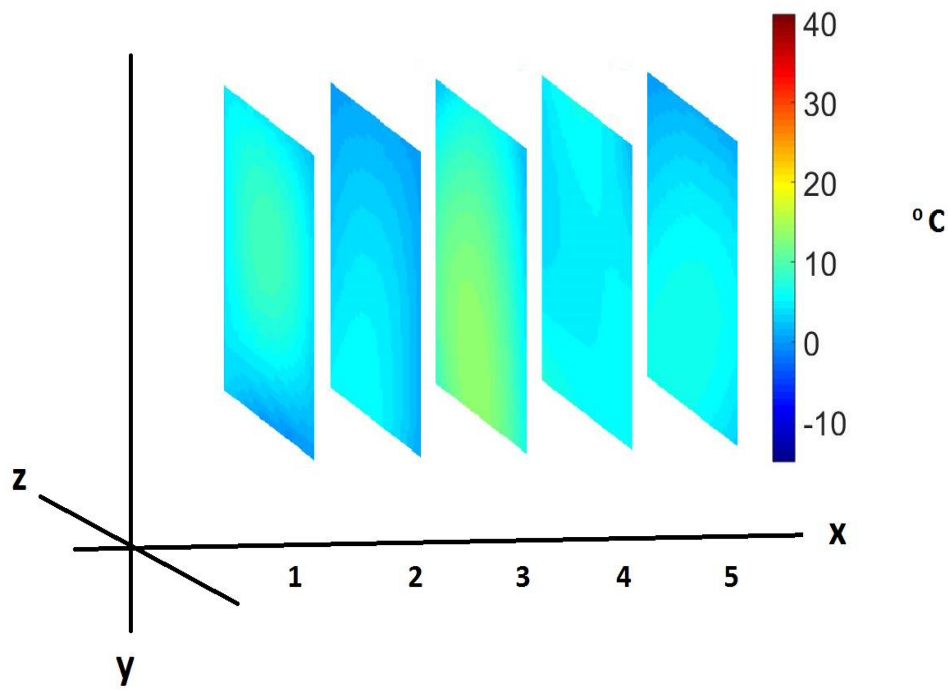
*Low ambient trips includes those having average ambient temperatures from -16.4 to 2.80 ^{0}C. [#]Trip durations range from 60 to 125 minutes. First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant.

Figure 7. A thermal map of average temperatures for each location throughout the trailer (see figure 1) at low* ambient temperatures within the first half of the trip duration#



*Low ambient trips includes those having average ambient temperatures from -16.4 to 2.80 °C.
#Trip durations range from 60 to 125 minutes.

Figure 8. A thermal map of average temperatures for each location throughout the trailer (see figure 1) at low* ambient temperatures within the second half of the trip duration#



*Low ambient trips includes those having average ambient temperatures from -16.4 to 2.80 °C.
#Trip durations range from 60 to 125 minutes.

Impact of Moderate Ambient Temperature

In trips with a moderate ambient temperature (6.2 to 23.4 ^{0}C), there were variations in the micro-environment temperatures. Variation along the Z axis (table 3 and figure 1) will be considered first. The temperature of center location was higher ($p<0.05$) than both the left and the right for the first half of trip (table 3). The left side was lower than the middle for the second half of the trip period while the right was not different ($p<0.05$) from the middle or the left. Temperatures measured at the middle and left position decreased ($p<0.05$) from the first half to the second half while the right location temperature remained the same (Table 4).

There was no difference between any of the Y or Z locations for the first or second half of trip along the Y axis (figure 1, Table 3). This may be the result of the management practices employed by the integrators (open, single side board, and double side board)(figure 2 through 5).

There were differences along the X axis (figure 1). Location 2 temperatures were lower ($p<0.05$) than the neighboring locations during the first half of transport. No difference was observed for the X axis in the second half of transport. Differences ($p<0.05$) in temperature were measured between the first and second half of transport for location 1 and 3. These locations have little exposure to ambient conditions. These locations within the transporter are also occupied by the birds for longer times while the transporter is being loaded.

The differences seen at moderate ambient conditions though significant were small both comparing locations within the trailer and first to second half of trip temperatures for each location. This shows air flow through the trailers is adequate to maintain moderate micro environment temperatures within the trailer.

Table 3. Variation in air temperatures in modules containing broiler chickens during trips within the trailer (see figure 1) at moderate* ambient temperatures.

	First Half of Trip#	Second Half of Trip#
Z axis		
Left	18.4 $\pm$ 0.4	18.1 $\pm$ 0.4[b]
Middle	20.2 $\pm$ 0.4[a]	19.9 $\pm$ 0.4[a]
Right	18.9 $\pm$ 0.4[b]	18.9 $\pm$ 0.4[ab]
Y axis		
Bottom	19.3 $\pm$ 0.4	19.2 $\pm$ 0.4
Middle	19.2 $\pm$ 0.4	19.0 $\pm$ 0.4
Top	19.0 $\pm$ 0.4	18.7 $\pm$ 0.4
X axis		
1	20.1 $\pm$ 0.5[a]	19.7 $\pm$ 0.5
2	18.1 $\pm$ 0.5[b]	18.3 $\pm$ 0.6
3	20.2 $\pm$ 0.5[a]	19.8 $\pm$ 0.5
4	18.7 $\pm$ 0.5[a]	18.5 $\pm$ 0.5
5	18.5 $\pm$ 0.5[a]	18.4 $\pm$ 0.5

[ab] Superscripts denote differences ($p<0.05$) within each column and axis.
*Moderate ambient trips includes those having ambient temperatures from 6.2 to 23.4 ^{0}C.
#Trip durations range from 23 to 107 minutes.
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip from the farm to the processing plant.

Table 4 Effect of trip duration on micro-environments matched paired analysis of temperatures for the first and second half of trip duration# at moderate* ambient temperatures(see Figure 1.)

	Z axis			**Y axis**			**X axis**				
	Left	Middle	Right	Bottom	Middle	Top	1	2	3	4	5
First Half of Trip#	18.37^{b}	20.18^{a}	18.90	19.27	19.20	18.99	20.10^{a}	18.11	20.19^{a}	18.69	18.47
Second Half of Trip#	18.09^{a}	19.94^{b}	18.92	19.21	18.99	18.73	19.68^{b}	18.30	19.82^{b}	18.54	18.43
Mean Difference	0.28	0.25	-0.02	0.06	0.20	0.26	0.42	-0.18	0.37	0.15	0.05
Std Error	0.12	0.12	0.10	0.10	0.11	0.13	0.16	0.12	0.18	0.14	0.11
N	157	156	151	159	153	152	98	80	95	97	94
P=	0.020	0.037	0.884	0.518	0.054	0.058	0.012	0.123	0.041	0.274	0.67

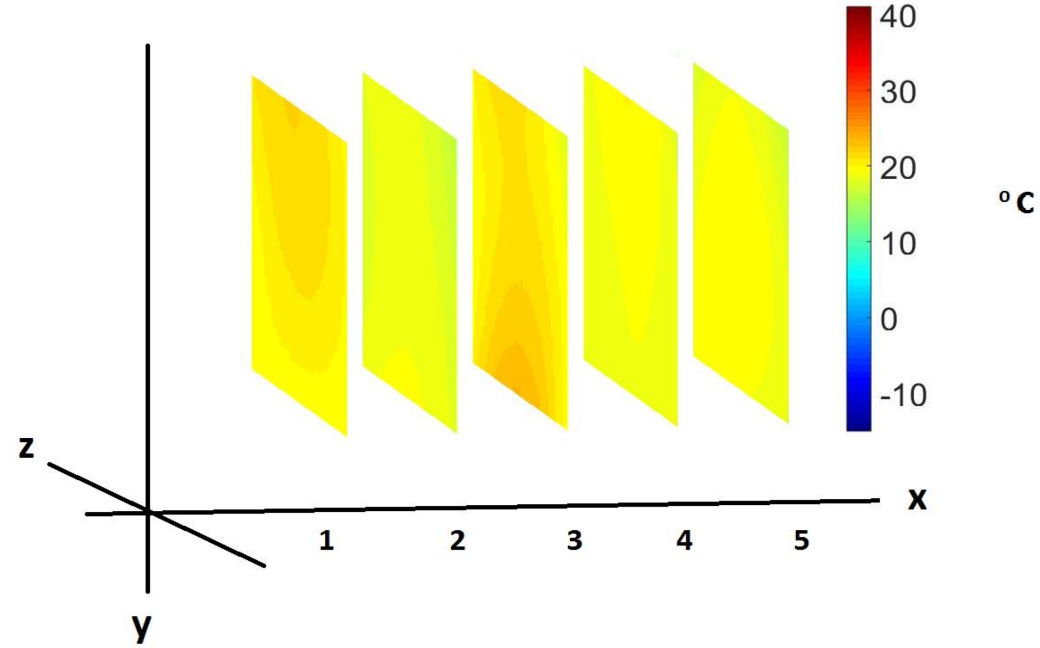
ab Superscripts denote differences ($p<0.05$) within each column and axis.

*Low ambient trips includes those having average ambient temperatures from 6.2 to 23.4 ^{0}C.

#Trip durations range from 23 to 107 minutes.

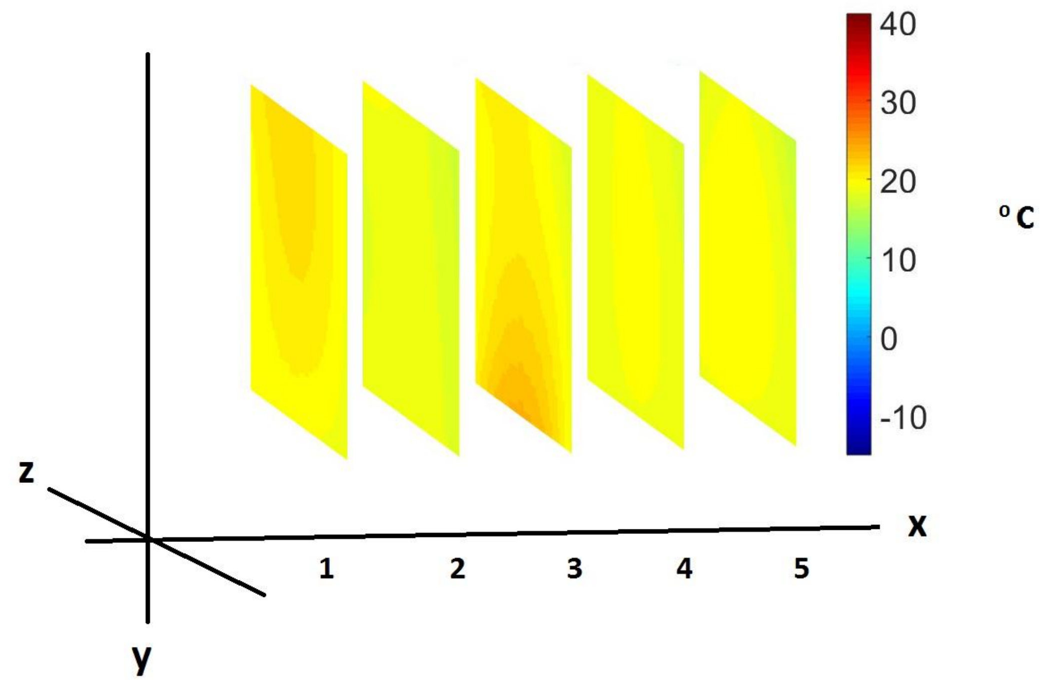
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant.

Figure 9. A thermal map of average temperatures for each location throughout the trailer (at moderate* ambient temperatures within the first half of the trip duration#.



*Moderate ambient trips includes those having ambient temperatures from 6.2 to 23.4 ^{0}C.
#Trip durations range from 23 to 107 minutes.

Figure 10. A thermal map of average temperatures for each location throughout the trailer (see figure 1) at moderate* ambient temperatures within the second half of the trip duration#



*Moderate ambient trips includes those having ambient temperatures from 6.2 to 23.4 ^{0}C.
#Trip durations range from 23 to 107 minutes.

Influence of High Ambient Temperature

Treatments of heat mitigation (figure 6) and open sided modules (figure 5) were used by integrators for trips in the high ambient temperature group (29.1 to 40.1 ^{0}C) (table 5).

Along the Z axis (see figure 1), temperatures were different (<0.05) at all locations in the first half of the trips?. In accordance with other reports (Mitchell and Kettlewell, 1998) the middle location had the highest temperature, followed by the right. For the second half of transport temperatures in these locations were no different ($p<0.05$). This shows that any temperature effect from loading on temperatures across the trailer are not seen during the second half of transport at high ambient temperatures.

Along the Y axis (figure 1) the top location temperatures were higher than the middle and bottom. This was expected due to the top of the module being exposed to the sun. Top location temperatures remained the highest in the second half of transport. Temperatures rose along the Y axis by an average of 2.2^{0}C from the first to the second half of transport.

Considering the X axis (figure 1) no differences were seen within the first or the second half of transport temperatures. This could be due to the use of open sided (figure 5) modules during high ambient temperatures, increasing airflow throughout the transport. Differences were seen at every location from the first to the second half temperatures.

It was concluded the rise in temperature from the first to second half of transport along all axis shows the diminishing effect resulting from heat mitigation practices employed during loading over the transport period. This is discussed further below. However the uniform temperatures between each location for the second half of transport show that air flow across the trailer is able to evenly dissipate heat from the thermal load.

Table 5. Variation in air temperatures in modules containing broiler chickens during transportation within the trailer (see figure 1) at high* ambient temperatures.

	First Half of Trip[#]	Second Half of Trip[#]
Z axis		
Left	29.7 $\pm$ 0.2[c]	32.3 $\pm$ 0.2
Middle	31.4 $\pm$ 0.3[a]	32.9 $\pm$ 0.2
Right	30.6 $\pm$ 0.2[b]	32.9 $\pm$ 0.2
Y axis		
Bottom	30.0 $\pm$ 0.2[b]	32.4 $\pm$ 0.2[b]
Middle	29.9 $\pm$ 0.2[b]	32.1 $\pm$ 0.2[b]
Top	31.7 $\pm$ 0.2[a]	33.7 $\pm$ 0.2[a]
X axis		
1	31.2 $\pm$ 0.3	33.2 $\pm$ 0.3
2	30.6 $\pm$ 0.3	32.6 $\pm$ 0.3
3	30.6 $\pm$ 0.3	32.7 $\pm$ 0.3
4	30.2 $\pm$ 0.3	32.6 $\pm$ 0.3
5	30.1 $\pm$ 0.3	32.6 $\pm$ 0.3

[abc] Superscripts denote differences ($p<0.05$) within each column and axis.
[*] High ambient trips include those having ambient temperatures from 29.1 to 40.1 ^{0}C
[#] Trip durations range from 45 to 75 minutes.
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip from the farm to the processing plant.

Table 6 Effect of trip duration on micro-environments matched paired analysis comparison of temperatures for the first and second half of trip duration# at high* ambient temperatures across the trailer area (Figure 1.)

	Z axis			Y axis			X axis				
	Left	Middle	Right	Bottom	Middle	Top	1	2	3	4	5
First Half of Trip#	29.70^{b}	31.37^{b}	30.56^{b}	29.95^{b}	29.94^{b}	31.73^{b}	31.15^{b}	30.59^{b}	30.60^{b}	30.22^{b}	30.10^{b}
Second Half of Trip#	32.32^{a}	32.94^{a}	32.94^{a}	32.39^{a}	32.07^{a}	33.74^{a}	33.18^{a}	32.58^{a}	32.65^{a}	32.64^{a}	32.60^{a}
Mean Difference	-2.62	-1.57	-2.38	-2.45	-2.13	-2.01	-2.03	-1.98	-2.05	-2.43	-2.49
Std Error	0.17	0.11	0.16	0.16	0.15	0.16	0.18	0.20	0.22	0.22	0.17
N	107	104	112	110	106	107	67	66	59	70	61
P=	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

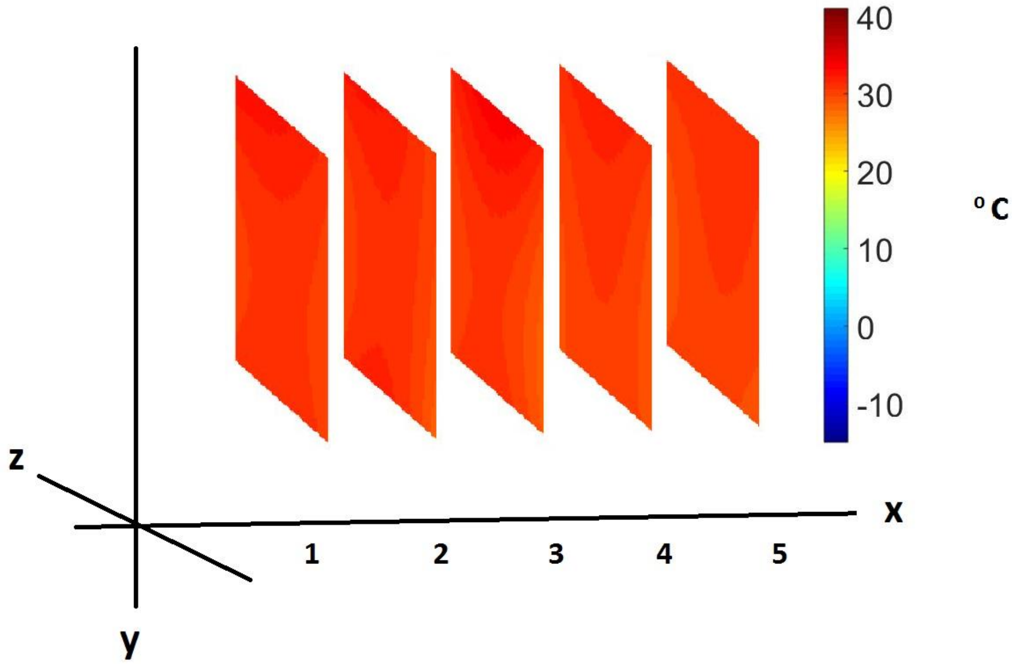
^{ab} Superscripts denote differences ($p<0.05$) within each column and axis.

* High ambient trips include those having ambient temperatures from 29.1 to 40.1 ^{0}C

\# Trip durations range from 45 to 75 minutes.

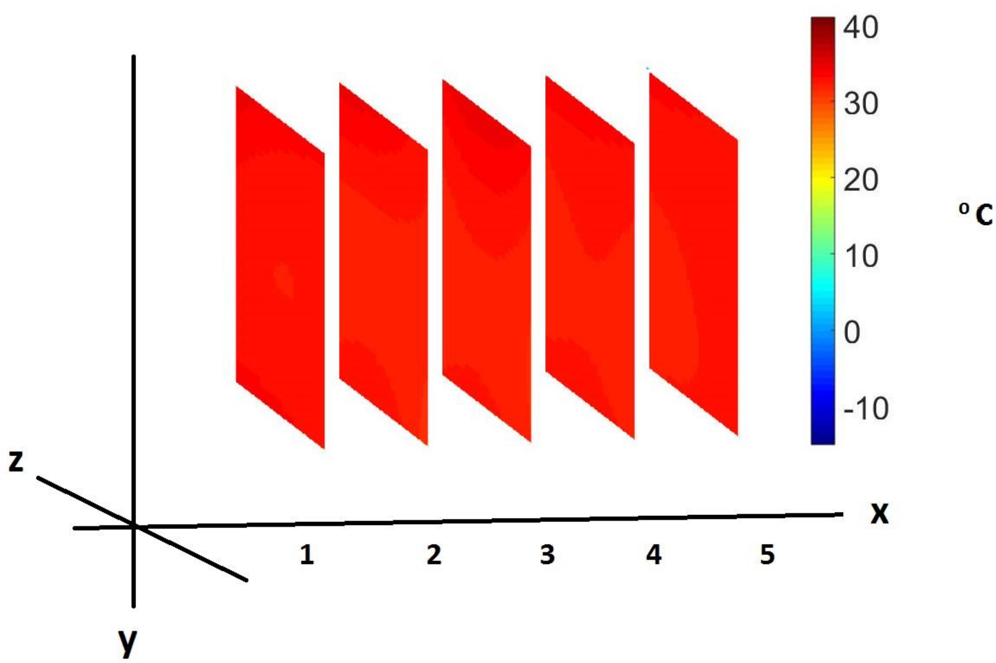
First half temperature is the average temperatures for logger locations (figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip from the farm to the processing plant.

Figure 11. A thermal map of average temperatures for each location throughout the trailer (see figure 1) at high* ambient temperatures within the first half of the trip duration#



* High ambient trips include those having ambient temperatures from 29.1 to 40.1 °C
# Trip durations range from 45 to 75 minutes.

Figure 12. A thermal map of average temperatures for each location throughout the trailer (see figure 1) at high* ambient temperatures within the second half of the trip duration#



* High ambient trips include those having ambient temperatures from 29.1 to 40.1 °C
# Trip durations range from 45 to 75 minutes.

Influence of Plastic Wrap as Temperature Mitigation

During the most adverse cold conditions plastic wrap was used to contain the heat produced by the broilers within the transporter (figure 2). The air temperatures broilers experienced when this treatment is employed is shown in tables 7 and 8.

Temperatures along the Z axis (figure 1), when plastic wrap was used were not different ($p<0.05$) within the first or second half of transport. Differences ($p<0.05$) were seen in temperatures at the left, middle, and right when comparing first half of trip to the second.

Considering the Y axis (see figure 1), the top and bottom locations have a lower temperatures than the middle location for the first half of trip temperatures. The temperatures at the bottom and middle locations are similar while that of the top location is lower ($p<0.05$). When comparing temperatures of the first half of trip to the second half of trip differences ($p<0.05$) for both the top and middle locations were shown ($p<0.05$) while there was no difference measured for the bottom. This is thought to be due to a gap that was present between the top of the plastic wrap and module. This would allow the heat load built during loading to escape once the trip begins.

Within the X axis (see figure 1), location 3 (table 6) temperature differed from all other locations except 1 for the first half of the trip. Temperatures along the X axis for the second half of trip was significantly ($p<0.05$) higher in location 3 compared to locations 1 and 2. First half temperatures compared to second half temperatures decreased ($p<0.05$) excluding location 4.

Table 7. Variation in air temperatures during transportation across the trailer area (figure 1) when plastic wrap* was used (see figure 2).

	First Half of Trip[#]	Second Half of Trip[#]
Z axis		
Left	5.4 $\pm$ 0.7	4.0 $\pm$ 0.8
Middle	7.1 $\pm$ 0.7	5.6 $\pm$ 0.8
Right	6.1 $\pm$ 0.7	5.2 $\pm$ 0.8
Y axis		
Bottom	6.1 $\pm$ 0.7^{b}	5.7 $\pm$ 0.8^{a}
Middle	8.5 $\pm$ 0.7^{a}	6.6 $\pm$ 0.8^{a}
Top	3.9 $\pm$ 0.7^{b}	2.5 $\pm$ 0.8^{b}
X axis		
1	5.5 $\pm$ 0.9^{b}	3.2 $\pm$ 1.1^{b}
2	5.0 $\pm$ 0.9^{b}	3.2 $\pm$ 1.0^{b}
3	9.2 $\pm$ 0.9^{a}	7.8 $\pm$ 1.0^{a}
4	5.7 $\pm$ 0.9^{b}	5.6 $\pm$ 1.0^{ab}
5	5.6 $\pm$ 0.9^{b}	4.8 $\pm$ 1.0^{ab}

^{ab} Superscripts denote differences ($p<0.05$) within each column and axis.

*Ambient temperatures where plastic wrap was used were -15.8 to 2.8 ^{0}C

[#] Trip duration range from 79 to 125 minutes.

First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant.

Table 8 Effect of trip duration on micro-environments matched paired analysis comparison of temperatures for the first and second half of trip duration[#] across the trailer (see Figure 1.) when plastic wrap was used[*].

	Z axis			**Y axis**			**X axis**				
	Left	Middle	Right	Bottom	Middle	Top	1	2	3	4	5
First Half of Trip[#]	5.40[a]	7.05[a]	6.05[a]	6.07	8.48[a]	3.86[a]	5.45[a]	5.01[a]	9.20[a]	5.69	5.55[a]
Second Half of Trrip[#]	4.00[b]	5.58[b]	5.17[b]	5.67	6.61[b]	2.48[b]	3.16[b]	3.20[b]	7.84[b]	5.53	4.83[b]
Mean Difference	1.40	1.47	0.88	0.39	1.87	1.38	2.29	1.80	1.36	0.13	0.72
Std Error	0.38	0.32	0.25	0.35	0.28	0.33	0.28	0.39	0.47	0.51	0.31
N	69	70	67	63	73	70	39	43	41	41	42
P=	0.0004	<0.0001	0.0009	0.2611	<0.0001	<0.0001	<0.0001	<0.0001	0.0056	0.7963	0.0243

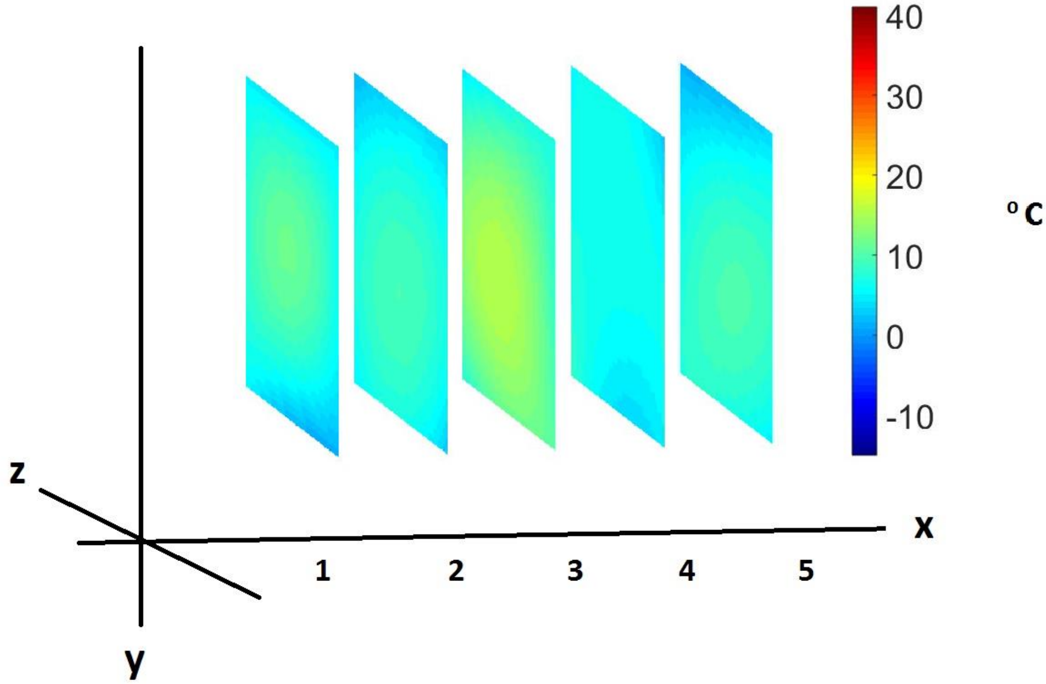
[ab] Superscripts denote differences ($p<0.05$) within each column and axis.

[*]Ambient temperatures where plastic wrap was used were -15.8 to 2.8 ^{0}C

[#] Trip duration range from 79 to 125 minutes.

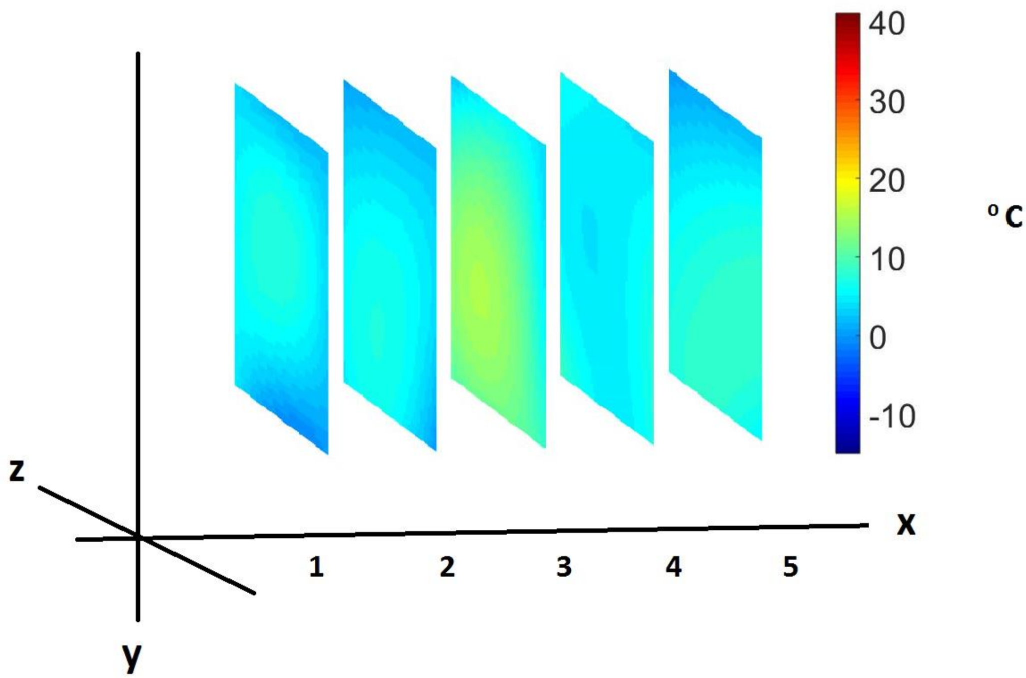
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant. Temperature was recorded every 30 seconds in each location.

Figure 13. A thermal map of average temperatures for each location throughout the trailer(see figure 1) when plastic wrap was used* within the first half of the trip duration#



*Ambient temperatures where plastic wrap was used were -15.8 to 2.8 ^{0}C
Trip duration range from 79 to 125 minutes.

Figure 14. A thermal map of average temperatures for each location throughout the trailer (see figure 1) when plastic wrap was used* within the second half of the trip duration#



*Ambient temperatures where plastic wrap was used were -15.8 to 2.8 ^{0}C
Trip duration range from 79 to 125 minutes.

Influence of Double Side Boards

In cold to cool (-16.4 to 10.4 ^{0}C) conditions double side boards are used to reduce the air flow through the modules during trips. Temperatures were compared along each axis while double side boards were used. Within each half of the trips only a single difference ($p<0.05$) was seen. In the second half of trip along the Z axis the middle was higher than both the left and right location (table 9).

When comparing the first and second half of trip duration (table 10) for the Z axis differences between the left and right were seen (0.9 to 2.3 ˚C). Along the y axis there was no difference ($p<0.05$) from the first and second half temperatures at the bottom location. However differences were present between the middle and top. For the X axis the 2nd and 3rd locations were no different from the first to second half of trip. All other locations decreased ($p<0.05$) from the first to second half of trip.

Temperatures at all locations in the trailer were higher than that of ambient. However temperatures remained cool within the trailer (why do you say it? A literature will help to make your point.). The decreases from the first to second half of the trip were small. This may indicate that the heat produced by the broilers and lost into the surrounding environment is near stabilization. Further work is needed to confirm the level of temperature stabilization using double side boards.

Table 9. Variation in air temperatures during transportation across the trailer area (see figure 1) when double side boards* were used (see figure 3).

	First Half of Trip#	**Second Half of Trip#**
Z axis		
Left	4.7 ± 1.2	3.5 ± 1.3[b]
Middle	8.6 ± 1.2	7.8 ± 1.3[a]
Right	6.2 ± 1.3	5.4 ± 1.3[ab]
Y axis		
Bottom	8.0 ± 1.3	7.3 ± 1.4
Middle	6.6 ± 1.2	5.4 ± 1.3
Top	5.0 ± 1.2	4.1 ±1.3
X axis		
1	8.2 ± 1.6	6.6 ± 1.7
2	5.0 ± 1.6	4.2 ± 1.7
3	8.0 ± 1.6	7.4 ± 1.7
4	7.2 ± 1.6	6.5 ± 1.6
5	3.6 ± 1.7	2.6 ± 1.7

[ab] Superscripts denote differences ($p<0.05$) within each column and axis.
*Ambient temperatures where double side boards were used were -16.4 to 10.4 ^{0}C
Trip duration range from 78 to 107 minutes.
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant.

Table 10 Effect of trip duration on micro-environments matched paired analysis comparison of temperatures for the first and second half of trip duration[#] across the trailer area (see Figure 1.) when double side boards* were used (see figure 3).

	Z axis			**Y axis**			**X axis**				
	Left	Middle	Right	Bottom	Middle	Top	1	2	3	4	5
First Half of Trip[#]	4.74[a]	8.58[a]	6.20[a]	8.04	6.64[a]	4.96[a]	8.21[a]	5.02	8.04	7.23[a]	3.60[a]
Second Half of Trip[#]	3.54[b]	7.79[b]	5.41[b]	7.33	5.38[b]	4.14[b]	6.64[b]	4.23	7.39	6.53[b]	2.62[b]
Mean Difference	1.20	0.79	0.80	0.71	1.25	0.82	1.57	0.79	0.65	0.71	0.98
Std Error	0.26	0.46	0.35	0.42	0.40	0.27	0.39	0.43	0.75	0.31	0.30
N	55	52	49	48	53	55	31	31	32	33	29
P=	<0.0001	0.0912	0.0292	0.0935	0.0031	0.0033	0.0003	0.0770	0.3911	0.0300	0.0025

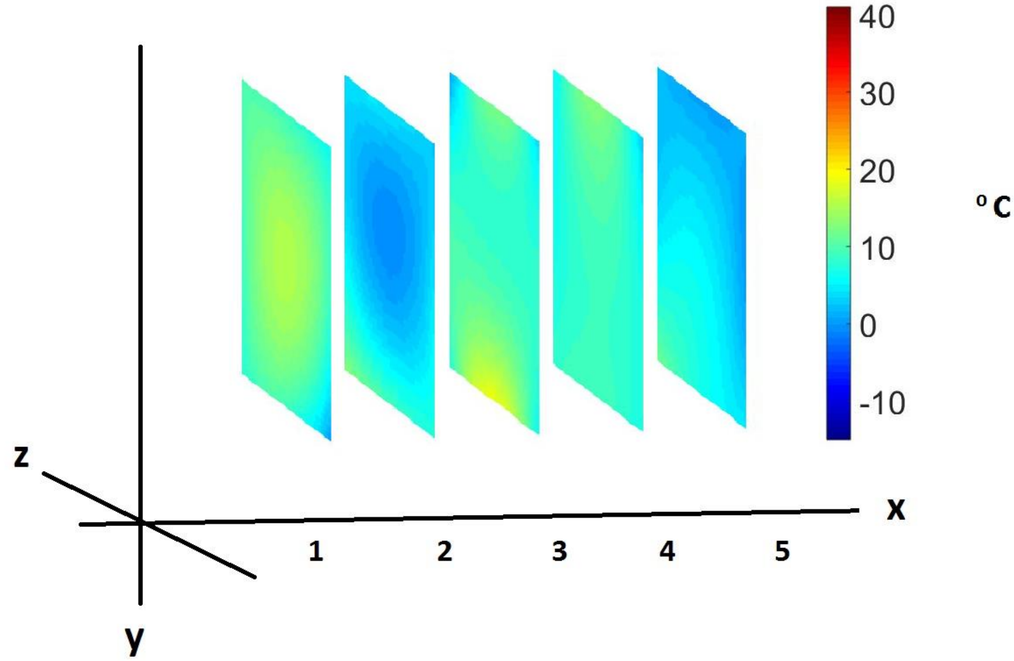
[ab] Superscripts denote differences ($p<0.05$) within each column and axis.

[*]Ambient temperatures where double side boards were used were -16.4 to 10.4 ^{0}C

[#] Trip duration range from 78 to 107 minutes

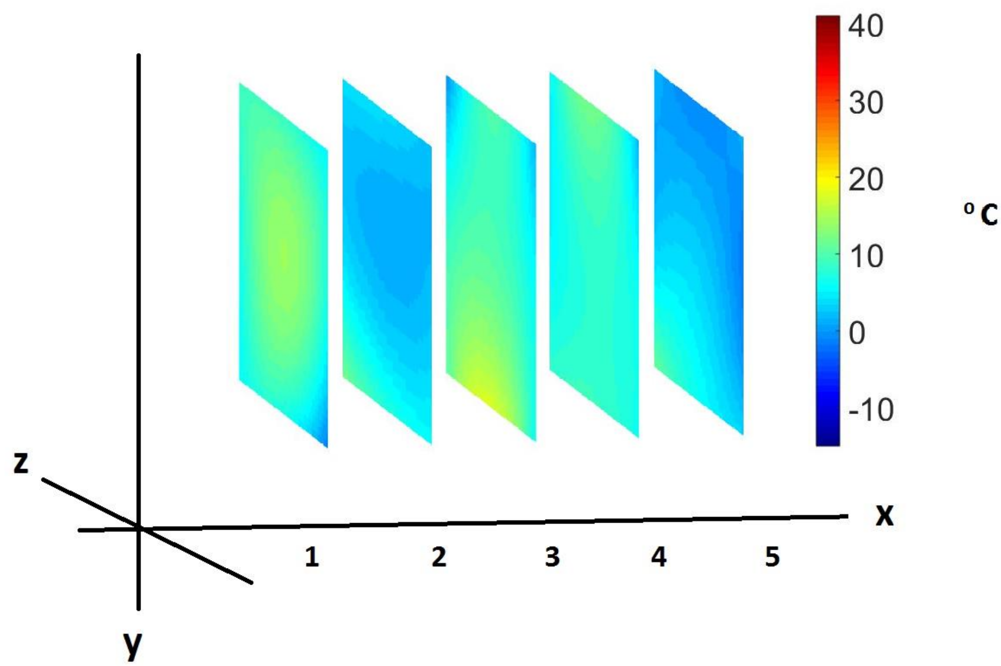
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant.

Figure 15. A thermal map of average temperatures for each location throughout the trailer (see figure 1) when double sideboards were used* within the first half of the trip duration#



*Ambient temperatures where double side boards were used were -16.4 to 10.4 ^{0}C
Trip duration range from 78 to 107 minutes

Figure 16. A thermal map of average temperatures for each location throughout the trailer (see figure 1) when double side boards were used* within the second half of the trip duration#



*Ambient temperatures where double side boards were used were -16.4 to 10.4 ^{0}C
Trip duration range from 78 to 107 minutes

Influence of Single Side Boards

Single side boards are used during the early spring and late fall (2.4 to 21.0 ^{0}C) when ambient temperature variability is high. Temperatures within the transporters using single side boards had few differences (tables 11 and 12).

Considering the Z axis differences ($p<0.05$) were seen between the middle to both left and right for the first-half of trip. For the second half left and middle locations remained different while there was no longer a significant difference ($p<0.05$) between the middle and right.

The few differences seen when using single side boards both along the axes and when comparing the first half of trip to the second suggest that the management practice is effective at maintaining adequate air low while not allowing temperatures to decrease below optimal levels.

Table 11. Variation in air temperatures within modules containing broiler chickens during transportation across the trailer(see figure 1) when single side boards* were used (see figure 4).

	First Half of Trip#	Second Half of Trip#
Z axis		
Left	15.8 ± 0.4[b]	15.3 ± 0.5[b]
Middle	17.8 ± 0.4[a]	17.4 ± 0.5[a]
Right	16.3 ± 0.5[b]	16.2 ± 0.5[ab]
Y axis		
Bottom	16.6 ± 0.4	16.4 ± 0.5
Middle	16.7 ± 0.5	16.4 ± 0.5
Top	16.6 ± 0.5	16.1 ± 0.5
X axis		
1	17.7 ± 0.5	17.0 ± 0.6
2	15.5 ± 0.7	15.6 ± 0.7
3	17.8 ± 0.6	17.3 ± 0.6
4	16.0 ± 0.6	15.6 ± 0.6
5	16.0 ± 0.5	15.8 ± 0.6

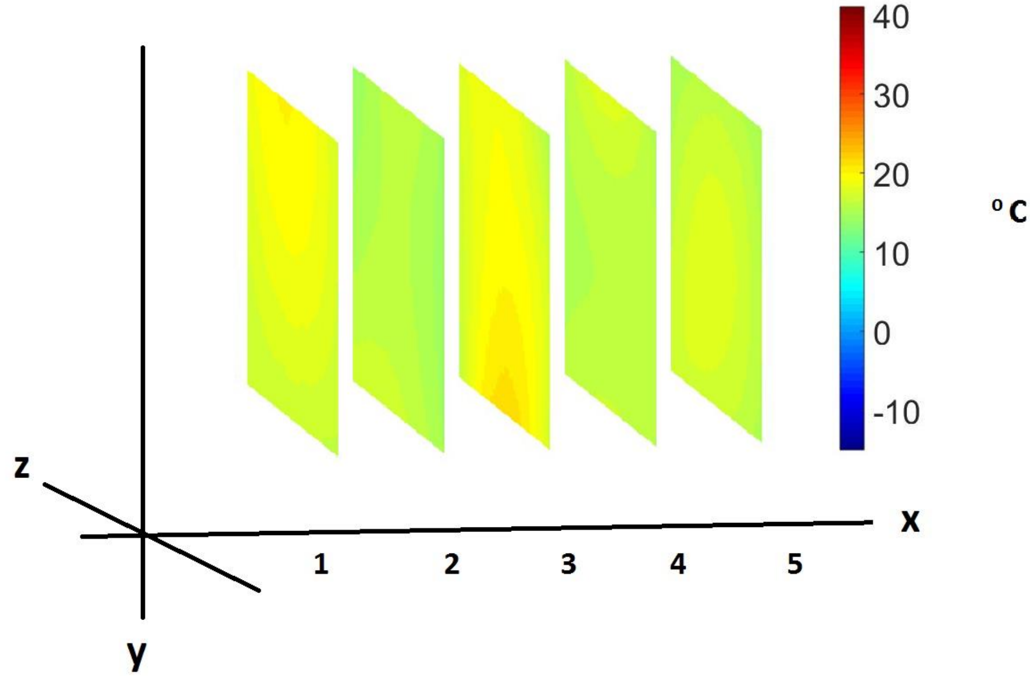
[ab] Superscripts denote differences ($p<0.05$) within each column and axis.
*Ambient temperatures where single boards were used were 2.4 to 21.0 ^{0}C
Trip duration range from 23 to 84 minutes.
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant.

Table 12 Effect of trip duration on micro-environments matched paired analysis comparison of temperatures for the first and second half of trip duration# across the trailer area (see Figure 1.) when single side boards* were used (see figure 4).

	Z axis			**Y axis**			**X axis**				
	Left	Middle	Right	Bottom	Middle	Top	1	2	3	4	5
First Half of Trip#	15.81	17.83	16.31	16.64	16.73	16.58	17.70	15.47	17.77	15.98	15.97
Second Half of Trip#	15.30	17.41	16.15	16.37	16.40	16.07	16.95	15.61	17.27	15.61	15.76
Mean Difference	0.51	0.42	0.16	0.27	0.33	0.51	0.75	-0.14	0.50	0.37	0.21
Std Error	0.15	016	0.14	0.23	0.15	0.18	0.21	0.18	0.24	0.18	0.13
N	114	112	105	114	109	108	72	48	69	70	72
P=	0.0011	0.0111	0.2537	0.0365	0.0257	0.0057	0.0006	0.4365	0.0451	0.0440	0.1142

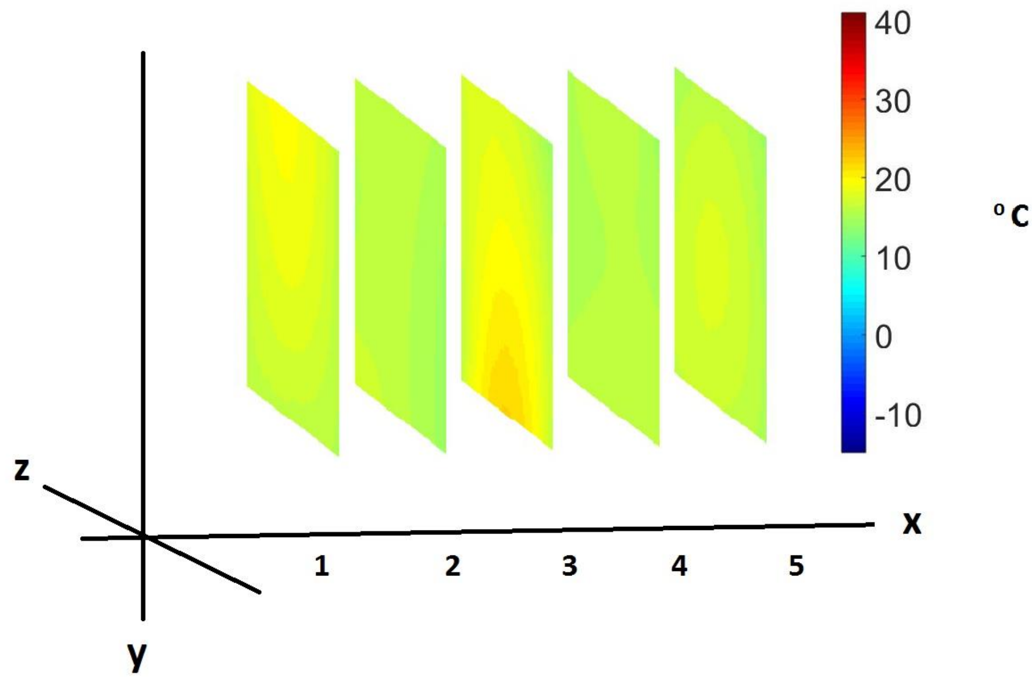
[ab] Superscripts denote differences ($p<0.05$) within each column and axis.
*Ambient temperatures where single boards were used were 2.4 to 21.0 ^{0}C
Trip duration range from 23 to 84 minutes.
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant.

Figure 17. A thermal map of average temperatures for each location throughout the trailer (see figure 1) when single sideboards were used* within the first half of the trip duration#



*Ambient temperatures where single boards were used were 2.4 to 21.0 °C
Trip duration range from 23 to 84 minutes.

Figure 18. A thermal map of average temperatures for each location throughout the trailer (see figure 1) when single side boards were used* within the second half of the trip duration#



*Ambient temperatures where single boards were used were 2.4 to 21.0 °C
Trip duration range from 23 to 84 minutes.

Influence of Open Sided Modules

Open sided modules are the preferred method of transport by industry managers. Temperatures throughout the transporters with open sides had no differences within any of the axes for the first and second half of transport (table 13). Differences ($p<0.05$) were seen between first and second half temperatures at the same locations along each axes excluding location 3 along the X axis (table 14).

Air flow seems to be adequate throughout the trailer when using open sided modules due to the lack of temperature differences along the axes. While the increase in temperatures from first to second half of trip were significant they were small. This demonstrates the ability of the air flow through the trailer to remove the majority of the heat load from the trailer during the trip.

Table 13. Variation in air temperatures within modules containing broiler chickens across the trailer (see figure 1) using open* sided modules (see figure 4).

	First Half of Trip#	**Second Half of Trip#**
Z axis		
Left	24.5 ± 0.8	24.7 ± 0.8
Middle	25.7 ± 0.7	26.0 ± 0.8
Right	24.8 ± 0.7	25.4 ± 0.8
Y axis		
Bottom	25.2 ± 0.7	25.7 ± 0.8
Middle	24.9 ± 0.7	25.2 ± 0.8
Top	24.9 ± 0.8	25.4 ± 0.8
X axis		
1	25.7 ± 0.9	26.2 ± 1.0
2	24.8 ± 1.0	25.2 ± 1.0
3	25.5 ± 0.9	25.8 ± 1.0
4	24.9 ± 0.9	25.3 ± 1.0
5	24.1 ± 1.0	24.5 ± 1.0

*Ambient temperatures where open sided module were used were 19.3 to 29.1 ^{0}C

Trip duration range from 63 to 105 minutes.

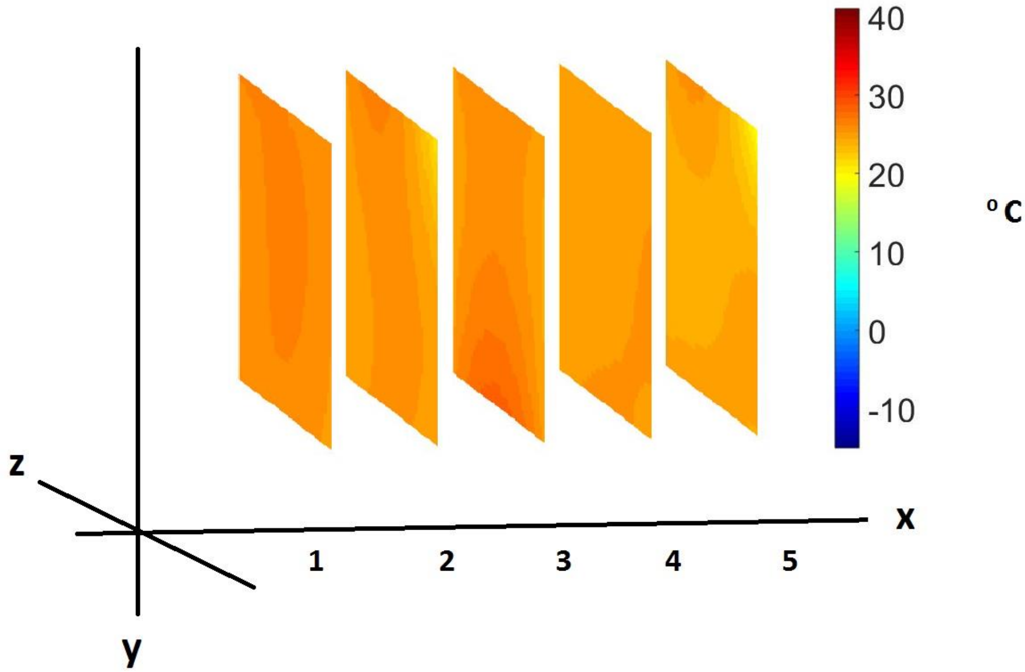
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant. Temperature was recorded every 30 seconds in each location.

Table 14 Effect of trip duration on micro-environments matched paired analysis comparison of temperatures for the first and second half of trip duration[#] across the trailer area (see Figure 1.) when using open sided modules (see figure 4).

	Z axis			**Y axis**			**X axis**				
	Left	Middle	Right	Bottom	Middle	Top	1	2	3	4	5
First Half of Trip[#]	24.47[b]	25.65[b]	24.88[b]	25.24[b]	24.89[b]	24.91[b]	25.73[b]	24.78[b]	25.49	24.88[b]	24.14[b]
Second Half of Trip[#]	24.70[a]	25.99[a]	25.43[a]	25.68[a]	25.16[a]	25.33[a]	26.18[a]	25.15[a]	25.76	25.25[a]	24.54[a]
Mean Difference	-0.23	-0.34	-0.55	-0.44	-0.27	-0.42	-0.46	-0.37	-0.27	-0.37	-0.41
Std Error	0.11	0.09	0.14	0.12	0.11	0.12	0.15	0.15	0.15	0.14	0.15
N	56	60	60	60	60	56	36	34	36	36	34
P=	0.0396	0.0005	0.0002	0.0005	0.0174	0.0007	0.0047	0.0171	0.821	0.0141	0.0120

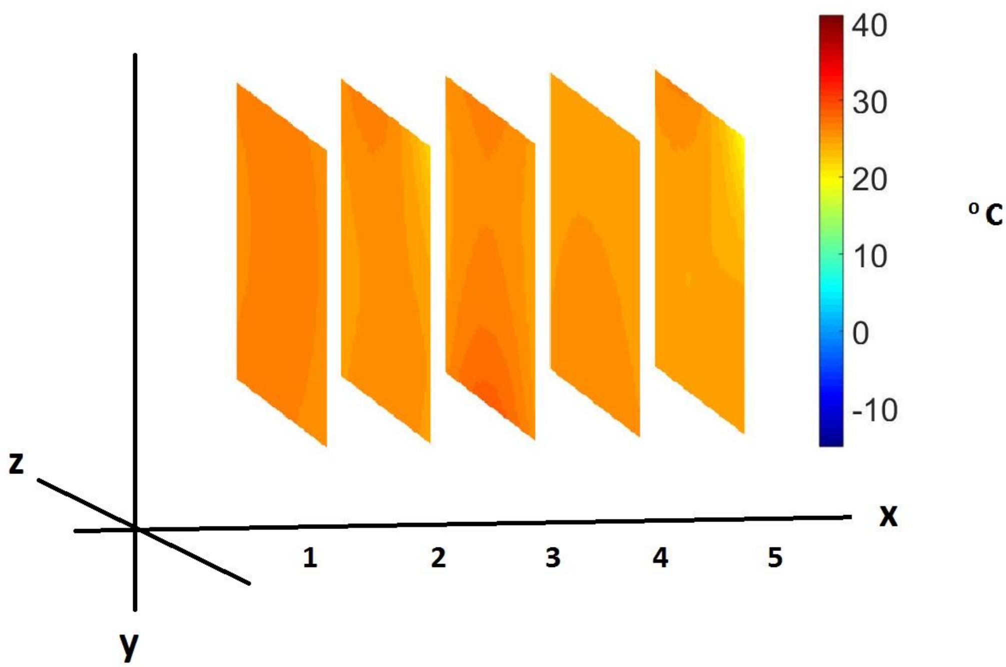
[ab] Superscripts denote differences ($p<0.05$) within each column and axis.
[*]Ambient temperatures where open sided module were used were 19.3 to 29.1 ^{0}C
[#] Trip duration range from 63 to 105 minutes.
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant. Temperature was recorded every 30 seconds in each location.

Figure 19. A thermal map of average temperatures for each location throughout the trailer (see figure 1) when open sides were used* within the first half of the trip duration#



*Ambient temperatures where open sided module were used were 19.3 to 29.1 ^{0}C
#Trip duration range from 63 to 105 minutes.

Figure 20. A thermal map of average temperatures for each location throughout the trailer (see figure 1) when open sides were used* within the second half of the trip duration#



*Ambient temperatures where open sided module were used were 19.3 to 29.1 ^{0}C
#Trip duration range from 63 to 105 minutes.

Influence of Heat Mitigation during Loading

Trailers monitored when heat mitigation (see figure 5) was applied on farms had unique temperature profiles (Table 15 and 16). Considering the Z axis all locations along the axis were different ($p<0.05$) for the first half of trips. Differences may be due to heat mitigation trailers (figure 6) placed on the right side of the transport while water was also directly applied by a hand-held hose from the left side. Temperatures were highest at the middle location as would be expected. Along the Y axis temperatures were higher at the top of the transport due to the exposure to direct sunlight.

Temperatures at all locations increased from the first to second half of transport (Table 16). This is due to the water applied during loading evaporating as the trailer travels to the processing plant.

Heat mitigation practices were able to maintain temperatures at or below the ambient temperature for the first half of transport yet still above thermal neutral levels dependent on air velocity and humidity (Tao and Xin, 2003).

Table 15. Variation in air temperatures within modules containing broiler chickens during trips across the trailer (see figure 1) using heat mitigation* (see figure 5).

	First Half of Trip[#]	Second Half of Trip[#]
Z axis		
Left	29.4 ± 0.3^{c}	32.4 ± 0.2
Middle	31.4 ± 0.3^{a}	33.0 ± 0.2
Right	30.4 ± 0.3^{b}	32.8 ± 0.2
Y axis		
Bottom	29.8 ± 0.3^{b}	32.4 ± 0.2^{b}
Middle	29.8 ± 0.3^{b}	32.1 ± 0.2^{b}
Top	31.6 ± 0.3^{a}	33.8 ± 0.2^{a}
X axis		
1	31.0 ± 0.4	33.1 ± 0.3
2	30.5 ± 0.4	32.6 ± 0.3
3	30.4 ± 0.4	32.7 ± 0.3
4	30.1 ± 0.4	32.7 ± 0.3
5	30.0 ± 0.4	32.7 ± 0.3

[ab] Superscripts denote differences ($p<0.05$) within each column and axis.

[*]Ambient temperatures where heat mitigation used were 30.5 to 40.1 ^{0}C

[#] Trip duration range from 42 to 74 minutes.

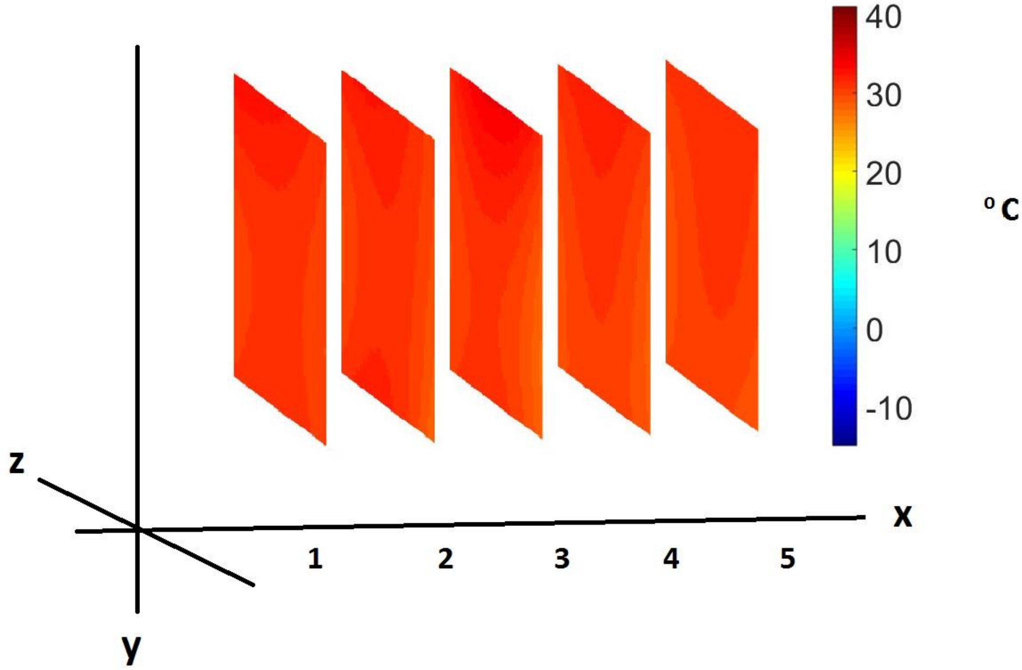
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant. Temperature was recorded every 30 seconds in each location.

Table 16 Effect of trip duration on micro-environments matched paired analysis comparison of temperatures for the first and second half of trip duration[#] across the trailer area (see Figure 1.) when using heat mitigation (see figure 5).

	Z axis			**Y axis**			**X axis**				
	Left	Middle	Right	Bottom	Middle	Top	1	2	3	4	5
First Half of Trip[#]	29.44[b]	31.41[b]	30.41[b]	29.78[b]	29.77[b]	31.63[b]	30.98[b]	30.50[b]	30.44[b]	30.05[b]	30.02[b]
Second Half of Trip[#]	32.42[a]	33.03[a]	32.83[a]	32.42[a]	32.09[a]	33.75[a]	33.13[a]	32.58[a]	32.68[a]	32.70[a]	32.67[a]
Mean Difference	-2.99	-1.63	-2.42	-2.64	-2.31	-2.12	-2.15	-2.08	-2.24	-2.65	-2.67
Std Error	0.16	0.13	0.18	0.17	0.16	0.17	0.20	0.22	0.25	0.23	0.18
N	94	89	97	95	91	94	58	58	50	61	53
P=	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

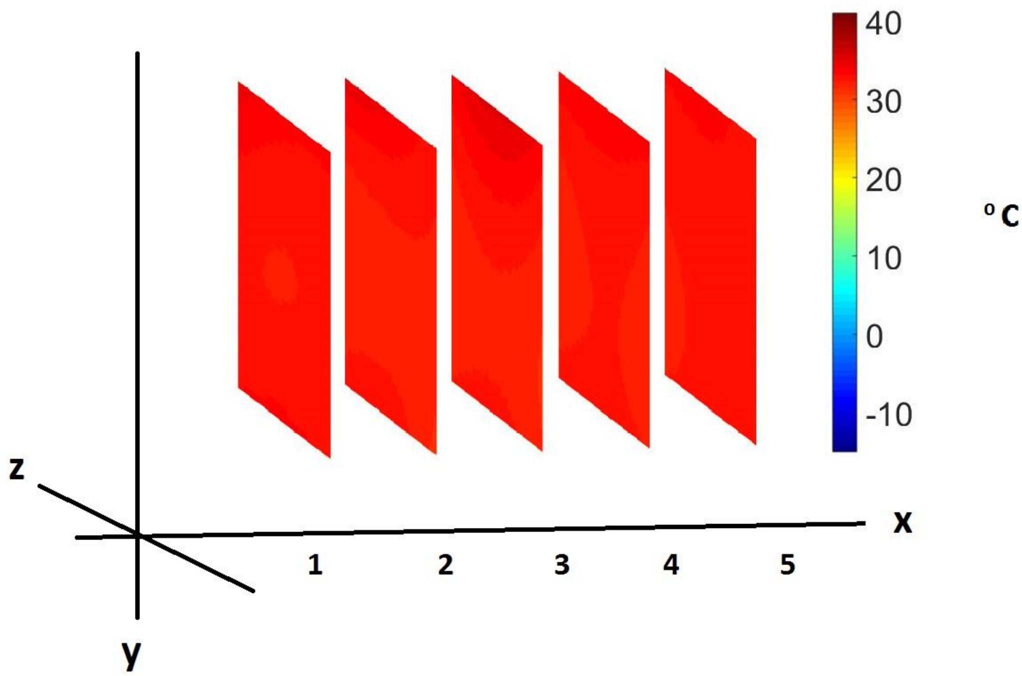
[ab] Superscripts denote differences ($p<0.05$) within each column and axis.
[*]Ambient temperatures where heat mitigation used were 30.5 to 40.1 ^{0}C
[#] Trip duration range from 42 to 74 minutes.
First half temperature is the average temperatures for logger locations (see figure 1) from the time of departure from the farm till half the trip duration to the processing plant. The second half temperature is the average temperature along the indicated axis within the trailer starting at the midpoint of the trip duration from the farm to the processing plant. Temperature was recorded every 30 seconds in each location.

Figure 21. A thermal map of average temperatures for each location throughout the trailer (see figure 1) when heat mitigation was used* within the first half of the trip duration#



*Ambient temperatures where heat mitigation used were 30.5 to 40.1 °C
#Trip duration range from 42 to 74 minutes.

Figure 22. A thermal map of average temperatures for each location throughout the trailer (see figure 1) when heat mitigation was used* within the second half of the trip duration#



*Ambient temperatures where heat mitigation used were 30.5 to 40.1 °C
#Trip duration range from 42 to 74 minutes.

Conclusion

Ambient Temperature Groups

Overall temperatures throughout the trailer were below ideal (Hunter et al., 1999) levels for low ambient trips. Temperature variation within the trailer was relatively small but statistically significant. While improvements are needed the common suggestion of using of curtain-sided trailer has its own problems. For instance, Knezacek et al. (2010) showed that using curtain sided trailers in extremely cold (-7.1 to -28.2) temperatures markedly raised temperatures at central locations (>30^{o}C). This was above optimal levels. Temperatures as low as -0.7^{o}C were also reported showing great variability of temperatures within a trailer (Knezacek et al., 2010). While improvements are needed to the management practices used to mitigate the cold temperatures any alterations should strive to maintain a similar uniformity of temperature to that of current practices.

Considering moderate ambient temperatures, some significant ($p<0.05$) changes were present from the first half of trip temperatures to the second, changes were few and small (less than 1^{0}C).

The conclusion was made that the lack of diverse temperatures indicates a relatively uniform environment is achievable in the trailer at moderate ambient temperatures. This uniform environment is improved more so once the heat built up during loading is removed during transport (table 4).

For trips at high ambient temperatures (29.1 to 40.1 ^{0}C), trailer temperatures were lower ($p<0.05$) during the first half of transport than the second due to the effects of heat mitigation practices. While these practices were effective, further improvements would be beneficial.

Temperature Mitigation Practices

Considering heat mitigation practices it was concluded that while on farm and early trip temperatures may remain in an acceptable range to maintain bird wellbeing if wind chill were to be considered.

However for trips of longer duration heat mitigation applications may not maintain a temperature to sustain wellbeing within the trailer. A stop for reapplication of heat mitigation or an onboard applicator for use during trips may improve the temperature within the trailer for longer trips.

It was concluded that while open sided modules provided reasonably comfortable temperatures for this duration, trips with longer transit time may exceed optimal or thermoneutral ranges if temperatures continued to increase. Such small changes as seen in this study may also be influenced by any increase solar radiation or a change in ambient wind speed. The influence of these factors as well as time of day need further investigation into their effects on the live haul environment under all temperature mitigation practices.

Small differences (<1^{o}C) were seen when the first and second half of trip using single side boards was compared. This led to the conclusion that the use of single side boards can be an effective management practice to maintain temperatures within the trailers at cool to mild ambient temperatures.

Trailer temperatures recorded for trips using double side boards indicated similar, but not as profound pattern compared to earlier reports (Mitchell and Kettlewell, 1998; Kettlewell et al., 2001; Knezacek et al., 2010), showing lower interior locations of transporter having the highest temperatures. However, results in this study were not as extreme in the differences of temperature across the trailer. While trailer temperatures were maintained above ambient when using double side boards the difference remained small. It was concluded that the use of double side boards improved the temperature within the trailer at cold temperatures. Even so, better methods of heat retention should be considered in extremely cold conditions.

Overall it was concluded the decrease in temperatures from the first to the second half of transport show that any effect that plastic wrap has on heat retention decreases during the two periods. Variation of temperatures within the transporter remained low compared to that of other finding using other transport systems (Mitchell and Kettlewell, 1998; Knezacek et al., 2010). This suggests that even with each module being wrapped air flow may be similar to that of double side boards.

When considering the entire range of temperatures characterized (-16.4 to 40.1^{o}C), temperatures within the transporter remain within a safe range (Hunter et al., 1999; Mitchell et al., 2001; Tao and Xin, 2003) for broilers accept at the most high and low ambient conditions. However the need remains for improvements to current system to provide optimal temperatures within transporters in sub-optimal ambient conditions. It should be noted that the extreme high and low ambient conditions included in this study are not representative of the majority of live haul conditions in the region, but are possible a small number of time per year. This suggest that the thermal environments within the broiler live haul trailers in the Central South United States do not compromise broiler welfare under the most frequent ambient conditions.

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Conclusion

The studies examined the temperatures experienced by market age broilers in the transporters during their movement from grower houses to processing plants. Temperatures were measured under standard industry transport “live haul” conditions in the Central Southern United states. Transportation was sub-divided by environmental temperatures: high (29.1 to 40.1 ^{0}C), moderate (6.2 to 23.4 ^{0}C), and low (-16.4 to 2.80 ^{0}C) ambient temperatures. Temperature mitigation practices were evaluated. In addition, effects on the micro thermal environment within the transporter by the different mitigation practices in use by the industry were investigated.

Research has been conducted in Europe to understand poultry transport under European industry standard practices (Freeman et al., 1984; Dalley et al., 1996; Hoxey et al., 1996; Mitchell and Kettlewell, 1998; Kettlewell et al., 2000; Dadgar et al., 2010). However, there is little research on the live haul environment using US standard equipment (Ritz et al., 2005). Ritz and colleagues (2005) in the South East United states found the thermal conditions during pre-loading and holding to be more of a concern than that of transport during hot conditions. No other work found in the literature has characterized the environments within industry transporters in the United States.

Our findings show that temperature mitigation practices improve the environment experienced by broilers during transport. Under cold conditions (-15.8 to 2.8 ^{0}C) when plastic wrap was used the use temperatures were 11.8 ^{O}C above ambient. However the temperatures within the transporter remained below optimal conditions (Hunter et al., 1999). During cold (-16.4 to 10.4 ^{0}C) conditions, using double side boards, broilers experienced a decrease in temperature from the first to second half of transport duration. Under moderate conditions (2.4 to 29.1 ^{o}C), when single side board and open sides were used, there were small changes ($p<0.05$) from the first to second half of trip duration (<1.00 ^{o}C). At high temperatures, heat mitigation practices decreased ($p<0.05$) temperatures from ambient. Temperatures experienced by broilers were an average of 3.99 ^{o}C below ambient for the first half of the transport duration. Temperatures rose during the second half of transport to only be 1.63 ^{o}C below ambient. It was concluded that optimal temperatures, to ensure the wellbeing of the broilers, may not maintained across the transporter depending on humidity, wind velocity, and duration (Tao and Xin, 2003).

When considering the micro-climates throughout the trailer temperatures were reported along each axis (X, Y, and Z). Differences along each axis ($p<0.05$) were small (<5.00 ^{o}C) compared to those reported using other transport systems (Kettlewell et al., 2001; Knezacek et al., 2010). Although the environments were improved relative to ambient temperatures, improvements to mitigation practices are needed.

The use of enclosed trailer is often suggested but caution is expressed to avoid induction of highly variable micro-climates. Improvements to the industry standard methods of temperature mitigation and research to understand micro-climates induced by improvements should continue together. Further work is also need to expand existing comfort indexes to include the complete range of conditions (temperature, humidity, air velocity, and duration) experienced during all seasons.

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Appendix

UNIVERSITY OF ARKANSAS

Office of Research Compliance

MEMORANDUM

TO: Dr. Yi Liang

FROM: Craig N. Coon, Chairman
Institutional Animal Care and Use Committee (IACUC)

DATE: 12-8-14

SUBJECT: IACUC APPROVAL
Expiration date: January 1, 2018

The Institutional Animal Care and Use Committee (IACUC) has APPROVED your protocol 15026: *'Characterizing Thermal micro-Environment during Poultry Transportation'* to begin January 2nd, 2015.

In granting its approval, the IACUC has approved only the information provided. Should there be any further changes to the protocol during the research, please notify the IACUC in writing (via the Modification form) prior to initiating the changes. If the study period is expected to extend beyond January 1, 2018 you must submit a new protocol prior to that date to avoid any interruption. By policy the IACUC cannot approve a study for more than 3 years at a time.

The IACUC appreciates your cooperation in complying with University and Federal guidelines involving animal subjects.

CNC/aem

cc: Animal Welfare Veterinarian

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