





Thermal Field in the Cargo Compartment of a Single Box Trucks During the Transport of Day-Old Chicks: a Kriging Interpolation Analysis

Perfil Térmico no Compartimento de Carga de um Único Caminhão Baú Durante o Transporte de Pintinhos de um Dia: Análise por Interpolação de Kriging

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Abstract

One-day-old chicks require strict thermal control during transportation to ensure their well-being and survival. This study aims to evaluate the internal environmental conditions inside the cargo compartment of a box truck during the transport of 62,000 chicks over a 520 km journey lasting 11 hours. Temperature data were collected using sensors and analyzed using the Kriging method to generate thermal distribution maps from the cargo compartment of the box truck. Although the air conditioning system of the box truck was designed to maintain an ambient temperature within the range of 24 °C to 26 °C, the results have shown a higher prevalence of elevated temperatures in the front section of the compartment, with peaks of 27 °C, thus, revealing significant temperature deviations from the recommended range, indicating inadequate environmental control. These findings emphasize the need for improved thermal regulation systems during road transportation to ensure the chicks' well-being and health, contributing to greater productivity efficiency in the poultry industry.

Keywords: Bird Transportation. Hygrothermal Conditions. Poultry Farming. Thermal Stress.

Resumo

Pintinhos de um dia de idade requerem controle térmico rigoroso durante o transporte para garantir seu bem-estar e sobrevivência. Este estudo avaliou as condições ambientais internas no compartimento de carga de um caminhão baú durante o transporte de 62.000 pintinhos em um percurso de 520 km com duração de 11 horas. Dados de temperatura foram coletados por meio de sensores e analisados utilizando o método de Kriging para gerar mapas de distribuição térmica do compartimento de carga. Embora o sistema de ar-condicionado do caminhão baú tenha sido projetado para manter a temperatura ambiente na faixa de 24 °C a 26 °C, os resultados mostraram uma maior prevalência de temperaturas elevadas na parte frontal do compartimento, com picos de 27 °C. Assim, revelando desvios significativos de temperatura em relação à faixa recomendada, indicando controle ambiental inadequado. Esses achados ressaltam a necessidade de melhorar os sistemas de regulação térmica durante o transporte rodoviário, visando assegurar o bem-estar e a saúde dos pintinhos e contribuir para maior eficiência produtiva na indústria avícola.

1 Introduction

The main challenge in managing densely populated broiler farming is controlling the environment's temperature, which must be adjusted according to weather conditions and the chickens' growth stage (Al-Abdullatif; Azzam, 2023; Madkour *et al.*, 2022). Proper temperature management is essential to ensure optimal growth and development during the brooding period (Lorencena *et al.*, 2022; Loyau *et al.*, 2014). Difficulties in temperature control can be mitigated by improving the climate system with additional equipment (sprinklers, exhaust fans, and insulation) (Martinez *et al.*, 2024; Ramadiani *et al.* 2021; Ribeiro, Yanagi Junior, 2022).

Chicks are ready for transport to the farm at the end of the 21-day incubation period (De Jong *et al.*, 2020; Sindhurakar; Bradley, 2010). Born with a residual yolk, they can remain comfortable without feed and water for up to two days, provided the temperature inside the chick boxes is maintained within the thermoneutral comfort zone (Moreira *et al.*, 2024; Panda; Bhanja; Sunde, 2015). Within a narrow range from 32 °C to 35 °C, the chick's metabolism remains maintained, with minimal heat production and low water loss (Clímaco *et al.*, 2024; McKechnie *et al.*, 2016). If the temperature exceeds this range, chicks will begin to use the energy from the yolk sac to facilitate panting behavior in an attempt to maintain their ideal body temperature from 40 °C to 40.5 °C (Dayan *et al.*, 2020; Maman *et al.*, 2019). In addition to an increase in rectal temperature, there is also an increase in respiratory rate, which consequently affects metabolism to stimulate evaporative heat loss (panting behavior) and maintain thermal balance (Shakeri *et al.*, 2020). The proteins used in this process will no longer be available for the immune and digestive systems development (Krishnan *et al.*, 2023). Conversely, if the temperature falls below the thermoneutral zone, chicks will be forced to use their energy resources for thermoregulation instead of growth and health (Clímaco *et al.*, 2024; Vieira *et al.*, 2019). Thus, temperature-induced stress causes discomfort and developmental complications in the birds (Bilal *et al.*, 2021; Lunny *et al.*, 2020), leading to long-term effects on growth and survival (Andreasson; Nord; Nilsson, 2018).

During the first 20 days, chicks exhibit more poikilothermic than homeothermic characteristics due to their low metabolic heat production during the first six days, their high surface area-to-body weight ratio, and their potential for dissipating metabolic heat (Mujahid, 2010; Price, Dzialowski, 2018). The transportation of one-day-old chicks presents several issues related to the lack of standardization in transport trucks regarding internal environment control and birds' welfare

(Nazareno *et al.*, 2015; Yerpes; Llonch; Manteca, 2021). The thermal stress birds may experience during transport leads to energy loss, which slows down chick's development upon arrival at the farm (Vieira *et al.*, 2019). Poor development results in a final product below industry expectations (Jacobs *et al.*, 2016). To achieve productive efficiency, broilers must be maintained within the thermoneutral zone from birth to slaughter (Oliveira *et al.*, 2018).

Previous studies indicate that internal transport conditions can exhibit significant thermal heterogeneity, even in climate-controlled trucks with air conditioning systems, leading to thermal stress in chicks and negatively impacting their development (Hu *et al.*, 2024; Nazareno *et al.*, 2015; Nazareno *et al.*, 2020; Yerpes; Llonch; Manteca, 2021). The thermal field analysis of poultry transport has shown that temperatures below the ideal range (32–35 °C) lead to energy consumption from the yolk sac for thermoregulation, compromising the immune and digestive systems development (Krishnan *et al.*, 2023; Mangan, Siwek, 2024).

In this context, this study aims to evaluate the thermal field within the cargo compartment of climate-controlled box trucks used for transporting one-day-old chicks by applying statistical interpolation through Kriging. The goal is to identify temperature distribution patterns and critical thermal zones that may compromise the animal's welfare, and, therefore providing insights for optimizing the climate control system and improving transport conditions in the poultry industry.

To analyze these variations, statistical interpolation using Kriging is an effective method, as it employs semivariograms to measure data autocorrelation (Batista *et al.*, 2017) and generate detailed thermal maps (Moonchai; Chutsagulprom, 2020). This method allows for the identification of thermal patterns and deviations inside the cargo compartment, providing essential insights for improving poultry transport (Landim, 2006; Novais, 2016; Vieira *et al.*, 2016).

2 Material and Methods

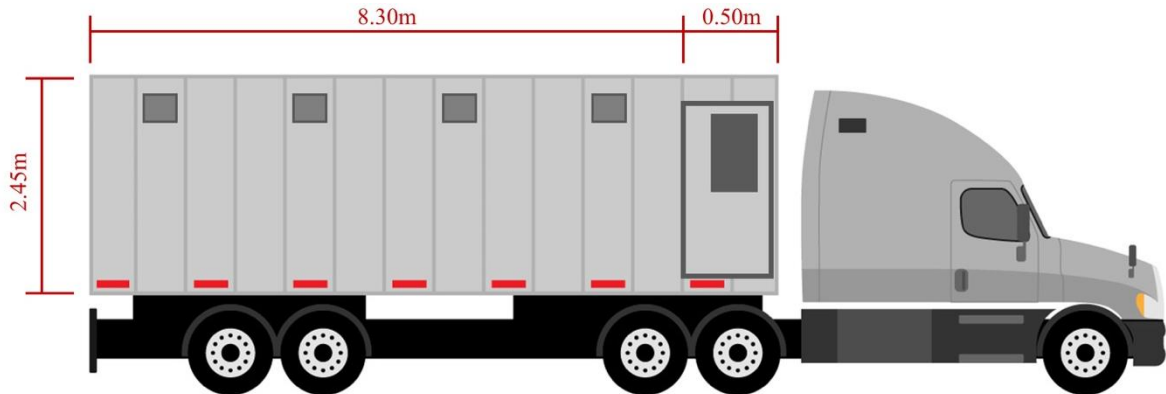
This section outlines the characteristics of the study object, the instrumentation employed, the experimental procedures followed, and the statistical interpolation methods utilized.

2.1 Characteristics of the Study Object

The trailer used for transporting the chicks has a cargo box length of 8.30m and an additional 0.50m allocated for air filters. It has a width of 2.45m and a height of 2.45m (Figure 1). The trailer is equipped with thermal insulation made of expanded polyurethane and features an internal and external aluminum coating. The compartment has two rear doors with non-hermetic sealing, two side

doors for refrigeration equipment maintenance, and an air intake.

Figure 1 – Side view of the chick transport trailer, showing the 8.30m-long cargo box, 2.45m width, 2.45m height, and an additional 0.50m allocated for air filters

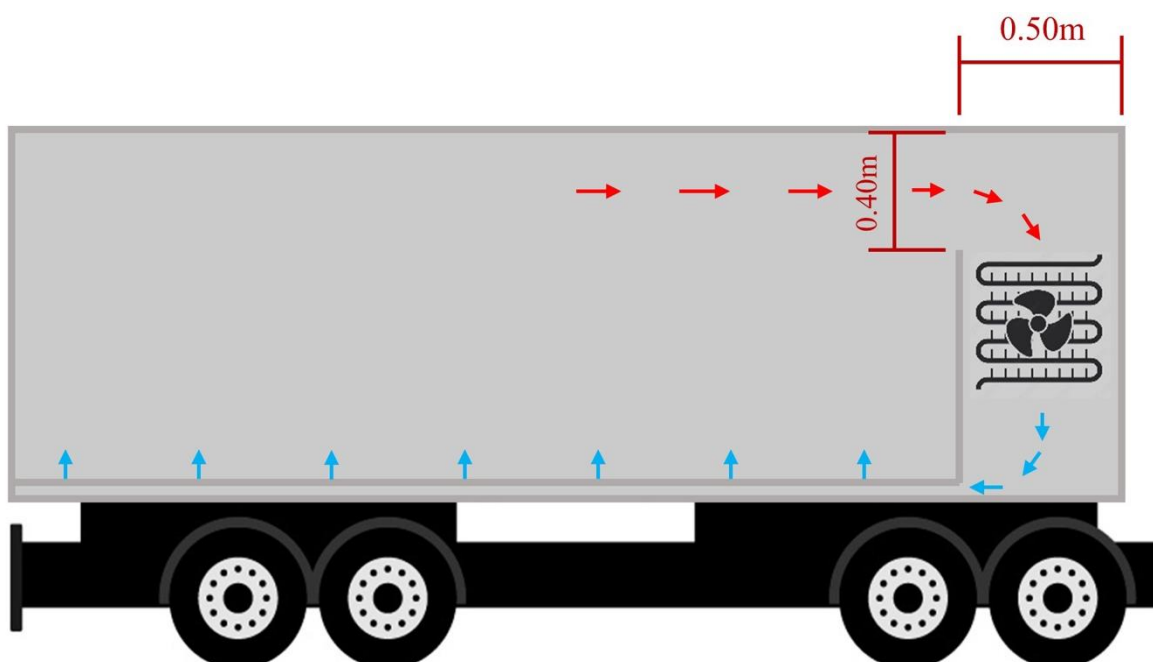


Source: the authors.

Air ventilation occurs through openings in the side walls. The trailer has a load capacity of 75,000 chicks. The boxes used for transporting the birds are made of high-density polyethylene, each with a capacity of 100 chicks.

Air enters through a vent on the side of the compartment, where it is conditioned by the refrigeration system (Figure 2) and distributed through perforated ducts running along the floor to the rear of the cargo area.

Figure 2 – Internal side view of the trailer, showing the refrigeration system and the air circulation through floor ducts



Source: the authors.

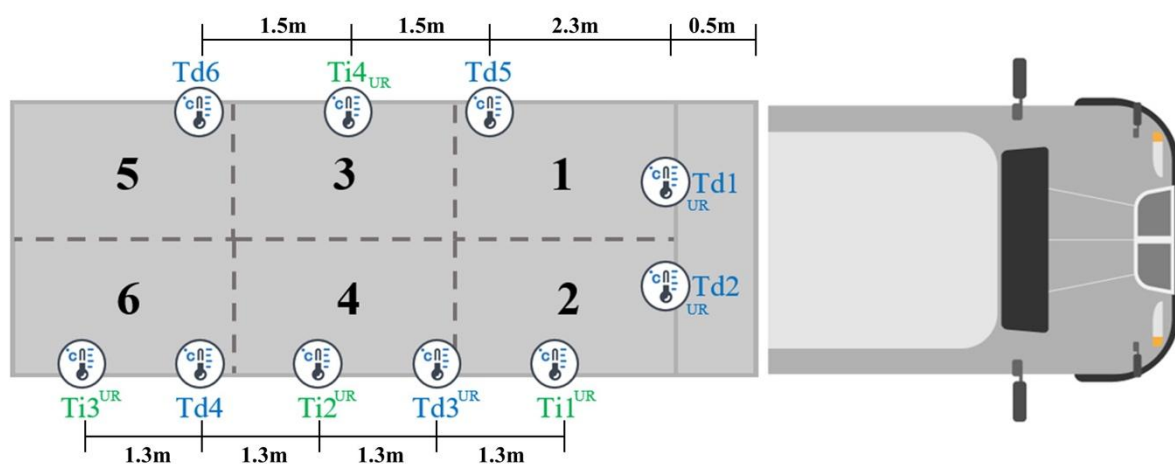
Inside the cargo compartment, there are six exhaust fans on the side walls, eight ceiling fans, two CO₂ sensors, eight temperature and relative humidity sensors, four additional temperature sensors, five air filters, and a refrigeration system (air-conditioning).

Inside the compartment, air circulation is maintained by the operation of the exhaust fans and ceiling fans. The refrigeration system is designed to keep the ambient temperature within the range from 24 °C to 26 °C.

2.2 Instrumentation

The cargo compartment was divided into six equal-sized zones, and the sensors used for data collection were arranged as shown in Figure 3, attached to the internal wall of the compartment at different heights. External temperatures were measured using a temperature sensor placed outside the driver's cabin. These data were compared with the temperatures recorded on the reference date by INMET (National Institute of Meteorology).

Figure 3 – Cargo compartment zoning and sensor positions, showing the six equal-sized zones and sensors installed at different heights on the internal wall.



Source: the authors.

2.3 Experimental Procedure

The collected data were processed using Excel to determine the average temperature in each zone. Based on this, the temperature difference between each zone and the truck's average temperature was analyzed, as well as the presence of the environment within the thermoneutral zone, with temperatures ranging from 23 °C to 26 °C.

The external temperature was determined as the average between the external temperature measured by the truck and the reference temperature provided by the National Institute of Meteorology, taken at the closest possible location and time to the measurement. The charts include

markers indicating the moments when heating, cooling, and cargo compartment exhaust systems were activated, as these systems were only turned on at certain points during the journey.

A mean deviation chart was plotted, which is a measure of variability indicating how far each data point deviates from the average. These values are calculated using Equation (2).

$$e = xi - \bar{x} \quad (2)$$

This value was represented as a percentage, along with the mean deviation, which represents the average of the absolute distances between each data point and the dataset mean, calculated using Equation (3):

$$DM = \frac{\sum |xi - \bar{x}|}{n} \quad (3)$$

Where n represents the number of data collection points. Finally, variance analyses were performed for each case, providing greater statistical confidence in the conclusions. This process was conducted using Excel's one-way ANOVA (Analysis of Variance), which statistically evaluates whether there are significant differences between the group means, considering both within-group and between-group variations.

The null hypothesis (H_0) was defined as the absence of significant differences between the measurement points means, while the alternative hypothesis (H_1) stated that at least one measurement point has a mean significantly different from the others. As a result, a P-value is obtained, representing the probability of observing an F-statistic. If this probability is high, we can assume the null hypothesis is true. This value is considered valid for $P \geq 0.05$.

2.4 Statistical interpolation

Kriging method was used to model the spatial dependence of temperature to estimate temperature values at other points inside the cargo compartment. Based on the collected data, a semivariogram was generated using the GS+ software. This semivariogram was then used to model the variability structure of the temperatures, being fitted to the most appropriate model. The model selection was based on the lowest sum of squared residuals.

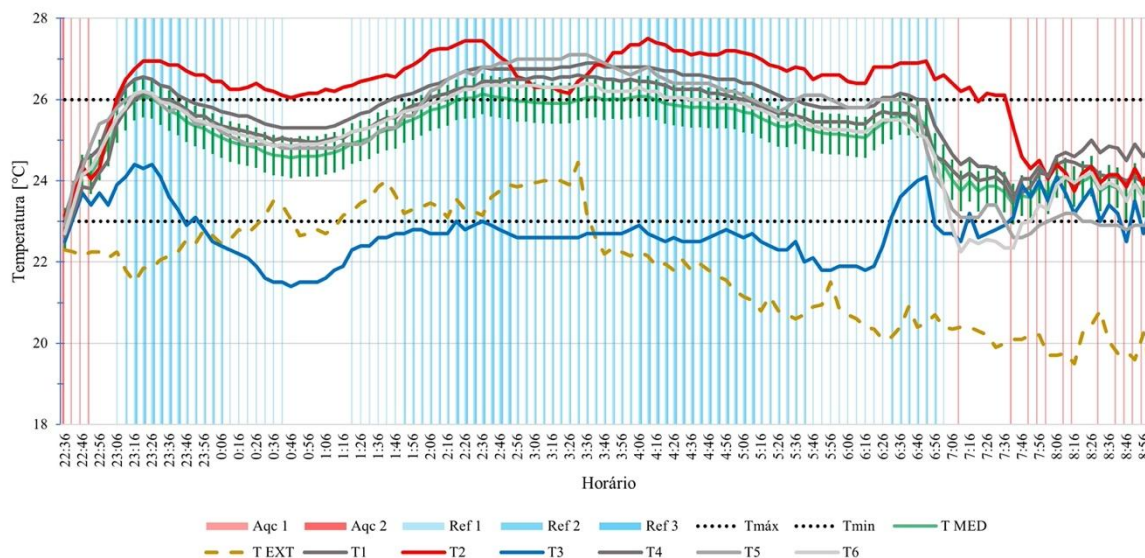
The theoretical model coefficients were estimated for the nugget effect of the semivariogram (C_0), the structured variance (C), the sill ($C_0 + C$), and the range (a) (Landim, 2006). Additionally, software provided by Gamma Design was used to generate surface temperature maps, enhancing the thermal analysis based on experimental data. From the data collected dataset, ten time instants were selected, corresponding to hourly measurements taken during the trip. For each instant, a temperature map was generated, and the parameters of each semivariance model were determined.

3 Results and Discussion

In this study, thermal conditions were compared across different exposure time intervals. The decision to work with compartment segmentation was made because the thermal load generated by the chicks was not a study factor. The truck was loaded on November 13th, 2023, at 10:30 PM with 62,000 newly hatched chicks in Pato Branco, Paraná. The journey lasted approximately 11 hours, covering about 520 kilometers, with Jaguapitã, Paraná, as the destination.

The thermal data for each sector of the cargo compartment are presented in Figure 4, where the most discrepant temperature zones (T2 and T3) are highlighted in different colors. The dashed lines help visualize the target temperature range required to keep the chicks within the thermoneutral zone, as recommended by the literature.

Figure 4 – Temperature data by zone, highlighting T2 (red), T3 (blue), T MED (green) with $\pm 0.5^{\circ}\text{C}$ error bars and T EXT (dashed brown).

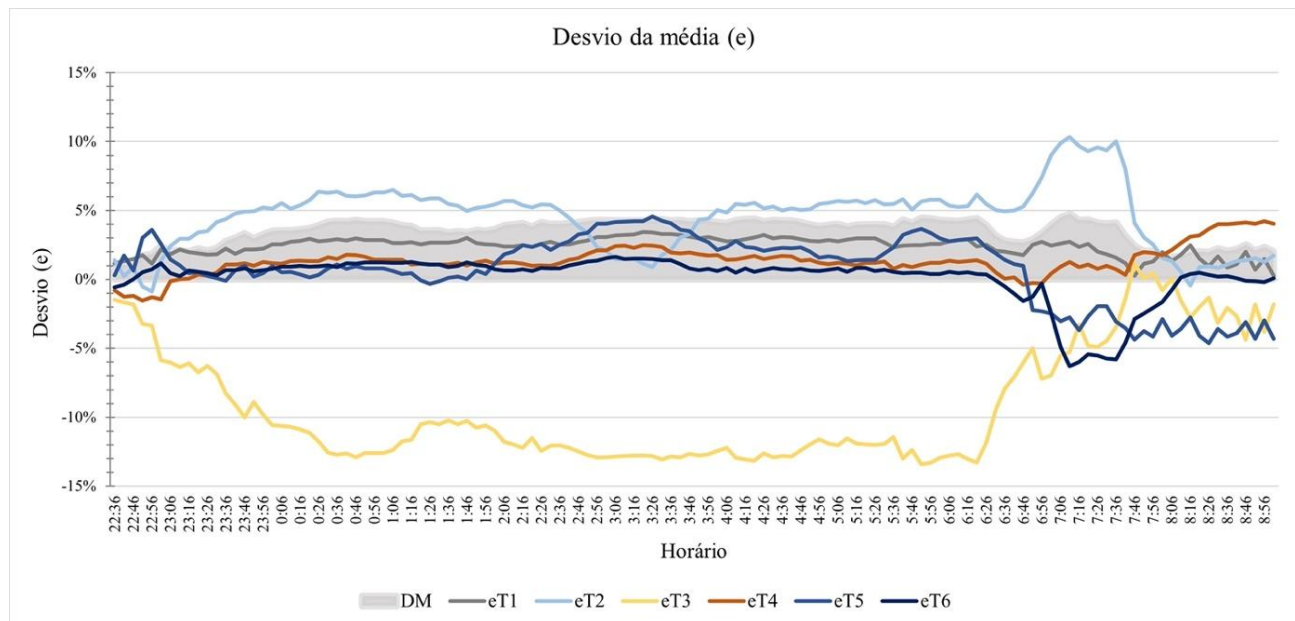


Source: the authors.

The truck average temperature is represented by the green line (T MED), with an error margin of $\pm 0.5^{\circ}\text{C}$, shown by error bars. The external temperature is depicted by the dashed brown line (T EXT). Bars along the chart indicate the activation of the truck's cooling (Ref) and heating (Aqc) systems. The truck operates with three cooling power levels and two heating power levels, which are represented by blue and red bars, respectively.

The deviation values of each sector from the average temperature of the cargo compartment can be seen in Figure 5, where the region with the highest deviation (eT3) is highlighted. The mean deviation was also included, represented by the hatched area in the chart.

Figure 5 – Temperature deviation by zone, highlighting the highest deviation in eT3 (yellow). The hatched area represents the mean deviation



Source: the authors.

The single-factor ANOVA indicated statistically significant evidence ($P < 0.01$) that at least one of the measurement zones has a different average temperature compared to the others. Zone 3 showed the highest deviation from the average temperature, which can be attributed to the position of the data logger, located at the separation between the upper and lower rows of the boxes. This configuration allowed for greater airflow, resulting in lower temperature readings.

In Zone 2, temperature values were slightly higher than in other sectors, suggesting possible heat concentration in the front region of the compartment. This effect may be related to the airflow returning to the conditioning system. On the other hand, the influence of external temperature was considered insignificant, as internal temperatures did not follow external variations. This is because the air admitted into the trailer is pre-conditioned, minimizing external interference in the collected data.

3.1 Statistical Interpolation

At the time intervals used for generating thermal maps, temperature values varied throughout the cargo compartment, indicating thermal heterogeneity. For the semivariance calculation, the spatial property values of each instant were used, with the results presented in Table 1. The coefficients of the theoretical model - nugget effect (C_0), sill ($C_0 + C$), and range (a) - were estimated for both the Gaussian (G) and spherical (E) models.

Table 1 – Semivariance Model and Parameters.

	23h	0h	1h	2h	3h	4h	5h	6h	7h	8h
Co	0.001	0.01	0.01	0.4	0.01	0.01	0.1	0.01	0.01	0.1
Co + C	6.5	9.9	10.6	14.2	8.2	12.3	15.5	13.3	12.9	4.9
Alcance	1.7	1.3	1.1	1.5	1.4	1.4	1.5	1.6	2.3	1.4
R ²	0.4	0.01	0.01	0.05	0.01	0.01	0.07	0.08	0.9	0.01
Método	G	E	G	E	E	E	G	G	G	E

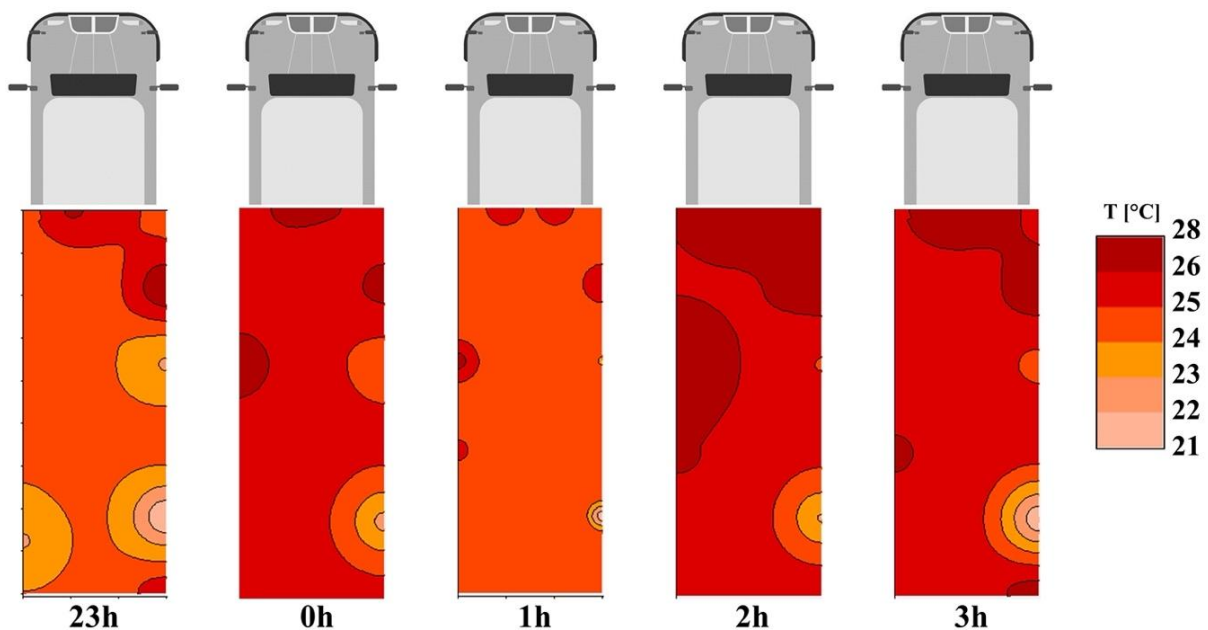
Source: research data.

The thermal maps generated (Figures 6 and 7) highlight the temperature variability at different points inside the compartment. Darker-colored regions indicate areas with higher temperatures, while the legend beside the maps details the temperature ranges in each analyzed zone.

Thermal maps generated allowed for the correlation of interpolated values using the Kriging method with experimentally obtained data. During the period from four to five hours, the cargo compartment exhibited the highest temperatures, as evidenced in Figure 5. Some discrepancies were observed between the methods. Kriging indicated lower temperatures in the rear right region of the truck, a behavior not identified in the temporal analysis. This can be attributed to the static nature of the interpolation model, which does not account for variations over time.

Overall, the thermal maps showed a higher incidence of elevated temperatures in the front section of the compartment, with peaks reaching up to 27°C, corroborating the experimental results, which also identified Region 2 as the most problematic.

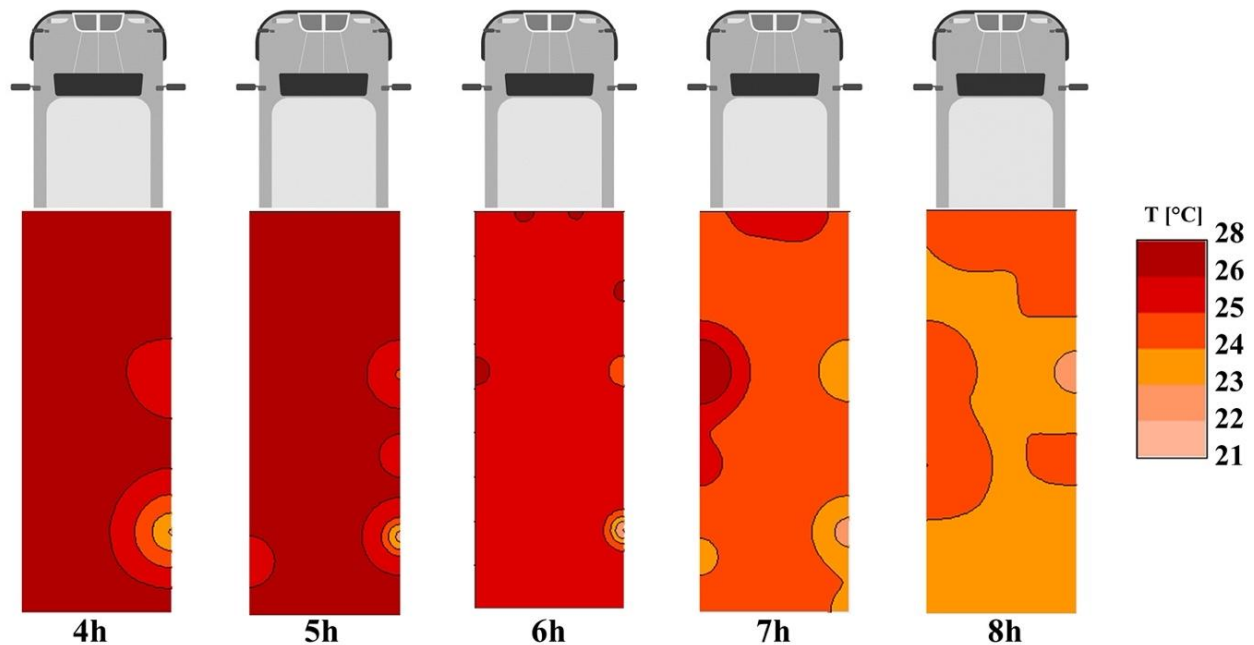
Figure 6 – Thermal map I of the cargo compartment, showing temperature distribution by hour



Source: the authors.

The findings of this study align with previous research on thermal conditions during the transportation of day-old chicks. The works of Nazareno *et al.* (2015) and Nazareno *et al.* (2020) similarly reported that microclimatic conditions in air-conditioned trucks frequently fell below the ideal thermoneutral zone.

Figure 7 – Thermal map II of the cargo compartment, showing temperature distribution by hour.



Source: Authors.

Consistent with our results, Nazareno *et al.* (2015) identified critical heat zones near the front of the truck, reinforcing the observed challenges in maintaining uniform thermal distribution. A potential solution to these airflow and temperature uniformity issues may lie in adopting positive-pressure ventilation systems, as demonstrated by Hu *et al.* (2024) in multilayer-caged hen houses. Their study found that positive-pressure fans significantly improved air circulation, reduced temperature differentials, and maintained relative humidity below 80%

While our study did not directly assess chick mortality or weight loss, Yerpes *et al.* (2021) examined the physiological impacts of transport conditions, demonstrating that weight loss was positively correlated with journey duration and relative humidity. These findings suggest that the thermal inconsistencies observed in our study could similarly contribute to stress-related effects on chick welfare and performance.

4 Conclusion

The study revealed significant thermal inhomogeneity in the cargo compartment during the chicks transport, with critical heat zones near the truck front. Despite being a climate-controlled

system, the temperature variations exceeded recommended limits, likely due to inefficient airflow distribution. These findings demonstrate the need for optimized fan placement and airflow paths to improve thermal uniformity. Future research should investigate alternative sensor arrangements and 3D thermal analyses to better characterize the compartment's microclimate and enhance the chicks' welfare during transport.

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