

ХОЛОДИЛЬНА ТЕХНІКА ТА ЕНЕРГОТЕХНОЛОГІЇ

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Improving the energy efficiency of refrigeration equipment with a direct sales function

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The increased use of refrigerants with low global warming potential GWP over the past decade indicates that manufacturers are already making gradual replacements with refrigerants with reduced environmental impact. Thus, in addition to HFC gas phase-out requirements, most EU countries are pursuing a trend to reduce the energy consumption of refrigeration appliances. Such countries restrict the import of equipment that does not meet the energy efficiency requirements. This paper presents the ecodesign of refrigeration equipment in relation to the requirements of the sales market using the Regulation on Conformity Assessment Procedure. HVAC&R equipment contributes to GHG emissions in two ways: directly through refrigerant leakage or venting, and indirectly through electricity use, the latter accounting for up to two-thirds of GHG emissions. The paper compares the energy and environmental characteristics of refrigerants R404a and R290 in freezer M200V. The experimental results show that the highest COP values in the system for R404a and R290 are 3.02 and 3.19, respectively. Possibilities of complete transition from F-gases to natural analogues with $GWP \approx 0$ are shown. At application of R290 its advantages on energy efficiency are obvious - reduction of electric power consumption of freezing chests on 8,9 %, influence on environment R404A – $GWP=3260$, R290 – $GWP=3$. The calculation of energy efficiency class for freezing chest was made. To improve energy efficiency, a number of design modifications were made: the density of the thermal insulation material and the compressor were changed. The energy consumption of the modified version at the second climatic class was measured at 1.23 kW/24h, and the energy efficiency coefficient according to the calculation $EEI = 34.904$, which corresponds to the energy efficiency class «C».

Keywords: Ecodesign; Chest freezer; Refrigerants; Energy efficiency class; Compressor; COP; R404a; R290.

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1. Introduction

Nowadays, requirements have been established for ecodesign, a technique used in the design of a product or service that takes into account environmental factors, so measures are taken to ensure that its production does not have negative effects on the environment [1].

Working priorities within the ecodesign and energy labelling framework on refrigeration appliances with direct sales function belonging to energy-related product groups have been identified and should be considered as priorities for preparatory studies and final adoption of measures [2].

Ecodesign work plan measures have an estimated potential to deliver total annual final energy savings of

more than 260 TWh in 2030, equivalent to a reduction in greenhouse gas emissions of about 100 million tons per year in 2030. Refrigeration appliances with a direct sales function are one of the product groups with an estimated 48 TWh of annual final energy savings in 2030 [3, 4].

The environmental aspect of refrigeration appliances with a direct sales function, that was identified as most relevant to the objectives is energy consumption during the use phase. This energy consumption could be reduced without increasing the overall cost of purchasing and operating the products by using cost-effective non-proprietary technologies.

The increased use of refrigerants with low global warming potential GWP over the past decade indicates that manufacturers are already making gradual replacements with refrigerants with reduced environmental impact.

Thus, in addition to HFC gas phase-out requirements, most EU countries are pursuing a trend to reduce the energy consumption of refrigeration appliances. Such countries restrict the import of equipment that does not meet the energy efficiency requirements. In order to control the compliance of such equipment, a unified register was created [5].

This paper presents the ecodesign of refrigeration equipment in relation to the requirements of the sales market using the Regulation on Conformity Assessment Procedure.

2. The main part

HVAC&R equipment contributes to GHG emissions in two ways: directly through refrigerant leakage

or venting, and indirectly through electricity use, the latter accounting for up to two-thirds of GHG emissions [6]. Energy labeling and eco-design requirements have created space for best-in-class natural alternative working fluids of refrigeration units. This increases the appeal of hydrocarbon-based refrigerants such as R290 and R600a – in commercial appliances. There are already billions of hydrocarbon-based domestic refrigerators successfully operating with proven efficiency.

Today, self-contained propane systems are becoming more common in commercial refrigeration systems around the world, especially in Europe [7-12].

2.1 Comparison of refrigerants.

The comparative analysis and experimental study of the unified refrigeration system operation on refrigerants R404a and R290 are carried out.

A freezer chest M200V from Juka-Invest Ltd. was selected [13]. This model is made with two refrigeration systems operating on R404a and R290. For the laboratory study, mathematical analysis of refrigeration systems was performed taking into account the thermal loads, which are caused by the design features of the refrigeration system and the freezer chest [14].

Refrigerating agents in the sequence (R404a → R290) were alternately filled into the refrigeration system. After setting the operating parameters, the refrigeration unit was switched on to the mains.

In accordance with the norms of conducting experiments on commercial refrigeration equipment, all measurements were taken after the freezer chest entered the operation mode. During the experiment the results shown in the tab.1 were obtained.

Table 1 – Summary table of the results of the experiment

Conditional designation		Work Period		Idle period		Work Period		Idle period	
		max	min	max	min	max	min	max	min
RA		R404A				R290			
T_{cd}	°C	36,2	26	35,3	25,4	35,5	25,2	34,1	25,3
T_{evp}	°C	-21	-36	-22	-36	-22	-36	-22	-35
T_{cam}	°C	-20,3	-21,9	-21,4	-23,1	-20,1	-22,7	-21,2	-23,3
T_{suc}	°C	32,9	2,8	32,4	19,8	33,8	8,8	33,7	23,4
T_{cm}	°C	48,5	44,6	48,4	45	48,3	44,3	48,1	44,7
T_{dis}	°C	75	38,1	72,1	39	70,1	36,8	66,8	37,9
T_{cs}	°C	39	29,1	36,6	29,2	38,6	28,8	34,6	28,5
T_{cf}	°C	37,6	30,1	34,9	27,3	34,7	28,8	32,5	25
τ_{cycle}	min	15		12		16		12	
M_{RA}	gram	95				75			

Table 1 continuation

Conditional designation		Work Period		Idle period		Work Period		Idle period	
		max	min	max	min	max	min	max	min
RA		R404A				R290			
Network analyzer									
P_n	W	186	155	2,6	2,3	163	134	2,7	2,4
I	A	1,24	1,1	0,02	0,03	1,12	1,05	0,02	0,02
U	V	220-230							
f	Hz	50							
N_e	kW/24h	2,20				2,01			
Calculation parameters									
$K\tau_{cycle}$		0,55				0,57			
COP		3,02				3,19			
EEI, %		58				46			
EEC		E				D			
$CO_2 E_Q$, ton		0,37				0			

Note: T_{cd} – average value of condenser temperatures; T_{evp} – average value of evaporator temperatures; T_{cam} – evaporator temperature; T_{suc} – suction pipeline temperature; T_{cm} – compressor shell temperature in the lubricant filling zone; T_{dis} – discharge pipeline temperature; T_{cs} – temperature of the beginning of condensation; T_{cf} – temperature of the end of condensation; τ_{cycle} – cycle time; M_{RA} – quantity of refrigerant; $K\tau_{cycle}$ – working time coefficient; COP – coefficient of performance; EEI – energy efficiency index; EEC – energy efficiency class; T_0 – boiling temperature; P_0 – boiling pressure; T_c – condensing temperature; P_c – condensation pressure; $CO_2 E_Q$ – CO_2 emission equivalent.

When R290 is used, its advantages are obvious: in terms of energy efficiency – reduction of electricity consumption by 8.9%; environmental impact R404A – GWP = 3260, R290 – GWP=3.

2.2 Requirements for reducing energy consumption.

One of the additional requirements of the external market of refrigeration equipment is the requirement to continuously improve energy efficiency. In order to be able to maintain a constant position in the refrigeration market, manufacturers are constantly conducting experiments aimed at improving energy efficiency.

One of such experiments was carried out in laboratory conditions on the basis of a freezer chest M200V, manufactured by Juka-Invest Ltd [15,16].

Considering the established requirements of energy-related ecodesign, an energy efficiency class calculation was carried out for the M200V freezer chest.

$$EEI = \frac{AE}{SAE}, \quad (1)$$

where: EEI – energy efficiency index expressed in percent (%); AE – annual energy consumption kWh/year:

$$AE = 365 \cdot E_{daily}, \quad (2)$$

where E_{daily} – the energy consumption of refrigerated appliance with a direct sales function over 24 hours, expressed in kWh/24 hours.

SAE is expressed in kWh/year. For refrigerated appliances with direct sales function with all compartments having the same temperature class and for refrigerated vending machines, the SAE is calculated as follows:

$$SAE = 365 \cdot P \cdot \sum_c^n (M + N \cdot Y_c) \cdot C_c, \quad (3)$$

where c – index number for the bay type in the range from 1 to n , where n is the total number of bay types; values M and N are tabulated values depending on the type of equipment to be calculated: for ice-cream freezers $M = 2.0$, $N = 0.009$; C – the temperature mode and the corresponding temperature coefficient values: the tabulated value depends on the temperature class of the equipment ($C = 1$); P – coefficient depending on the type of refrigeration equipment ($P = 1$); Y_c – equivalent volume of freezer compartments for ice cream with target temperature T_c , (V_{eqc}), calculated as follows:

$$Y_c = V_{eqc} = NetVolume \cdot \frac{12 - T_c}{30} \cdot C, \quad (4)$$

where T_c is the average temperature in the compartment ($T_c = 18$, table value); C – climate class coefficient ($C = 1$).

According to the electricity measurements carried out before the freezer chest modification, the electricity consumption was 1.84 kW/24h.

According to the calculation $EEI = 51.794$ – the energy efficiency class corresponds to «E».

To improve energy efficiency, a number of design modifications were made:

In order to reduce heat losses during the creation of insulation walls, the density of the thermal insulation material for two-component polyurethane foam was changed from 42 to 58 kg/m³.

The change in the density of the thermal insulation layer was achieved by calculating the change in the ratio of the components of the polyurethane foam.

Calculation for the machine for filling of polyurethane foam:

$$t = \frac{V \cdot \rho}{t_m}, \quad (5)$$

where t (s) – feeding time during foaming; V (m³) – volume of filling with insulation; ρ (kg/m³) – density; t_m (kg/s) – mass feeding of the mixture (technical characteristics of the machine for foamed polyurethane foam filling), $t_m = 1.17$ kg/s.

Component A

$$m_A = \frac{\left(\frac{t_m}{1/t}\right)}{2,5}. \quad (6)$$

Component B

$$m_B = m_A \cdot 1,5. \quad (7)$$

Thus, when the insulation volume in the M200V – $V = 0.142$ m³, and the insulation density $\rho = 42$ kg/m³, the feeding time was $t = 5.1$ s. The consumption of components was $m_A = 2.386$ kg; $m_B = 3.578$ kg.

At initial technical data for FPU the change of heat conductivity coefficient in the range of 0.019-0.035 W/m·K depending on density in the range of 30-150 kg/m³.

The thermal conductivity coefficient corresponds to the value $K_1 = 0.0294$ W/m·K.

When the density was increased to $\rho = 58$ kg/m³ the initial data were: $t = 7.04$ s; $m_A = 3.294$ kg; $m_B = 4.942$ kg; $K_2 = 0.0273$ W/m·K.

The evaporator winding on the inner body of the freezer chest is shifted 50mm higher and the winding pitch is changed from 40mm to 35mm.

It can be stated that freezer chests of this type utilise cooling by static air movement in a closed volume. Thus the height of the evaporator placement depends on the height of the loading line, and the temperatures in the cooled volume decrease as a function of depth. Thus it can be stated that changing the height of the evaporator relative to the loading line (without changing the height of the loading line and without reducing the usable volume), will allow lower temperatures to be obtained at the loading line, and reducing the winding pitch will increase energy efficiency and compensate for the thermal loads associated with changing the location of the evaporator winding.

The compressor Embraco EMC 3119 U (0.236 kW) was replaced by Embraco EMC 3117 U (0.197 kW).

Based on the previously applied modifications and on the basis of the thermal calculation of the freezer chests, the compressor was calculated and selected for replacement in the equipment under study.

After the modifications were made, the operation was compared and electricity was measured. The test data are summarised in tab. 2 and Figure.

Table 2 – Comparison of compressor characteristics

Name	Embraco EMC3119	Embraco EMC3117
Cooling capacity	0.236 kW	0.197 kW
Efficiency, COP	1.9 W/W	1.83 W/W
Refrigerant	R290	R290
Application conditions	L/MBP LC	L/MBP
Motor type	RSCR	RSCR
Research conditions	ASHRAE LBP32	ASHRAE LBP32

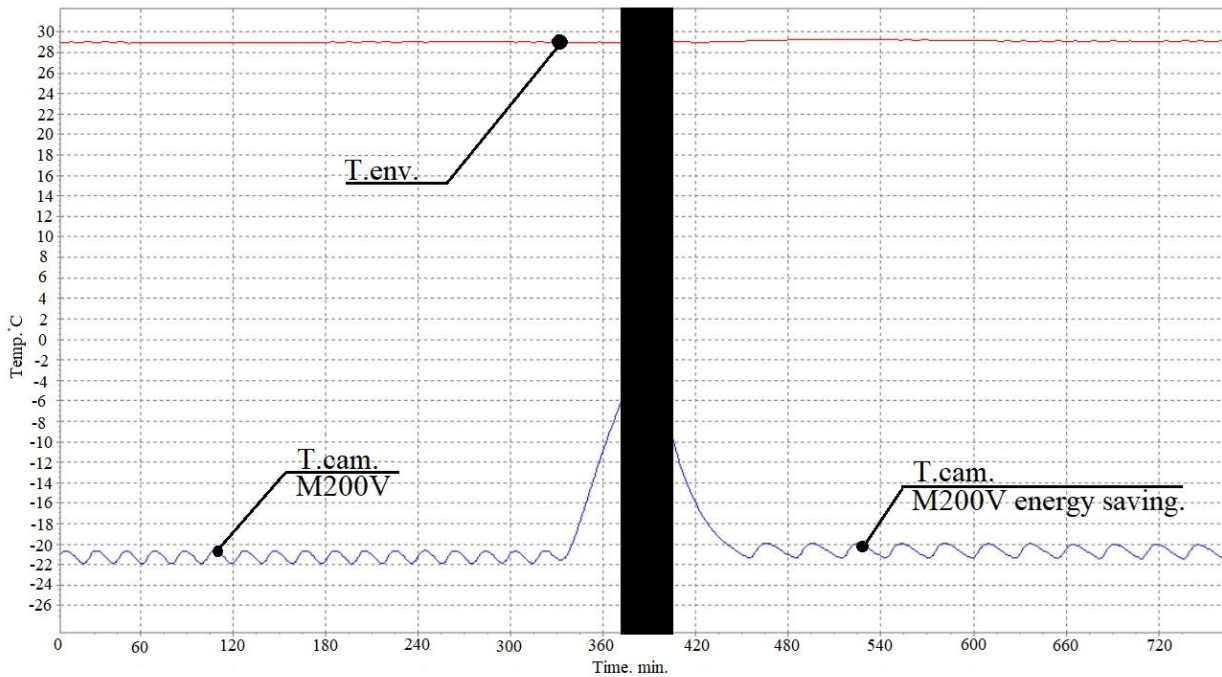


Figure – Comparison of M200V and M200V energy saving freezers on the temperature vs time graph: T_{env} – ambient temperature; T_{cam} M200V – dynamics of temperature change on the loading line of the freezer chest M200V in basic configurations; T_{cam} M200V energy saving – dynamics of temperature change on the loading line of the freezer chest M200V in the modified, energy saving version.

The energy consumption of the modified version in the second climate class was measured at 1.23 kW/24h and the energy efficiency coefficient according to the EEI calculation = 34.904, which corresponds to energy efficiency class «C».

3. Conclusions

The conclusion of such research becomes the confirmation of possibility of full transition to natural refrigerating working agents from $GWP \approx 0$. High energy efficiency of the refrigerating agent R290 is revealed.

At application of R290 its advantages on energy efficiency are obvious – reduction of electric power consumption of freezing chests on 8,9%.

The calculation of the energy efficiency class for the freezer chest was carried out. To increase energy efficiency, a number of structural changes were made: the thickness of the heat-insulating material and the compressor were changed. The energy consumption measurement of the modified version at the second climate class was 1.23 kW/24h, and the energy efficiency coefficient, according to the EEI calculation = 34.904, which corresponds to the energy efficiency class «C».

CRedit author statement

Ivan Konstantinov: Conceptualization, Formal analysis, Visualization, Resources, Software Writing – Original Draft, Project administration. **Mykhailo Khmelniuk:** Methodology, Investigation, Validation, Data Curation, Writing – Review & Editing, Supervision.

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Підвищенням енергоефективності холодильного обладнання з функцією прямих продажів

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Збільшення використання холодоагентів із низьким потенціалом глобального потепління GWP протягом останнього десятиліття свідчить про те, що виробники вже здійснюють поступову заміну холодоагентами з меншим впливом на навколишнє середовище. Таким чином, на додаток до вимог щодо поступової відмови від використання газу HFC, більшість країн ЄС дотримується тенденції до зниження споживання енергії холодильними приладами. Такі країни обмежують імпорту обладнання, яке не відповідає вимогам енергоефективності. У цій роботі представлено екодизайн холодильного обладнання щодо вимог ринку збуту з використанням Положення про процедуру оцінки відповідності. Обладнання HVAC&R сприяє викидам парникових газів двома способами: безпосередньо через витік або вентиляцію холодоагенту та опосередковано через використання електроенергії, на останнє припадає до двох третин викидів парникових газів. У статті порівнюються енергетичні та екологічні характеристики холодоагентів R404a та R290 у

морозильній камері M200V. Експериментальні результати показують, що найвищі значення COP у системі для R404a та R290 становлять 3,02 та 3,19 відповідно. Показано можливості повного переходу від фторних газів до природних аналогів з $GWP \approx 0$. При застосуванні R290 його переваги по енергоефективності очевидні – зниження споживання електроенергії морозильних камер на 8,9 %, вплив на навколишнє середовище R404A – $GWP = 3260$, R290 – $GWP = 3$. Проведено розрахунок класу енергоефективності морозильного ларі. Для підвищення енергоефективності було внесено ряд конструктивних змін: змінено густину теплоізоляційного матеріалу та компресора. Енергоспоживання модифікованої версії за другим кліматичним класом виміряно на рівні 1,23 кВт/24 год, а коефіцієнт енергоефективності за розрахунком $EEL = 34,904$, що відповідає класу енергоефективності «С».

Ключові слова: Екодизайн; Морозильна скриня; Холодильні агенти; Клас енергоефективності; Компресор; COP; R404a; R290.

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