Comparative Study between the Operation of Refrigeration Installations with Refrigerants R134A and R471A for a Refrigerated Warehouse. Case Study

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Abstract: *In the context of the acceleration of the transition process from refrigerants with high global warming potential (GWP over 1500 units) to refrigerants with low global warming potential, within the limit of 150 units according to the F-GAS regulation, the refrigeration industry has difficulties in the development of refrigerants that meet safety standards (class A1L – non-toxic and non-flammable), environmental standards (GWP-under 150 units), efficiency standards (COP) and long-term viability. The study shows that slowly but surely, refrigerants are starting to appear that meet all these regulations and that can be integrated into commercial installations of small and medium power up to 50kW. Based on the versatility of the refrigeration plant components, starting with the compressor, the condenser, the evaporator, continuing with the refrigeration automation and ending with the command-and-control automation, the article wants to show that, very soon, we can choose technical solutions that comply with the current requirements.*

Keywords: *R134, refrigerants, R471A, GWP, COP*

1. Introduction

Refrigeration installations represent a set of components brought together in subsystems such as refrigerating units, heat exchanger and command and control automation [1].
All refrigeration installations have the role of ensuring, primarily, the temperature in a space or fluid that in turn cools a technological process [1, 2].
The availability of good quality perishable food products, throughout the year, is dependent on ensuring optimal temperature and humidity parameters in cold storage. The cooling of raw materials and food products through the refrigeration plant is among the first stages of their processing processes. Due to the fact that, in the food industry, refrigeration installations represent one of the largest consumers of electricity in companies in the food industry, the choice of the refrigerant must take into account both its thermodynamic properties and its impact on the environment [3, 4].
So, the challenge of our days is conception the refrigeration system in accordance with the energy efficiency and environmental protection norms.

2. Method of approach

In the conception phase of the technical solution for cooling finished products stored at ºC temperature, and taking into account the efficiency of installation costs and annual operating costs, the following refrigeration systems were considered for analysed the refrigerated warehouse:

- cooling with direct expansion system with mixed refrigerant R134A, GWP=1430, with possibility of retrofitting R513A, GWP= 631 [5];
- cooling with direct expansion system with refrigerant R471A, mixture of 78.7% R1234ze(E), 17% R1336mzz and 4.3% ignition inhibitor HFC227ea, GWP=148 [5].

The subject of the comparative analysis was carried out for a refrigerated warehouse with the destination of cooling the finished product, located in the western part of Romania highlighted on the climatic zoning map I of Romania (-12°C) (Fig. 1) [6] with the aim of making it more efficient investment costs related to operating costs respecting environmental protection norms, following the following steps:

- determining the thermal requirement according to the application requirement;
- selection of equipment according to thermal requirements;
- determining the installation costs for the refrigeration system;
- estimation of maintenance costs;
- estimating the costs of retrofitting the installation;
- life cycle cost analysis for refrigeration systems, including installation costs, annual maintenance, energy required to operate the system.

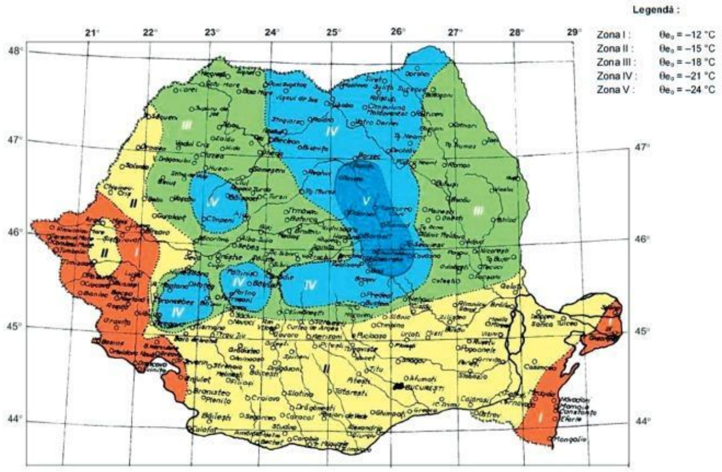


Fig. 1. Climatic zoning map of Romania and the Republic of Moldova [6]

2.1. Description of the refrigerated warehouse analyzed

The feasibility analysis of the solution was suitable for an existing cold store with C1 15-minute fire-resistant flammability envelopes, consisting of heat-insulated metal panels with basalt mineral wool G=15 cm, reaction to fire class B-s2d0 EI-30. The wall of the cold store doubles the covering on the inside perimeter with metal panels thermally insulated with polyurethane with a thickness of 10 cm (Fig. 2) [4].

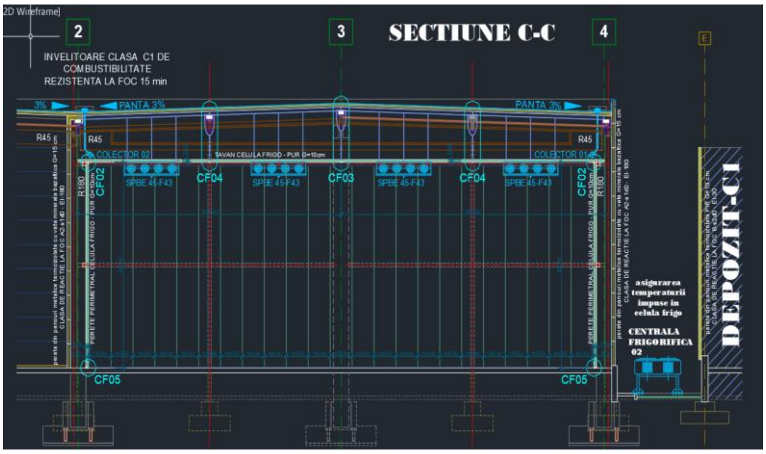


Fig. 2. Refrigerated warehouse envelope plan section

The surface of the warehouse analyzed is S = 533.60 m^2 and a height H = 8.5 m. The 20 cm thick concrete floor is for a bearing capacity of 50 kN/m^2.

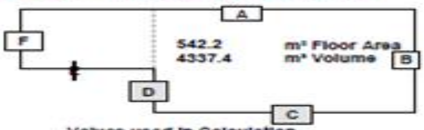
The thermal requirement for the cold store was simulated using the Cold Store Cooling Load Calculation software [7], and the input/output data are presented in Fig. 3 [7].

Client:			Enquiry N°.	
Project:	Depozit frigorific		Date.	05-12-23

Cold Store Dimensions (Internal) — **Inputs** — **Cold Store Configuration.**

For a Square or Rectangular Store input Dimensions A & B only. C & D will Auto Calculate for both Square and "L" shaped Stores.

Dimension for Wall A	23.41	m
Dimension for Wall B	23.16	m
Dimension for Wall C	23.41	m
Dimension for Wall D	6	m
Dimension for Wall E	0	m
Dimension for Wall F	0	m
Cold Store Height.	8	m



Information	Inputs		Values used in Calculation.	
Cold Store Temperature .	0	°C		
Ambient Temperature Wall A.	25	°C	25	Wall TD °C
Ambient Temperature Wall B.	25	°C	25	Wall TD °C
Ambient Temperature Wall C.	25	°C	25	Wall TD °C
Ambient Temperature Wall D.	25	°C	25	Wall TD °C
Ambient Temperature Wall E.		°C		Wall TD °C
Ambient Temperature Wall F.		°C		Wall TD °C
Ambient Temperature Ceiling.	30	°C	30	Ceiling TD °C
Ambient Temperature Floor.	10	°C	10	Floor TD °C
Wall Insulation.	Polyurethane (PUR)		0.025	K Value. W/m.K
Wall Insulation Thickness.	100	mm	0.250	U Value. W/m².°C
Ceiling Insulation.	80		0.025	K Value. W/m.K
Ceiling Insulation Thickness.	100	mm	0.250	U Value. W/m².°C
Floor Insulation.	Concrete (No Insulation)		0.550	K Value. W/m.K
Floor Insulation Thickness.	200	mm	2.750	U Value. W/m².°C
Product.	Margarine			
Approx. Product Mass per m³	200	Kg/m³	1.34	SH above Freezing. kJ/Kg°C
Product Input Load per Day.	40000	Kg	1.05	SH below Freezing. kJ/Kg°C
Total Weight of Product in the Store.	80000	Kg	51	Latent Heat. kJ/Kg.
Temperature of Product Entering Store.	8	°C		Respiration. kj/kg/24h.
Final Product Temperature.	2	°C	-1.00	Freezing Temperature °C
Air Changes per Day			0.8	Air Changes/24hr.
Store Usage Factor.	Normal Usage		1	Factor
Number of Personnel	2		345	Watts / Person.
Personnel Hours per Day	4	Hrs.		
Number of Trucks	3000			
Rating of Truck. (Typically 3000 Watts)	1	Watts	3000	Watts
Trucks Hours per Day	1	Hrs.		
Lighting in Watts		Watts		Watts
or				
Lighting in Watts per m²	10	Watts / m²	5422	Watts
Lighting Hours per Day.	4	Hrs.		
Additional Loads.	100	Watts/hr	100	Watts

Project:			**Enquiry N°.**	
Insulation				**Percentage of Total**
Wall A	191.2	m²	1195.3 Watts.	
Wall B	189.2	m²	1182.6 Watts.	
Wall C	191.2	m²	1195.3 Watts.	
Wall D	189.2	m²	1182.6 Watts.	
Wall E		m²	Watts.	
Wall F		m²	Watts.	
Ceiling	542.2	m²	4066.3 Watts.	
Floor	542.2	m²	14909.8 Watts.	
		Insulation Total	**23731.9 Watts.**	59.4%
Product Load				
SH above Freezing	1.34	kJ/Kg°C	3722.2 Watts.	
SH below Freezing.		kJ/Kg°C	Watts.	
Latent		kJ/Kg	Watts.	
Respiration		kJ/Kg/24h	Watts.	
		Product Total	**3722.2 Watts.**	9.3%
Air Change Load	84	kJ/m³	**3329.1 Watts.**	8.3%
Personnel Load			**115.0 Watts.**	0.3%
Truck Load			**125.0 Watts.**	0.3%
Lighting Load based on Wattage			**Watts.**	
Lighting Load based on Watt/m²			**903.6 Watts.**	2.3%
Additional Load			**100.0 Watts.**	0.3%
Total Load (Net)			**32026.8 Watts.**	
Hours Run per Day	11	Hrs.	**69876.7 Watts.**	
Cooler Fan Motor Input Power.	3993	Watts.	**5390.5 Watts.**	6.2%
Guide Value (Click Box if accepted)	3993	Watts		
Applicable for KÜBA Coolers Only.				
Defrost Heat Load.	32842	Watts.	**3941.0 Watts.**	4.5%
Guide Value (Click Box if accepted)	32842	Watts.		
Defrosts per Day.	4			
Defrost System.	Electric Defrost (Time Control)			
Contingency Allowance %	10	%	**7920.8 Watts.**	9.1%
Total Cooling Load.			**87.1 kW**	

Fig. 3. Simulation of the thermal requirement according to the application requirement [7]

The air flow was determined to ensure the number of air hourly exchanges necessary for the proper cooling of the product (Table 1).

Table 1: Number of hourly air exchanges / refrigerated warehouse

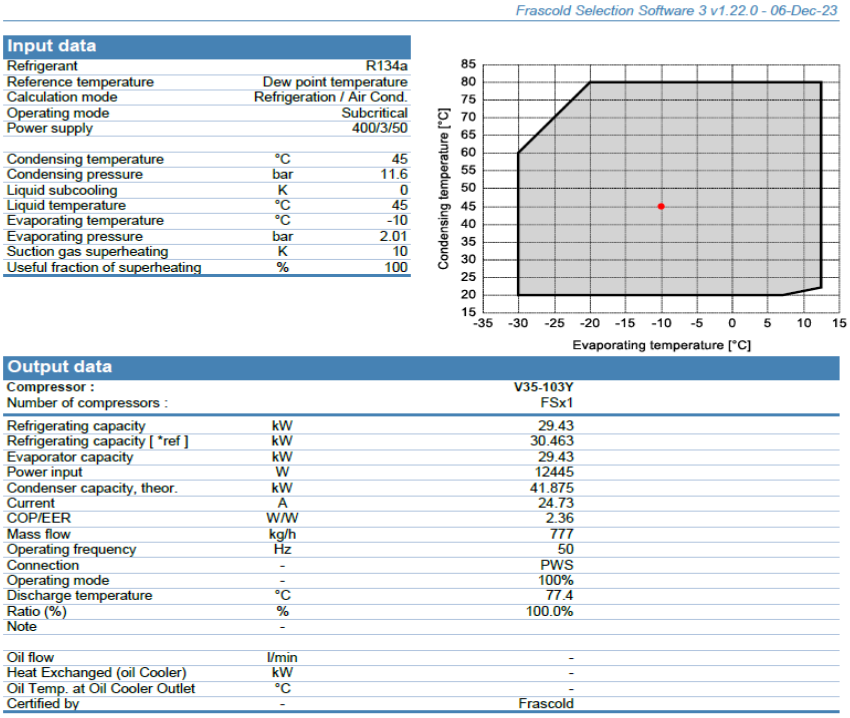
Room type	Deposit volume [m³]	Air flow rate circulated by vaporizers [m³/h]	Number of air hourly exchanges
Refrigerated warehouse with cooling load	4536.9	65520	14

2.2 Refrigeration systems analyzed

The technical solutions analyzed consist in the choice of a refrigeration installation with direct expansion that works with refrigerant R134A or a refrigeration installation with direct expansion that works with refrigerant R471A related to energy consumption and environment protection.

- *R134 A system*

First installation consists of a refrigerating plant composed of a compact, cased and fully self-contained refrigerating and electronic assembly with 3 pieces of Frascold compressors model V35-103Y (the simulation of input/output data is shown in Fig. 4 [8]), Modine remote condenser with vertical air jet equipped with 5 fans, model EGK715DN4D02V (Fig. 5) [9] and 4 Modine evaporators model CTE502A8ED (Fig. 6) [9] fully equipped with thermostatic valve, separation ball valves and solenoid valve on each of them.


Frascold Selection Software 3 v1.22.0 - 06-Dec-23

Input data		
Refrigerant		R134a
Reference temperature		Dew point temperature
Calculation mode		Refrigeration / Air Cond.
Operating mode		Subcritical
Power supply		400/3/50
Condensing temperature	°C	45
Condensing pressure	bar	11.6
Liquid subcooling	K	0
Liquid temperature	°C	45
Evaporating temperature	°C	-10
Evaporating pressure	bar	2.01
Suction gas superheating	K	10
Useful fraction of superheating	%	100

Output data		
Compressor :		V35-103Y
Number of compressors :		FSx1
Refrigerating capacity	kW	29.43
Refrigerating capacity [*ref]	kW	30.463
Evaporator capacity	kW	29.43
Power input	W	12445
Condenser capacity, theor.	kW	41.875
Current	A	24.73
COP/EER	W/W	2.36
Mass flow	kg/h	777
Operating frequency	Hz	50
Connection	-	PWS
Operating mode	-	100%
Discharge temperature	°C	77.4
Ratio (%)	%	100.0%
Note	-	
Oil flow	l/min	-
Heat Exchanged (oil Cooler)	kW	-
Oil Temp. at Oil Cooler Outlet	°C	-
Certified by	-	Frascold

Fig. 4. Simulation of input/output data for V35-103Y compressors with R134A [8]

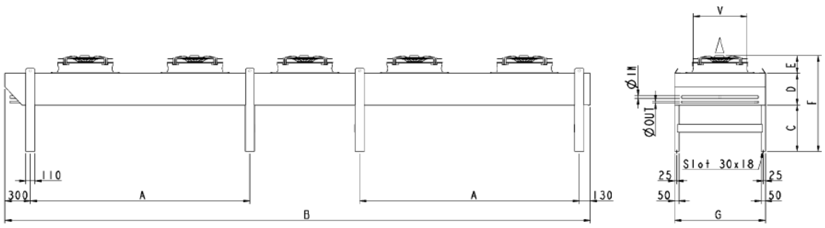


Fig. 5. Condenser Modine EGK715DN4B01V [9]

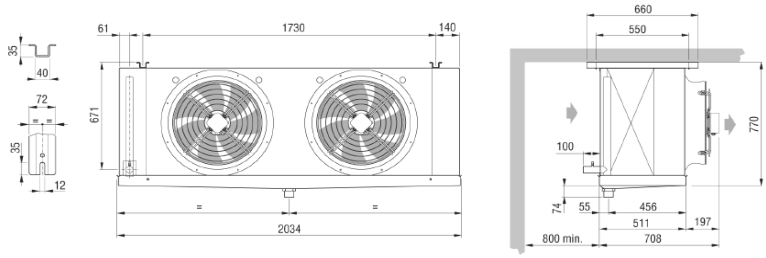


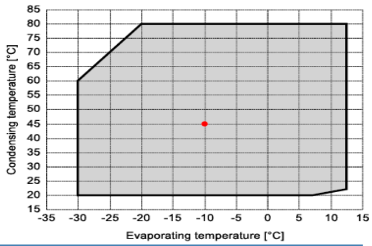
Fig. 6. Evaporators Modine CTE502A8ED [9]

- *R471A system*

The second installation consists of a refrigerating plant composed of a compact, cased and fully self-contained refrigerating assembly with 5 pieces of Frascold compressors model V35-103Y, remote (the simulation of input/output data is shown in Fig. 7) [8] Modine condenser with vertical air jet equipped with 4 fans, model EGK814DN4A02V (Fig. 8) [9] and 4 pieces of Modine evaporators model CTE503A8ED (Fig. 9) [9] fully equipped with thermostatic valve, separation ball valves and solenoid valve on each of them.

Frascold Selection Software 3 v1.22.0 - 06-Dec-23

Input data		
Refrigerant		R471a
Reference temperature		Dew point temperature
Calculation mode		Refrigeration / Air Cond.
Operating mode		Subcritical
Power supply		400/3/50
Condensing temperature	°C	45
Condensing pressure	bar	11.6
Liquid subcooling	K	0
Liquid temperature	°C	45
Evaporating temperature	°C	-10
Evaporating pressure	bar	2.01
Suction gas superheating	K	10
Useful fraction of superheating	%	100



Output data		
Compressor :		V35-103Y
Number of compressors :		FSx1
Refrigerating capacity	kW	17.89
Evaporator capacity	kW	17.89
Power input	W	8275
Condenser capacity, theor.	kW	26.21
Current	A	22.15
COP/EER	W/W	2.16
Mass flow	kg/h	777
Operating frequency	Hz	50
Connection	-	PWS
Operating mode	-	100%
Discharge temperature	°C	72.56
Ratio (%)	%	100.0%
Note	-	
Oil flow	l/min	-
Heat Exchanged (oil Cooler)	kW	-
Oil Temp. at Oil Cooler Outlet	°C	-
Certified by	-	Frascold

Fig. 7. Simulation of input/output data for V35-103Y compressors with R471A [8]

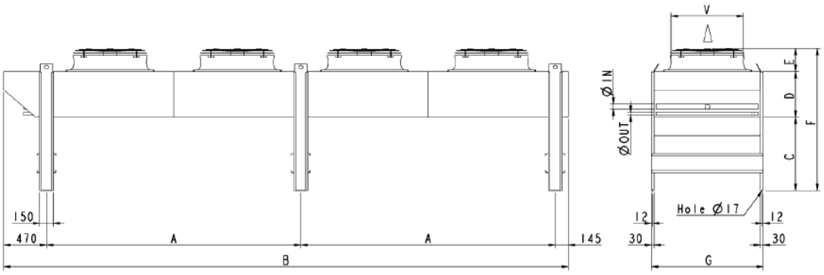


Fig. 8. Condenser Modine EGK715DN4B01V [9]

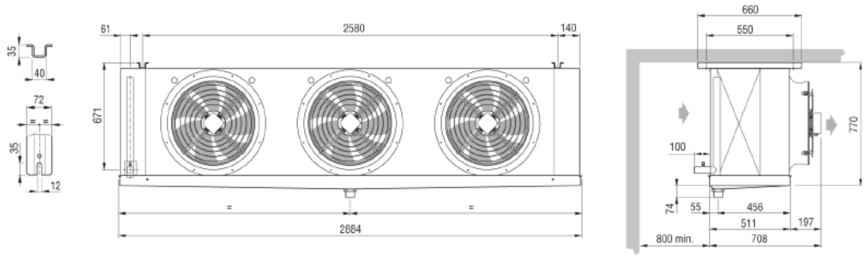


Fig. 9. Evaporators Modine CTE502A8ED [9]

3. Result

In order to choose a system that meets the environmental protection requirements, the refrigerating installation that works with R471A meets this condition. Comparing the cost efficiency of the refrigeration systems analyzed in Table 2, the factors that were taken into account are presented: installation costs, maintenance costs, costs related to the estimated annual electricity consumption, as well as the cost of the retrofit according to the regulations, assuming that the refrigeration system it works according to the data resulting from the thermal demand.

Table 2: The costs of refrigeration systems analyzed

Refrigeration system	Installation costs [Euro]	Annual maintenance costs [Euro]	Annual electricity cost [Euro]	Retrofit costs [Euro]	Total annual costs [Euro]
R134A	97776	2000	14080	77107	16080
R471A	149426	2000	10220	-	12972

For the calculation of the annual cost of the energy required to power the refrigeration equipment, an approximate price of 0.16 EUR/kWh was considered.
The lifetime of the installation, having provided annual service, is between 15 and 20 years (Table 3).

Table 3: Energy savings according to the life cycle for a period of up to 20 years

Lifetime [years]	Energy savings / year I.F. R471A vs.R134A [Euro]	Total recovered [Euro]	Investment value recovered only from energy savings [%]
10	3860	38600	25.8%
15		57900	38.7%
20		77200	51.7%

4. Discussions

Analyzing the initial costs of the investment, it can be seen that a refrigerant solution with a GWP greater than 150 units is cheaper than an installation with GWP under the limit of 150 units. But this must also be correlated with a possible improvement of the installation by retrofitting the refrigerant if the situation requires it according to the regulations to be implemented and then the advantage is clearly in favor of the installation with R471A.

5. Conclusions

The theoretical results of the case study showed that for such applications with large volume deposits, the correct choice of the technical solution from the point of view of energy efficiency is very important in the medium and long term.
Of particular importance is the fact that the installation with R471A refrigerant can be used in the long term, without the need for substantial changes in the installation or retrofit, giving it reliability and durability.
This solution no longer requires subsequent retrofit interventions, protecting the investor from other subsequent expenses.
The technical solution with refrigerant R471A can be considered as an optimal solution from the energy point of view, but especially optimal from the point of view of environmental protection, regarding installations with refrigerating power up to 100kw.

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