

Functional Definition of the Basic Construction of Food Transport Containers Providing Universal Cooling, Storage and Handling Capabilities

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Abstract: During the solution of the design task the proper construction version was selected on the basis of some design boundary conditions (using standard sized container, product to be transported, cooling by multi-dimensional, multi-injection “air-flow” technology) with the help of functional analysis after testing several solution variants. After that the geometrical, functional and structural design task was resolved. The selected construction was a 20-foot raised container with two refrigerated compartments of different temperatures which are separated by a movable bulkhead. After the design and sizing of the refrigeration unit, the technical design of the frame and the shell structure, the 3D models meeting the production requirements and the technical documentation were completed. During our further work we are evaluating the construction design with the help of structural and operational simulations before the manufacture of the prototype.

Keywords: refrigerated container; function analysis; multi-injection airflow; computer-aided design; 3D model

1 Introduction

Due to the HACCP requirements the storage and transportation of food products and food raw materials at a suitable temperature is an extremely important issue in logistics. Currently the availability of technical solutions regarding the transportation part of the cooling chain is limited, the use of transportation vehicles with refrigerated cargo holds is the most common. However, even if for a short time, the cooling chain can be compromised due to technical deficiencies and human error. The solution to the technical deficiencies is the design of intelligent refrigerated compartments to be implemented in the project.

In this article we are going to present the functional definition of the basic construction of refrigerated containers, for which work the background is provided by the research and development GOP project consortium.

1.1 Container Selection Procedure

Extensive international literature deals with container transportation and the structure of containers. [1...4, 13, 14] In Figures 1 and 2 Scharnow presents general procedures and logical thinking suitable for selecting the most appropriate container type for the given method of transportation and the type of cargo transported. [5]

The selected container type determines the whole transportation system since emission level functions of different pollutants are also applicable as route costs of transportation assignment problems, thus taking fuel consumption and environmental impact into account during process design. [12, 15]

The figures presented can be of great assistance in the case of general selection tasks, however deeper functional analyses and/or the design of new constructions may be necessary to meet special needs.

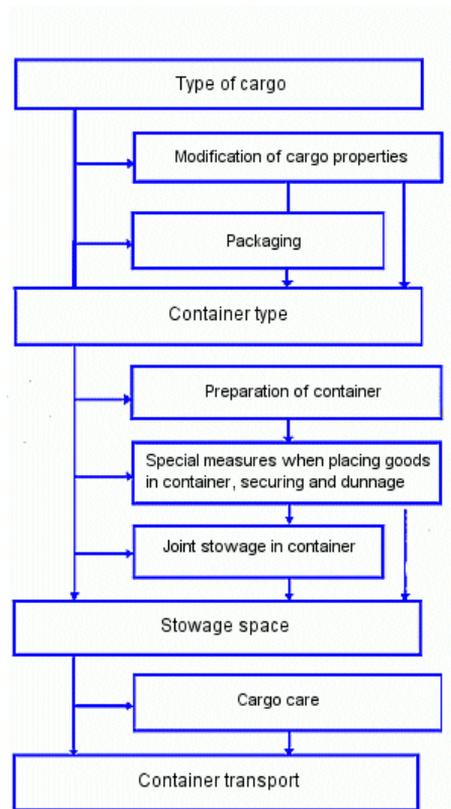


Figure 1

Adapting a cargo type to container transport conditions [5]

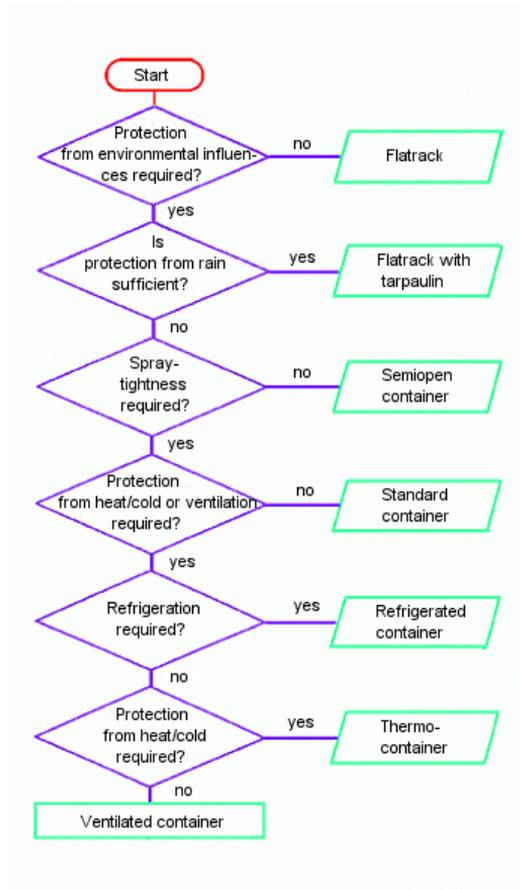


Figure 2

Selection of the appropriate container type [5]

1.2 Expected Functions

The development of the project consortium will result in a more uniform temperature distribution through the multi-injection airflow than the current single point injection. The split air space will make it possible to transport food products with different temperature needs (-20°C and 4°C) at the same time during short-distance transportation.

The installation of air curtain technology into mobile refrigerated spaces, which has not been implemented before, prevents temperature fluctuations in the refrigerated space when the doors are open, which relatively frequently occurs during short-distance transportation.

Through the GPS based registration it will become possible to track accurately in real time and trace back authentically the number of stops, the speed, the number of door openings, the real-time temperature and the temperature distribution of the compartments possibly having different temperatures.

The alarm system to be developed during the project will facilitate the timely reactions, it will send an alarm signal to the driver if the temperature changes and it will signal the failure through the tracking system and send a text message about the failure to the designated people. As a result of the system with active intervention capabilities, it will be possible to take action even from the site of the company by adjusting the temperature in the refrigerated compartment.

2 Compiling the Requirements

The criteria of the requirements are compiled partly according to the criteria given in the research and development project defining the design task and partly according to the technological and construction criteria. [7]

The most important requirements have been defined as follows:

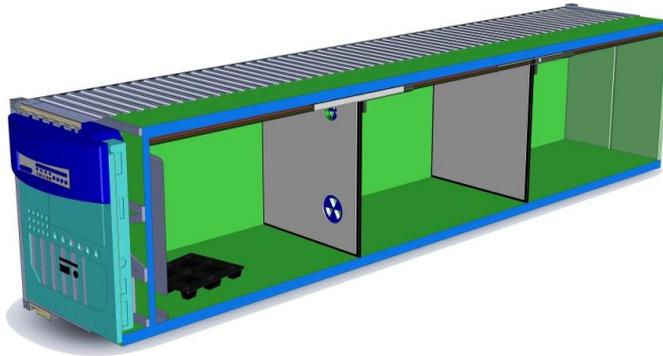
- 1 Size (required space)
- 2 It can be loaded through both ends
- 3 The refrigerated container should have several multi-temperature and adjustable size storage compartments (can be cooled and heated)
- 4 Variable interior space (to the largest extent possible)
- 5 Symmetrical design (it does not matter which side functions)
- 6 It must be possible to turn the container on the vehicle without external equipment (use of legs)
- 7 Better use of interior space
- 8 The refrigerated container must be capable of supplying middle- and small-sized retail food shops (as well)
- 9 The cargo space must be easily cleanable
- 10 The type and quantity of the food product to be transported (quick frozen (-20°C) and fresh (~0°C) fish products)
- 11 Homogeneous temperature distribution
- 12 Setting given temperature limits in all the points of the refrigerated space,
- 13 Uniform pack sizes [ACL 80x120x14 Hyg. pallet, Fish Box (25 kg) closed boxes].

- 14 To be suitable for using in both mobile (road) and stand-by state
- 15 To be constructed using commercial units distributed by firms having local (Hungarian) contact and workshop for trading, assembly and maintenance (as well)

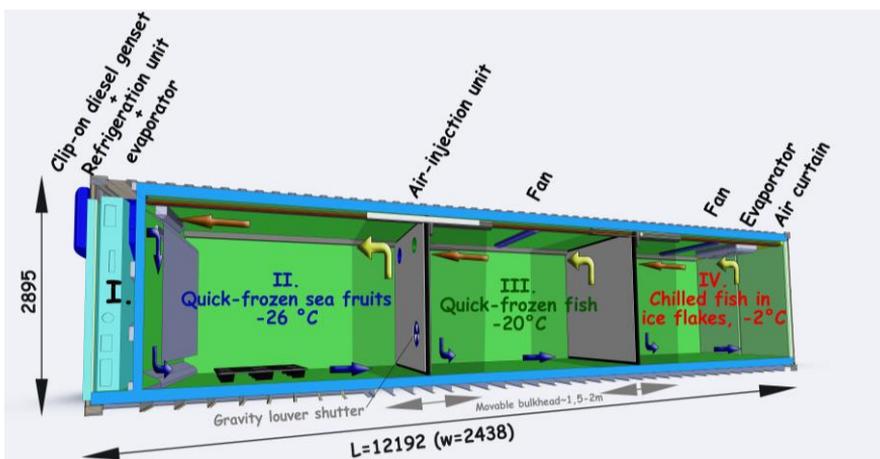
3 Construction Variants of the Refrigerated Container

According to the project requirements 3 variants were created whose design variants can be seen in Figures 3, 4 and 5.

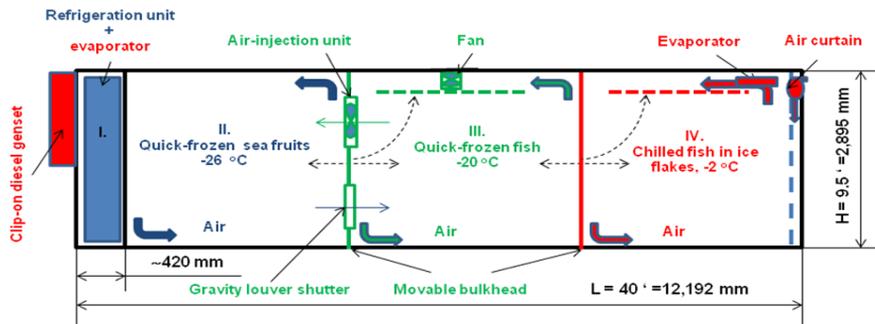
3.1 First Design Variant



a)



b)



c)

Figure 3

The first design variant, a) Perspective view of the container b) The cooling characteristics, flow directions c) The diagram of the cooling system

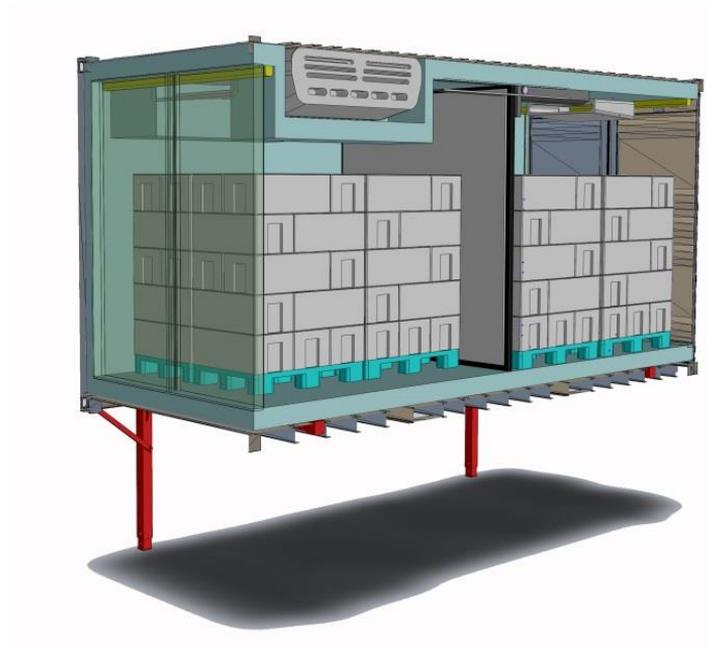
The first design variant can be loaded from one end, it is suitable for road, rail and water-way transportation (river, sea), it is 40 feet long, with 3 temperature settings, adjustable compartments, assembled with diesel genset + electrical refrigeration unit + air injection unit.

Figure 3 illustrates the sketch of a great capacity container recommended particularly for long way transportation. Because it is suitable for all the road, rail and water-way transportations, the food products can be carried in the very same container all the way i.e. without transshipment. Basically it has 3 compartments (storage spaces) but these can be modified even into 2 and 1 compartment by adjusting the bulkheads which are movable horizontally and can be folded upwards. The temperature of the compartments (storage spaces) can be continuously controlled between -30 and +30 degrees centigrade. Owing to the water-way (river and/or maritime) transportation, the refrigeration unit is recessed into the container body (see at space I) and powered by electrical energy. For road and rail transportations the electrical energy needed to power the refrigeration unit is provided by diesel genset clipped on the container body. For stand-by state and water-way transportation the electrical energy is provided by 1 or 3 phase mains. The cooling (and heating) air is produced by the refrigeration unit and circulated by the fans of evaporators as well as individual fans. The figure shows: on the one hand a “split” refrigeration system (see at compartments II and IV), on the other hand an air injection unit (see at compartment III). Air cooling can be generated directly (by the refrigerant of the refrigeration unit) or indirectly (by a secondary coolant). Due to the less refrigerant mass, the latter one creates less environment load. The thermal energy loss and thus the environment load is reduced by the application of the air curtain, which uses the ambient air and starts to work when the container door is opened. The main disadvantage of the construction shown in Figure 3 is „the clumsy” agility and product loading in inhabited settlements owing to its long size. Furthermore, because the loading in and out is possible just

by one end of the container, the planning of transportation route needs more thorough logistical preparatory work. The disadvantage of the air-injection cooling can be that it can cause heavy turbulence and great fluctuation of temperature in the compartment (see at space III). Furthermore, the food products situated close to the place of air injection can be warmed up (perhaps contaminated), or can be supercooled (perhaps frozen which is undesirable for chilled products). [8, 9, 10]

3.2 Second Design Variant

The second design variant shown in Figure 4 can be loaded via both ends, it is suitable for road and rail transportation, it is 20 feet long, with 2 temperature settings, adjustable compartments, assembled with diesel genset + electrical refrigeration unit.



a)

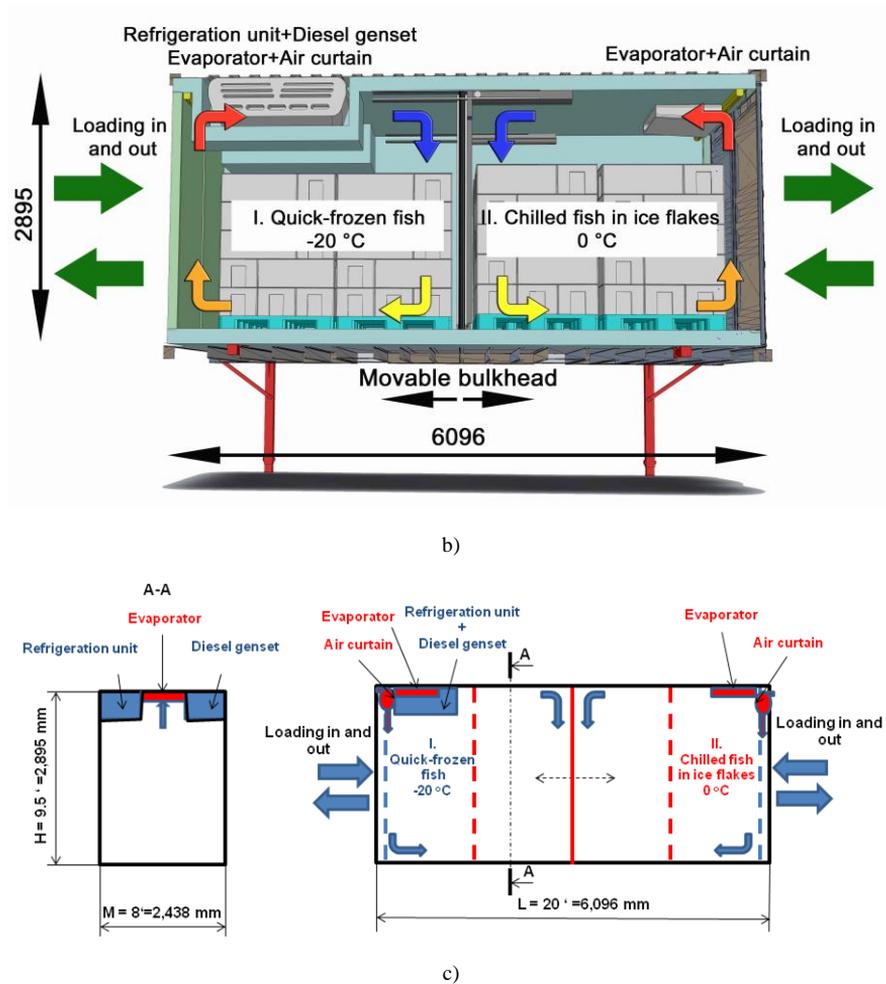


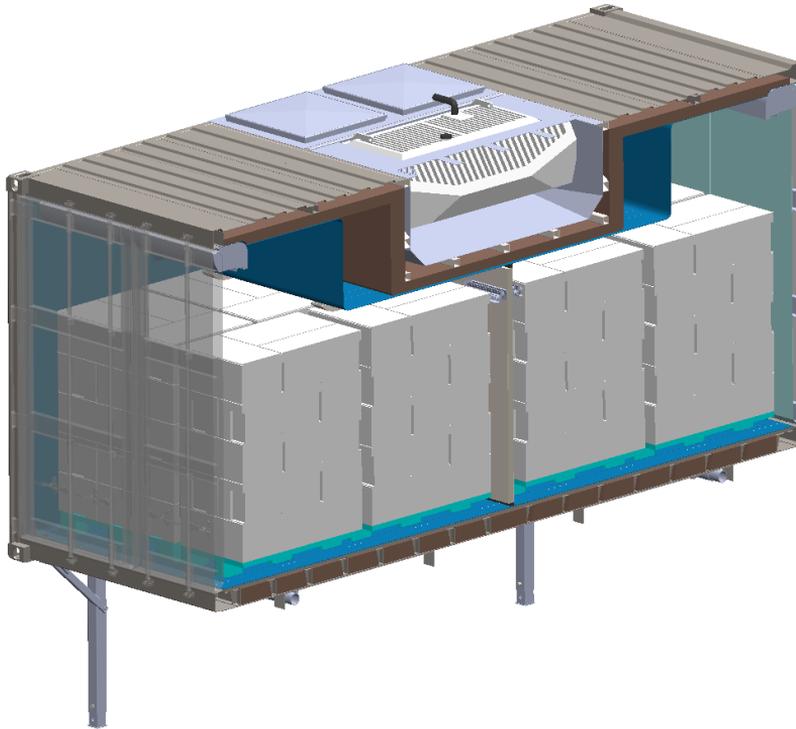
Figure 4

The second design variant, a) A Perspective view of the container b) The cooling characteristics, flow directions c) The diagram of the cooling system

The main and unique characteristics of the container version illustrated in Figure 4 are the smaller size and that it can be loaded via both its front and rear ends. These properties make this version more suitable for transportation of food products within inhabited settlements and supply smaller retail food shops. Its disadvantage is that for loading via the front end of the container located behind the driving cabin of the vehicle the container has to be uncoupled and that is why the refrigeration compressor cannot be driven directly by the vehicle motor i.e. so called „direct drive” refrigeration units cannot be applied. In that case the container is placed on a special under-frame.

3.3 Third Design Variant

The third design variant shown in Figure 5 can be loaded via both ends, it is suitable for road and rail transportation, it is 20 feet long, with 2 temperature settings, adjustable compartments, assembled with diesel refrigeration unit.



a)

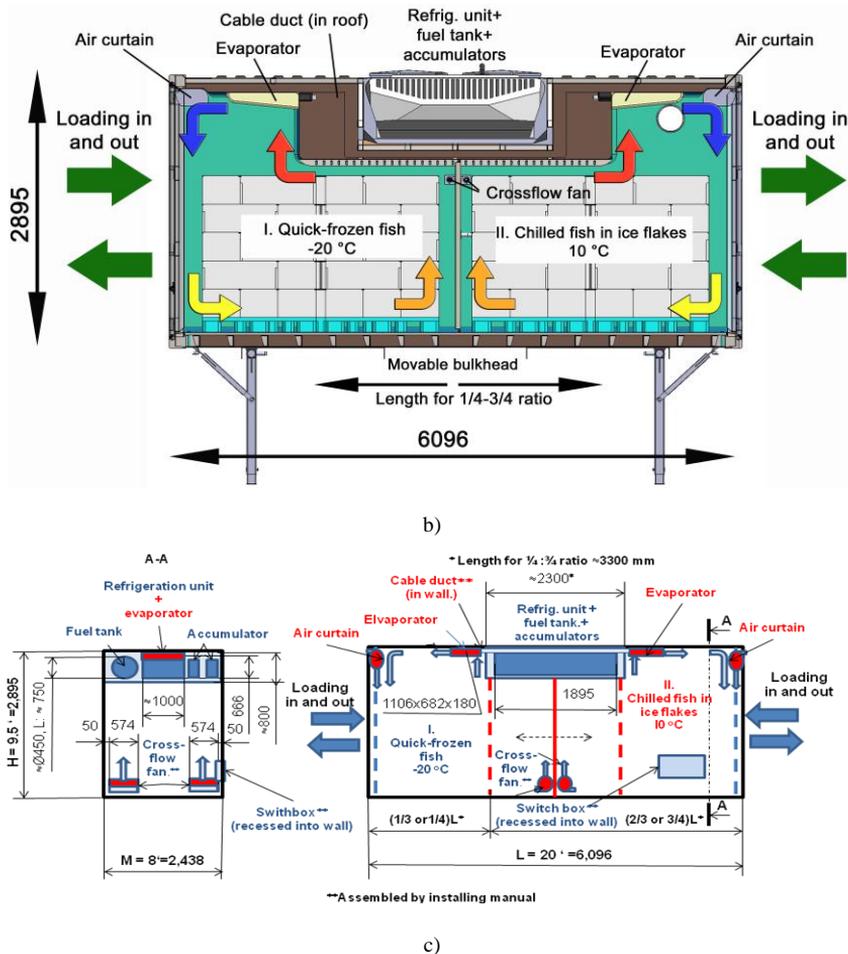


Figure 5

The third design variant, a) A Perspective view of the container b) The cooling characteristics, flow directions c) The diagram of the cooling system

The third design variant of the container illustrated in Figure 5 shows such a construction which keeps the advantageous properties of the previous two versions and eliminates or at least reduces the disadvantageous ones. Its main characteristics: (1) – own diesel engine for refrigeration unit, (2) – 2 refrigeration compressors (one diesel unit + a second electrical one for stand-by state), (3) – cross flow air cooling of condenser of the refrigeration unit relative to the direction of travel of the vehicle, (4) – refrigeration unit is located in the gravity axis of the container, (5) – easy accessibility of the refrigeration units to assemble and maintain them, (6) – installation of DC crossflow fans, (7) – double air curtains, (8) – installation with GPS positioning and temperature transmitter. The applied 3 cylinder 4-cycle liquid cooled 0.854 L diesel engine has a 16 kW

maximum output power (at 3600 rpm). Due to its overall dimensions (LxWxH 518 x 454 x 576 mm) can easily fit into the space has been designed in the middle section of the container roof. The diesel drive of the refrigeration unit makes the cooling of compartments independent of the speed and direction of travel of the vehicle and can be even used in stand-by position. The independent diesel engine consumes less fuel and reduces the impact on the environment. The installation of two separate refrigeration compressors increases the safety of refrigeration transportation. The dual energy supply (diesel and electrical) makes the refrigeration system more flexible and makes it possible (in stand-by state) to specify and modify the type of driving power depending on the cost of energy sources. Owing to the cross direction position of the condensing unit relative to the direction of travel of the vehicle the operation of refrigeration unit becomes independent of the direction of travel of the vehicle [8, 9]. Due to the mounting of the refrigeration unit and its accessories in the gravity axis of the container the route traceability of the vehicle is safer. The refrigeration unit and its accessories can be accessed by a built-in telescopic ladder so they can be assembled and maintained on their spot but can also be removed. The cross flow fans making the airflow more uniform within the container spaces are located and fixed on the movable bulkheads, they can be moved along with that one, and can be powered by DC accumulators both in road and stand-by state. The temperature of compartments is decreased by about 10 degrees centigrade by the application of the double air curtains when the container is opened for loading in and out. The GPS system makes it possible to track the route, the mobile and stand-by position of the vehicle, its fuel consumption and the temperature of the compartments, furthermore if the refrigerated mobile container breaks down, it helps to organize a rescue action. The prototype of that version will be manufactured. On the basis of the results of the measurements made on the prototype, the simulation performed for the design can be verified and the construction itself can be developed further.

4 The Complex Comparison of the Design Variants

We have evaluated the design variants presented in Chapter 3 together in the table below from the point of view of meeting the defined requirements and on the basis of the results of the evaluation we have selected the variant considered the most suitable. During the evaluation (comparison) the constructions a weighting factor method were applied. The score interval for the design variants is 0-10 and the weighting factors for the requirements are shown in the table below. The results (Total score) have been calculated according to the following formula:

$$Score = \sum \lambda_i v_{ij} \text{ [12].}$$

Table 1
Complex evaluation table of the design variants

Requirements [λ]	1 st design variant [v ₁]	2 nd design variant [v ₂]	3 rd design variant [v ₃]
Size (required space for commercial units) [6]	2	8	8
It can be loaded through both ends [5]	0	10	10
The refrigerated container should have several storage compartments of different size and different temperature (can be cooled and heated) [8]	10	10	10
Variable interior space (to the largest extent possible) [10]	10	3	8
Symmetrical design (it does not matter which side functions) [5]	2	2	10
It must be possible to turn the container on the vehicle without external equipment (use of legs) [4]	0	8	8
Better use of interior space [5]	10	5	7
The refrigerated container must be capable of supplying middle- and small-sized retail food shops (as well) [6]	1	8	8
The cargo space must be easily cleanable [5]	2	5	8
The type and quantity of the food product to be transported (quick frozen (-20°C) and fresh (~0°C) fish products) [10]	10	10	10
Homogeneous temperature distribution [10]	4	6	8
Setting given temperature limits in all the points of the refrigerated space [10]	3	5	8
Uniform pack sizes [ACL 80x120x14 Hyg. pallet, Fish Box (25kg) closed boxes] [8]	10	10	10
To be suitable for using in both mobile (road) and stand-by state [4]	10	10	10
To be constructed using commercial units distributed by firms having local (Hungarian) contact and workshop for trading, assembly and maintenance (as well) [4]	10	10	10
Total score (S)	548	693	848

During the construction further functions considered important may emerge, which might need further evaluation and possibly constructional corrections.

Conclusions

During the solution of the design task the possible design variants were analysed and the proper version was selected through complex engineering and functional analyses. We compiled a comprehensive set of requirements to develop each design variant considering technological, structural, cooling technology and economical aspects as well. In order to make the most reliable evaluation of the design variants the diagram of the cooling system was prepared for each variant, furthermore the 3D model of the whole structure was created, which helps to accurately show both all the details of the construction and how the structural design and the units of the cooling equipment fit.

Following the complex comparison the refrigerated container loadable via both ends, suitable for road and rail transportation, 20 feet long, with 2 temperature settings, adjustable compartments and assembled with diesel refrigeration unit was selected. Before starting to manufacture the prototype, the construction will be examined through structural as well as thermal and fluid flow simulation and the possible corrections will be made accordingly.

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