**Keywords:** food transport; refrigerated transport; operating conditions; cold chain

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# AN ASSESSMENT OF THE EFFICIENCY OF SELECTED REFRIGERATION UNITS OF VEHICLES FOR FOOD TRANSPORT DEPENDING ON THE OPERATING CONDITIONS

**Summary.** This paper represents an attempt to determine the efficiency of refrigeration units of selected types of food transport vehicles, taking into account their operating conditions. The tests included a delivery vehicle, a truck and a semi-trailer. The monitoring covered transport in the summer and winter seasons that requires intensive use of cooling systems associated with the necessity to open the cargo space multiple times at various times. The results indicate difficulties in maintaining refrigeration standards in the transport of food in the operating conditions tested. The monitoring showed an increase in temperature inside the isothermal car body up to the level of 14°C. The results of the research indicate the use of properly configured calculation algorithms to theoretically determine the efficiency of refrigeration units taking into account the conditions of vehicle operation. The test results indicate that the final correctness of the configuration of cooling devices requires verification in field conditions.

## 1. INTRODUCTION

Food transport is one of the main segments of the goods supply chain. A significant number of food products have to be transported in compliance with certain thermal standards necessary to maintain the applicable sanitary and quality requirements of the goods transported. Source data show that about 30% of transported food products require transport in a controlled temperature. The detailed conditions of refrigerated transport of food are regulated by the international ATP agreement, which defines the recommended scope of transport of groups of perishable goods [1]. The convention specifies the highest temperature level at which food products can be transported. At the same time, the contract emphasizes that the refrigerated means of transport have to be prepared in such a way that the temperature during the transport service does not exceed the maximum value [27].

The key role in refrigerated transport of food is played by the proper selection of transport centers, ensuring the maintenance of thermal standards of goods in accordance with the standards [9]. An important element in the process of selecting vehicles transporting food at a controlled temperature is determining the actual efficiency of refrigeration units, taking into account the operating conditions of the vehicles. In engineering practice, two methods are applied to select refrigeration units used in food transport vehicles. The first one uses the characteristics provided by manufacturers. In the second one, the cooling capacity of the refrigerating unit is defined on the basis of actual data determined in vehicle operational tests. When selecting a cooling unit only on the basis of the technical characteristics provided by the manufacturer, it should be taken into account that they are indicative and constitute average values for a specific range of operating conditions [11]. As the results of the research conducted so far show, in real conditions of use, there are often operational differences that may result in insufficient performance of the refrigerating units [26]. Improper selection of refrigeration units may violate the applicable thermal standards and break the cold chain in the transport of food products. The risk occurs especially during transport tasks in high external temperatures, when it is necessary to open the cargo space multiple times.

The aim of this paper was to determine the efficiency of refrigeration units of selected types of food transport vehicles taking into account their operating conditions.

## 2. LITERATURE OVERVIEW

Transport is a process during which, due to numerous threats, goods are particularly exposed to the loss of quality. The group of goods characterized by increased sensitivity to transport conditions includes foodstuffs. Certain groups of food products require the use of lower temperatures during transport to inhibit unfavorable changes in quality [15]. The analyses conducted [9, 13] show that there is an upward trend in the market of freight transport at controlled temperatures. This is especially true of highly developed countries, where, currently, 90% of food products are transported with a cold chain. In developing countries, the share of food supplies under certain thermal conditions is unsatisfactory and amounts to less than 50% [6, 22]. According to the authors, this may cause food waste and significant economic losses.

The growing demand for specialized refrigerated food transport services is accompanied by increasing expectations regarding the quality of the transport services provided. To meet market expectations and provide the transported goods with proper thermal conditions, specialized isothermal means of transport are used. They allow limiting heat exchange between the inner and outer surfaces of the car body. According to the provisions of the ATP agreement, vehicles intended for transporting food at a controlled temperature must be equipped with active refrigeration devices whose efficiency will reduce the temperature to the level required for individual groups of goods and their maintenance during the transport task, irrespective of operating conditions. In accordance with modern standards, isothermal vehicles should also be equipped with measuring equipment that allow real-time control and archiving of microclimate parameters inside the isothermal body.

Despite technological developments, the transport of food products requiring compliance with certain thermal standards is still considered a critical point in the supply chain, which generates measurable financial losses of up to 12% of the value of transported goods [16].

One of the essential elements necessary for the proper conduct of refrigerated transport of food is the correct choice of means of transport, with particular focus on the parameters of refrigerating devices and factors that may significantly affect the efficiency of their work. First of all, it should be stated that the operating efficiency of refrigeration devices mounted on the transport chosen is much lower than that of stationary devices [23, 24]. According to the authors, an extremely important element in the refrigerated transport of food is the initial cooling of the refrigerated body [18] and the goods transported before their loading into vehicles [20]. However, as shown by field studies, there are still significant differences between individual cargo batches and between their layers [18]. The source data show that the optimal use of the cooling capacity of the units is possible when the load is properly distributed inside the isothermal car body. The arrangement of the cargo should allow the free flow of the cooled air stream around the cargo units. According to Bieńczak et al. [1], only partial use of the cooled air stream causes deterioration of the air exchange conditions and lower convection coefficient values, and disturbs the rhythm of the refrigerating unit operation. The modeling of the air flow carried out by Lafaye et al. [14] shows, in particular, the need to maintain the correct spacing between the side walls of the vehicles and the pallet units. In addition to the distribution of goods, an equally important element of ensuring the correct temperature in the isothermal body is the correct arrangement of sensors controlling the operation of refrigeration units and the frequency of temperature measurements.

The authors also pay attention to the uneven circulation of the air stream generated by the units. Refrigeration equipment usually mounted in the front section directs a stream of cooled air to the end sector of the hold, resulting in higher temperatures directly at the aggregate as well as in the center of the cargo space [11].

According to Góral et al. [11], heat losses in refrigerated trucks may be related to the wear and tear of the car bodies of refrigerated vehicles and the increased risk of external air infiltration through leaks. Research by Tassou et al. [24] shows that the reduction of the insulating properties of materials used in the construction of isothermal bodies amounts to 3-5% per year.

During the implementation of retail deliveries, time and multiple opening of the refrigerating chamber door are important elements of the intensity of heat energy exchange in refrigerated transport. According to Góral et al. [11], the amount of heat exchanged with the inflow of infiltrating air depends primarily on the time of opening the door and also (Sun et al. [23]) whether the body in the loading area is equipped with a strip or air curtain. According to Bieńczak et al. [1], as a result of opening the door, a much greater amount of heat penetrates into the car body as compared to the energy penetrating through the walls of the cold store. According to the authors, the installation of strip curtains reduces the migration of warm air to the interior of isothermal bodies by 40% [23]. Grajewska et al. [9] showed that opening the door for more than one hour results in a temperature increase of about 2°C per hour and a decrease in relative humidity by 6%.

A proper implementation of the task of refrigerated food transportation significantly depends on external conditions, especially on air temperature [28].

## 3. RESEARCH METHODOLOGY

This research was conducted in 2019 in the summer and winter seasons. The research process consisted of two stages. In the first stage, the actual conditions of refrigerated transport of selected food products in various operating conditions were analyzed. The monitoring covered transport of food products made in the summer and winter seasons. The evaluation covered deliveries to retail collection points that require an intensive use of refrigeration systems due to the necessity to open the cargo space multiple times.

For the tests, an Iveco Daily vehicle with a permissible total weight not exceeding 3.5 tons was used. The vehicle was equipped with an 8-pallet loading space. The body of the vehicle was made of Sandwitch plates, and the plating was made of polyester–glass laminate. The floors were covered with a rough texture Marothann screed. For active cooling of the vehicle's cargo space, the Thermo King V-300 MAX refrigeration unit was used. To maintain the temperature of 0°C, the cooling capacity of the aggregate was 2950W, and the fans' expenditure was 1400 m3/h. The car was equipped with special internal and external temperature recorders with the possibility of printing a temperature record report. Temperature recorders read and record the temperature cyclically every 15 minutes. To assess temperature changes accurately, a data recording system was applied from an additional sensor inside the body connected to the car location system. The temperature measurement sensor inside was mounted under the refrigerating unit at a distance of 30 cm from the bottom wall. This system made it possible to record the temperature in real time. The analysis of changes in thermal conditions collected during the tests was carried out on the basis of printouts from the data recording system.

The second stage of the research involved the development of an algorithm that allows an assessment of the efficiency of selected refrigerating units installed in the transport vehicle used for refrigerated transport of food. The calculation formula was in accordance with the calculation procedure of DIN 8959 [5].

The DIN 8959 standard of the German Institute for Standardization defines the method of calculating the demand using the formula

$$Q_P = k \times A \times (t_{zew} - t_{wew}) \,, \tag{1}$$

where $Q_p$ –is the cooling capacity demand [W], $k$ is the heat transfer coefficient [W/(m²K)], $t_{(ext)}$ is the average external temperature [°C], $t_{(int)}$ is the average internal temperature [°C] and $A$ is the average body area, calculated from the outer and inner surfaces [m$^2$].

DIN 8959 also stipulates that additional heat loads, such as the influence of sunlight, gusts of wind or the car body leak, must also be taken into account when calculating the total demand. This coefficient is determined using the formula:

- for long-distance transport:

$$Q_{dod} = 0.75 \times k \times A \times (t_{zew} - t_{wew}) = 0.75 \times Q_p \quad (2)$$

- for the distribution of goods, where an additional heat load is associated with the need to open the door during unloading

$$Q_{dod} = \frac{C_1 \times V \times \Delta h}{3.6} , \quad (3)$$

where $Q_{dod}$ is the additional heat load [W], V is the cargo hold volume [$m^3$], Δh is the air enthalpy difference, i.e. heat content in the air, inside and outside the cargo hold [kJ/$m^3$] and $C_1$ is the air exchange rate due to frequent opening of the hold door [-].

The C1 coefficient value is calculated using the formula:

$$C_1 = \frac{a \times n}{z} , \quad (4)$$

where a is the door opening time coefficient; the DIN 8959 standard adopts the following values: up to 1 minute a = 0.5, up to 3 minutes a = 0.6, up to 5 minutes a = 0.7, n is the number of door openings per hour and z is the transportation time.

On this basis, the algorithm formulated a tabular simulation of ensuring sufficient cooling capacity of the unit for various operating conditions of the body use.

The analytical method allowed determination of which aggregate should be used to ensure optimal conditions for the transport of food products depending on the operating conditions. By selecting the aggregate in an analytical manner, one can be sure that the cooling system will provide an excess of cooling capacity and will allow maintenance of the proper temperature in extreme conditions, e.g., in summer.

In the next stage, a computational simulation was carried out for aggregates installed on three types of vehicles used in refrigerated transport of food: a delivery truck, a truck and a semi-trailer.

An Iveco 35C15 car was used with an 8-pallet FRC class body with the following technical characteristics of cargo spaces:

- external dimensions [m]: 4.20 x 2.06 x 2.10;
- internal dimensions [m]: 4.20 x 2.06 x 2.10;
- insulation wall thickness [cm]: 6;
- heat transfer coefficient [W/$m^2$K]: 0.38;
- Thermo King V-300 MAX unit: to maintain the temperature at 0°C, the cooling capacity of the refrigerating unit is 2950W and the fan's capacity is 1400 $m^3$/h.

The second MAN TGS 26.480 truck with a 20-pallet FRC class body had the following technical characteristics of the cargo spaces:

- external dimensions [m]: 8.14 x 2.60 x 2.70;
- internal dimensions [m]: 8.00 x 2.46 x 2.56;
- insulation wall thickness [cm]: 7;
- heat transfer coefficient [W/$m^2$K]: 0.32;
- Carrier SUPRA 750 refrigerating unit: to maintain the temperature at 0°C, the cooling capacity of the refrigerating unit is 6780W and the fan's capacity is 2140 $m^3$/h.

A Schmitz Cargobull S.KO-24 semi-trailer with an FRC class bodywork equipped with ducts for the air distribution system in the cargo space had the following technical characteristics of cargo spaces:

- external dimensions [m]: 8.14 x 2.60 x 2.70;
- internal dimensions [m]: 8.00 x 2.46 x 2.56;
- insulation wall thickness [cm]: 7;
- heat transfer coefficient [W/$m^2$K]: 0.35;
- Thermo King SLXi-400 unit: to maintain the temperature at 0°C, the cooling capacity of the refrigerating unit is 9900W and the fan's capacity with a loaded space is 5100 $m^3$/h.

All bodies tested met the standards of a cold store with reinforced FRC insulation with a coefficient of K≤0.4 [W/$m^2$K].

It was assumed that the vehicles would be used for the transport of food products at temperatures not exceeding 6°C [27]. The algorithm was a form in which values that were important for the calculations were entered. The form provided enabled the entry of the following parameters:

- external and internal dimensions of the car body,
- heat transfer coefficient through the body walls,
- expected highest temperature at which transport will take place,
- expected temperature inside the refrigerated compartment,
- intensity of operating conditions,
- air enthalpies inside and outside the refrigerated compartment and
- cooling capacity of the refrigerating unit.

An exemplary calculation algorithm for the cooling capacity of the refrigerating unit is presented in Table 1.

The results obtained are presented in a graphical, tabular form, and they are discussed later.

## 4. RESEARCH RESULTS

During the transport of food products monitored during the research, it was necessary to maintain a maximum temperature of 6°C.

Fig. 1 shows an example of a thermograph record during tests of an Iveco Daily 35C15 delivery vehicle with a Thermo King V-300 MAX unit. The diagram describes the temperature changes in deliveries made during the summer period, during which it was necessary to unseal the isothermal chamber of the vehicle multiple times to unload the goods. The data analysis shows that during deliveries of this nature, it was found that the thermal standards for the transported goods were repeatedly exceeded. The activities related to the delivery of individual batches of goods and the need to open the cold store resulted in continuous temperature increases inside the isothermal car body (Fig 1). In the time between consecutive deliveries, despite the continuous operation of the unit, the temperature inside the cold store was reduced only by about 4-5°C. In the second period of the transport task, the internal temperature reached maximum values over 15°C (Fig. 1) and, despite the continuous operation of the unit, it did not drop below 7-8°C.

Maintenance of the recommended transport standards was definitely hampered by the high external temperature, which exceeded 25°C in the second period of the transport task (Fig. 1). Further results of the monitoring carried out indicate that the interactions between the outside and inside temperature were the main factors hindering the maintenance of the recommended thermal conditions for refrigerated transport of food. This was confirmed from subsequent results of the observations.

The data presented in Fig. 2 show that during operations carried out at an external temperature below 18°C, no problems were found with maintenance of the transport temperature range applicable for a given type of product. In the event of exceeding the thermal optimum, the operation of the unit in a short time of 4-5 minutes allowed achievement of the proper temperature level inside the cargo space (Fig. 2). The unit needed much less time to cool the temperature inside the refrigerated compartment; the average operating time of the unit from automatic switching on was about 5 minutes. It was noticed that the opening of the refrigerator door during delivery resulted in low amplitudes of temperature changes in the refrigerated box, amounting to about 2°C on average. During the transport, the downtime of the unit was significantly extended compared to summer deliveries, which has significant economic and operational implications.

Fig. 3 shows an example of a thermograph record that describes the changes in cooling temperature in long-distance transport during which the goods were delivered to several recipients. Deliveries of this type, due to indirect unloading and loading operations, were particularly difficult to carry out while maintaining the appropriate thermal regime. Due to the unloading of large batches of goods transported, the unloading activities took about 20-30 minutes. However, the relatively long time between consecutive deliveries made it possible to reduce the temperature to the recommended range thanks to the active operation of the unit.

The results of monitoring the supply of refrigerated food products justify the conclusion that during the implementation of this type of transport task, the cold chain is usually broken, which was mainly caused by the necessity to repeatedly unseal the isothermal chambers of vehicles and the insufficient efficiency of refrigerating units, which, despite continuous operation, did not lower the temperature to the applicable level.

Table 1

Algorithm for calculating the demand for the cooling capacity of the unit for the example of an Iveco 35C15 car with a Thermo King V-300 MAX unit

| | Length | Width | Height |
|---|---|---|---|
| External dimensions of the body [m] | 4.32 | 2.18 | 2.22 |
| Internal dimensions of the body [m] | 4.20 | 2.06 | 2.10 |
| External volume [$m^3$] | 20.91 | | |
| Internal volume [$m^3$] | 18.17 | | |
| External body area | 38.02 | | |
| Internal body area | 34.94 | | |
| Geometric mean surface area of the car body [$m^2$] | 36.45 | | |
| Car body heat transfer coefficient [$W/m^2K$] | 0.38 | | |
| Microclimate conditions | | | |
| Expected maximum outside temperature [°C] | 35 | | |
| Average internal temperature [°C] | 4 | | |
| Enthalpy outdoors for an average humidity of 80% | 26.18 | | |
| Indoor enthalpy for an average humidity of 80% | 3.37 | | |
| Enthalpy difference | 22.81 | | |
| Air exchange rate due to continuous door opening | 3.6 | | |
| Characteristics of work | | | |
| Estimated number of door openings per hour | 6 | | |
| Estimated transport time | 1 | | |
| Door open time coefficient - choose from the following | 0.6 | | |
| Opening time factor from 1 min | 0.5 | | |
| Opening time factor up to 3 minutes | 0.6 | | |
| Opening time factor up to 5 minutes | 0.7 | | |
| Factor taking into account breaks of the refrigerating unit - (for 2 door openings within an hour) | 1.6 | | |
| Factor taking into account breaks of the refrigerating unit - (for 3 and more door openings per hour) | 1.8 | | |
| Cooling capacity demand | | | |
| Cooling capacity demand for the car body [W] | 429 | | |
| Taking into account additional loads for long-distance transport [W] | 322 | | |
| Taking into account additional burdens for distribution [W] | 414 | | |
| Demand for distribution with breaks in the refrigerating unit operation [W] - for 2 openings | 1350 | | |
| Demand for distribution, taking into account breaks in the unit operation [W] - for 3 and more openings | 1519 | | |
| Total cooling capacity demand for distribution | 2363 | | |
| Total cooling capacity requirement for long-distance transport | 2087 | | |

In the second part of the paper, to calculate the correctness of the selection of refrigeration units for car bodies used for the transport of foodstuffs, an algorithm that takes into account a number of variables describing the conditions of delivery was used. Technical data of the body, and differentiating conditions of vehicle operation were entered into the formula. The calculation procedure takes into account the multiple of opening the chamber door and the time of door opening.

In the simulation calculations performed for a refrigerated truck equipped with a Thermo King V-300 MAX refrigeration unit, which was previously used for the tests, local distribution was assumed with a maximum supply intensity of ten in one hour (Tab. 2).

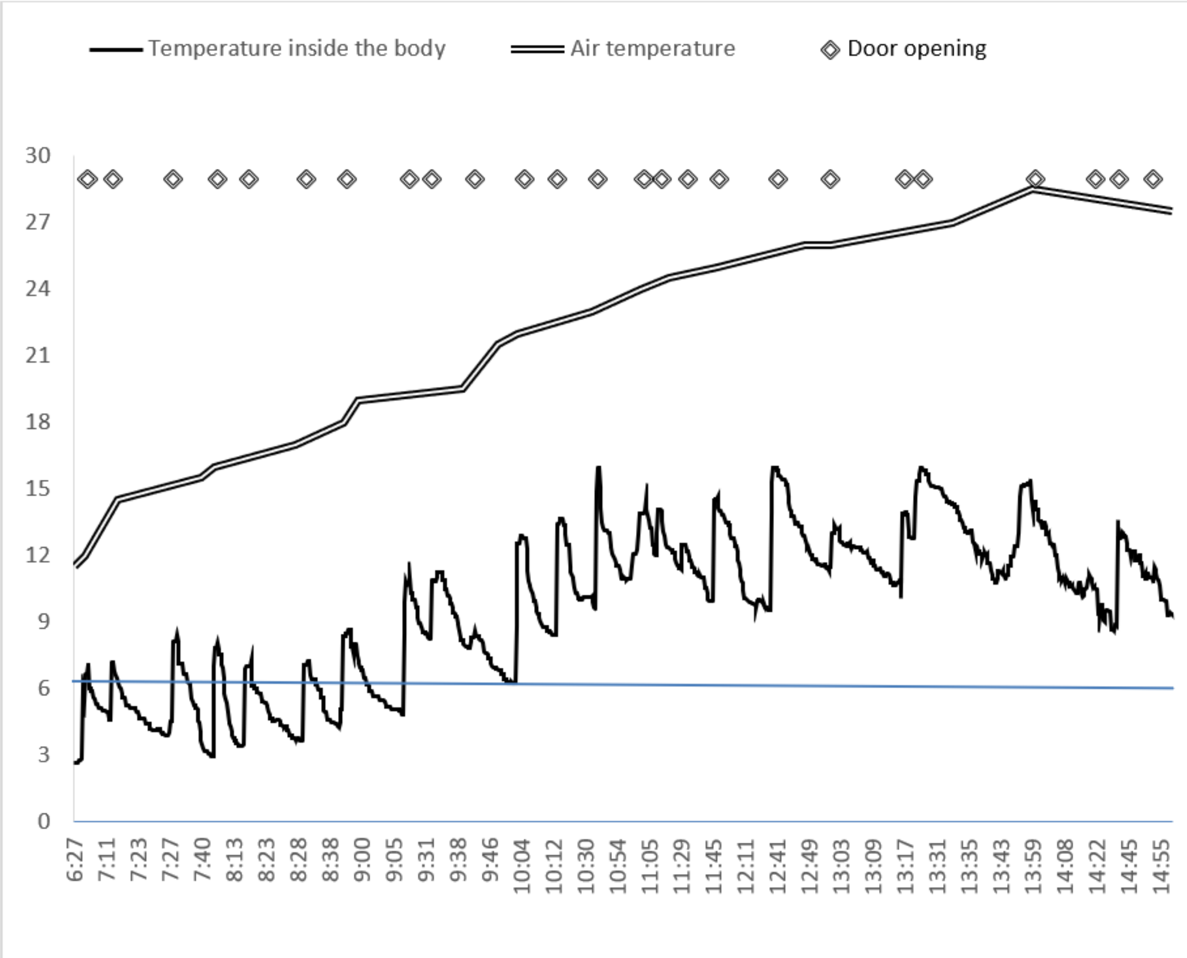


Fig. 1. Results of temperature monitoring and door openings in retail refrigerated transport in the summer period

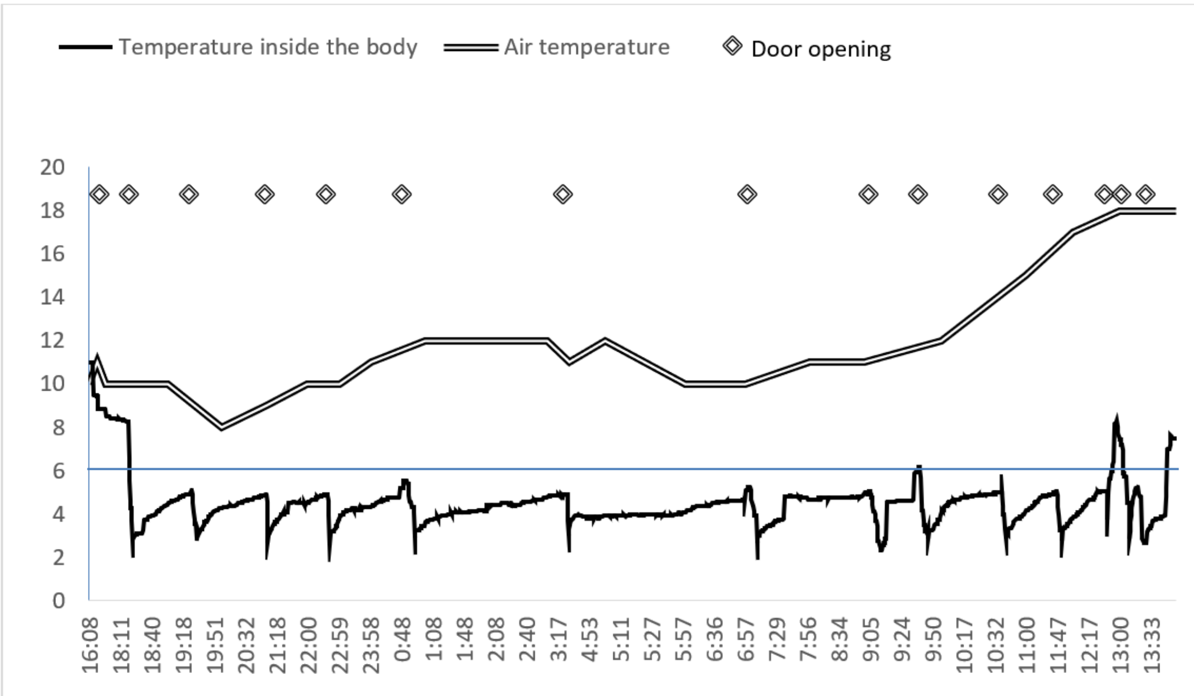


Fig. 2. Results of temperature monitoring and door openings during the retail delivery process in winter

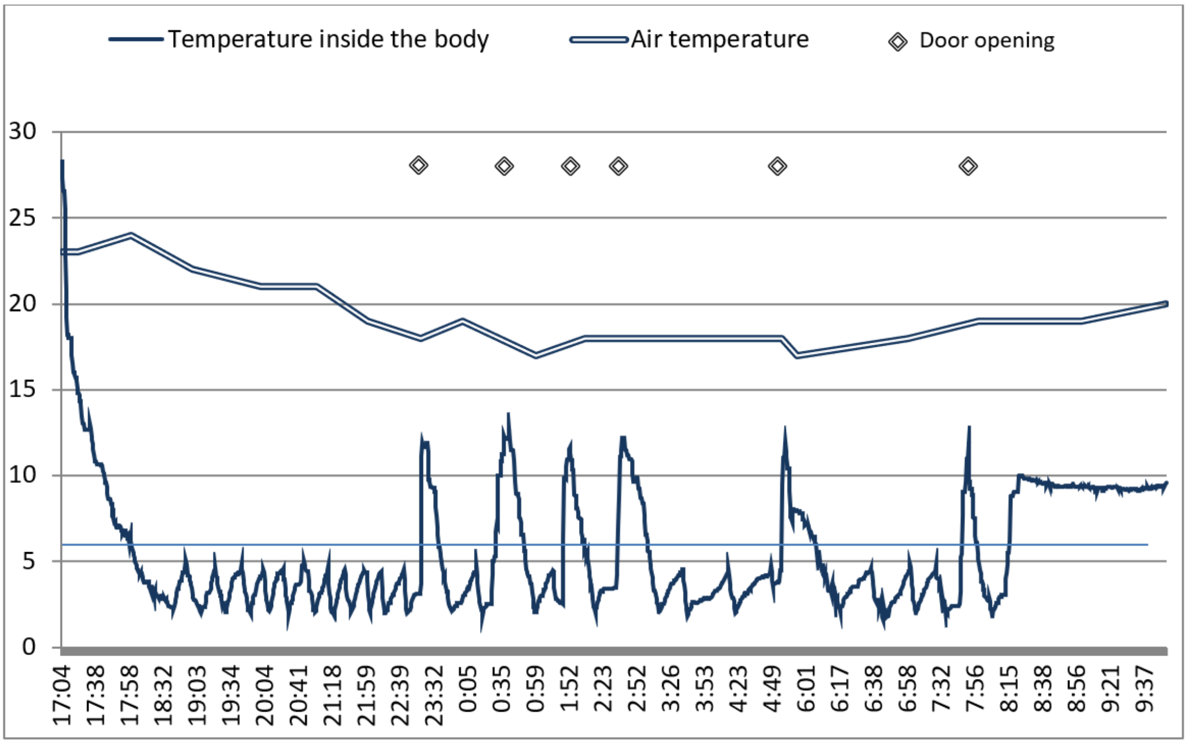


Fig. 3. Results of monitoring the cooling temperature in indirect long-distance transport in the summer season

The algorithm calculation procedure showed that the total cooling capacity demand for long-distance transport was 2087 W, and the refrigerating unit capacity was 2950 W. The results of the calculations showed that the Thermo King V-300 MAX unit fully covered the demand for cooling capacity for specific operating conditions in the range of up to ten deliveries, and the door opening time does not exceed one minute. Longer time of opening the door for a period of 3 or 5 minutes resulted in insufficient cooling capacity of the unit (Tab. 2). The chamber opening time of 5 minutes resulted in insufficient power of the unit with deliveries of more than seven per hour. With a further increase in the frequency of deliveries, the power shortage of the refrigerating unit was about 10%.

Table 2

Results of simulation calculations of the cooling capacity of the Thermo King V-300 MAX refrigerating unit depending on the operating conditions

| Simulation of meeting the cooling capacity by a refrigerating unit | | | | | |
|---|---|---|---|---|---|
| Number of door openings per hour | Cooling capacity demand | | | | Refrigerating unit performance |
| | Distribution | | | Long-distance transport | |
| | door opening time | | | | |
| | 1 minute | 3 minutes | 5 minutes | | |
| 2 | 1416 | 1475 | 1535 | | |
| 3 | 1686 | 1782 | 1879 | | |
| 4 | 1847 | 1976 | 2105 | | |
| 5 | 2008 | 2169 | 2330 | | |
| 6 | 2169 | 2363 | 2556 | 2087 | **2950** |
| 7 | 2330 | 2556 | 2782 | | |
| 8 | 2492 | 2749 | 3007 | | |
| 9 | 2653 | 2943 | 3233 | | |
| 10 | 2814 | 3136 | 3459 | | |

Another means of transport included in the simulation calculations was a 20-pallet FRC truck equipped with a Carrier SUPRA 750 refrigerating unit with a cooling capacity of 6780 W. The calculations performed showed a total cooling capacity requirement for long-distance transport of 3805 W. A further analysis showed that the Carrier SUPRA 750 refrigerating unit was powerful enough to compensate for the temperature increase due to external air infiltration of the cargo space covering nine deliveries with a door opening cycle of 1 minute. The cooling capacity of the chiller also allows you to make up to eight deliveries with a door open time of up to 3 minutes, and six deliveries with a door open time of up to 5 minutes. The simulation of the refrigerating unit performance with variable supply intensity is presented in Table 3.

Table 3

Results of simulation calculations of the cooling capacity of the Thermo Carrier SUPRA 750 refrigerating unit depending on the operating conditions

| Simulation of meeting the cooling capacity by a refrigerating unit | | | | | |
|---|---|---|---|---|---|
| Number of door openings per hour | Cooling capacity demand | | | | Refrigerating unit performance |
| | Distribution door opening time | | | Long-distance transport | |
| | 1 minute | 3 minutes | 5 minutes | | |
| 2 | 3111 | 3277 | 3443 | 3805 | 6780 |
| 3 | 3798 | 4066 | 4334 | | |
| 4 | 4244 | 4602 | 4960 | | |
| 5 | 4691 | 5138 | 5585 | | |
| 6 | 5138 | 5675 | 6211 | | |
| 7 | 5585 | 6211 | 6837 | | |
| 8 | 6032 | 6747 | 7462 | | |
| 9 | 6479 | 7283 | 8088 | | |
| 10 | 6926 | 7820 | 8714 | | |

The simulation assumptions for the operation of the isothermal semi-trailer included long-distance conditions. The algorithm calculation procedure showed the total cooling capacity demand for long-distance transport at the level of 8403W, and the efficiency of the 9900W refrigerating unit. Taking into account the way the body was used, the choice of the Thermo King SLXi-400 unit was optimum. It provides sufficient cooling capacity to maintain the correct temperature inside the trailer. As shown by the calculations, the use of isothermal trailers for deliveries with increased unloading intensity is associated with the risk of breaking the cold chain. In retail deliveries, equipping the semi-trailer with even such a strong unit allowed for only two safe deliveries within an hour, with an opening time of 1 minute (Tab. 4).

## 5. DISCUSSION AND CONCLUSIONS

It is difficult to accurately determine heat losses in refrigerated trailers used for the transport of food. Heat losses and their intensity depend on many factors related to the parameters and technical condition of vehicles [4, 8] and their operating conditions [17, 21]. Maintaining the thermal standard in food supplies is particularly difficult in the case of transport tasks for which there is a need to perform numerous unloading and loading operations [3]. Difficulties in maintaining thermal standards in food transport were confirmed by the results of the authors' own research. The results indicate that the transport of food, which was carried out in the summer period with the prevailing high external temperatures and simultaneously requiring multiple opening of the cargo space, led to a break in the cold chain in deliveries (Fig. 1, 3). The analysis of the test results showed that the main reason for the increase in temperature in the cold store was the number of unloading points and the related need to open the cargo space. It is worth emphasizing that the observed exceedance of the permissible thermal standards was significant. The monitoring showed an increase in temperature inside the isothermal car body up to the level of 14°C. Despite the continuous operation of the refrigerating unit (Fig. 1), the temperature inside was reduced only to the value of 7-8°C. These conditions were a breach of the standards set out in the ATP Agreement [27], which is a standard in European conditions [7]. Undoubtedly, the break in the cold chain has lowered the sanitary standard and safety of the transported products and should be the basis for eliminating them from the trade [25].

Table 4

Results of simulation calculations of the cooling capacity of the Thermo King SLXi-400 refrigerating unit depending on the operating conditions

| Simulation of meeting the cooling capacity by a refrigerating unit | | | | | |
|---|---|---|---|---|---|
| Number of door openings per hour | Cooling capacity demand | | | | Refrigerating unit performance |
| | Distribution | | | Long-distance transport | |
| | door opening time | | | | |
| | 1 minute | 3 minutes | 5 minutes | | |
| 2 | 9772 | 10193 | 10614 | 8403 | 9900 |
| 3 | 11657 | 12337 | 13017 | | |
| 4 | 12791 | 13697 | 14604 | | |
| 5 | 13824 | 15058 | 16191 | | |
| 6 | 15058 | 16418 | 17778 | | |
| 7 | 16191 | 17778 | 19365 | | |
| 8 | 17324 | 19138 | 20951 | | |
| 9 | 18458 | 20498 | 22538 | | |
| 10 | 19591 | 21858 | 24125 | | |

The results obtained may indicate an incorrect selection of the refrigerating unit for transport tasks that require multiple door openings. In addition, operational activities could reduce the efficiency of cooling devices as a result of their frosting, which has been pointed out by other authors [12, 19]. Bieńczak et al. [1] believe that one of the main reasons for the increase in temperature inside isothermal car bodies is a significant difference between inside and outside temperatures. Continuous operation of the refrigerating unit caused by high ambient temperature results in a decrease in its efficiency. The authors also point out that the cause may be the deterioration of the thermal insulation properties of the car body due to aging processes [11].

According to authors [2, 10], the use of strip curtains is a solution that limits heat loss during unloading operations. Curtains allow reduction of heat loss by up to 40% [23]. In addition, air curtains do not hinder handling activities. However, it is a cost-effective and energy-consuming solution justified for use in large transport units.

Organizational and optimization changes in the supply chain can be helpful in maintaining the thermal balance in food transport. The irregularities in the refrigerated transport of food, found on the basis of the monitoring carried out in the authors' own research, became the basis for the theoretical determination of the efficiency of selected refrigerating unit, taking into account the difficult delivery conditions (Tab. 2-4).

In recent years, a significant number of calculation models used to determine energy balances in refrigerated food transport have been developed. Models based on the laws of physics make it possible to take into account in detail the influence of a large number of different operating conditions on the thermal energy balance. The balances developed can be useful to assess the correctness of the selection of refrigeration units for a specific type of transport used in the transport of food [7].

In the authors' own research, simulation calculations with the use of cooling demand were carried out in accordance with the DIN8959 standard of the German Institute for Standardization.

The results of the calculations show that the cooling devices mounted on delivery vehicles and lorries, in the case of the implementation of intensive indirect deliveries, did not provide sufficient cooling capacity. The power deficit was found mainly in situations where it was necessary to open the doors of the cargo space for vehicles included in the simulation calculations for a long time.

The calculation procedure of the algorithm showed that in the case of a refrigerated trailer, the choice of the refrigerating unit was optimal for the body. The research clearly showed that refrigerating transport vehicles with large capacities, such as semi-trailers, could not be used for transport tasks where there were indirect links. If it is necessary to use them, it is a must to separate the cargo spaces with bulkhead walls; this enables each of them to be treated as an independent structure equipped with a cooling unit.

The research shows that there are problems with maintaining the cold chain in food supply. To limit them, it is possible to use computational algorithms to determine the cooling capacity of refrigerating units taking into account the conditions of vehicle operation. The test results show that the final correctness of the configuration of cooling devices requires verification in field conditions.

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Received 29.06.2020; accepted in revised form 04.12.2021