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COMPARATIVE ANALYSIS OF VARIABLE REFRIGERANT FLOW SYSTEMS AND CHILLER-FAN COIL SYSTEM FOR OFFICE BUILDINGS

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Abstract. The paper is dedicated to the technical and economic analysis of air-conditioning solutions for office buildings. În this paper two air conditioning systems were compared: the variable refrigerant flow (VRF) system and the chiller-fan coil system. Comparison of the technical and economic indicators was done using the "global cost" method. As a result of the analysis, it was found that: the energy saving in the air conditioning system to a great extent depends on building design solutions and the type of air conditioning system.

Keywords: *VRF, air conditioning system, chiller-fan coil system, cooling power, Global Cost, cooling energy consumed, economic effect.*

1. Introduction

The increasing demand for improving the thermal comfort in buildings has led to the large-scale deployment of HVAC systems, which has led to a steady increase in energy consumption in buildings [1, 2]. Cooling demand is steadily rising, mainly due to revenue growth, and is also expected to grow with climate change. Capital investments for Air Conditioning Systems often reach 20% of the total cost of the building. According to the representative of Schneider Electric Romania, the costs for an office building are divided into two categories:

- The first category is the initial investment, which usually accounts for only 25% of the costs;
- The second category is operating expenses, which represent 75% of the costs and lie for a period of 25-30 years.

Constructions, engineering installations under the economic aspect involve a very large volume of resources that requires the adoption of a concept, the use of a methodology to allow for the determination of the costs of building objects throughout their life.

2. Methodology

Comparison of projects/variants, or more precisely, comparison of their technical and economic indicators, is possible only if these indicators are calculated for the same duration of investment [3, 8]. There are several ways of equating alternative projects in terms of operating time. In this paper, the economic analysis of the investments was done with the Global Cost (GC) method.

By content, the Global Cost is defined as the economic amount between the initial efforts to make an investment and the subsequent costs related to its maintenance and exploitation. Schematically this definition can be represented as follows:

Global Cost = Initial Costs + Costs Subsequent

The "Global Cost" indicator expresses the current value of the initial investment costs and the subsequent costs of the operation building and construction, and maintenance (intervention, current repair and capital repair), the economic life of the investment project or the duration conventional time (about 20 to 25 years) [4]. GC calculations aim at obtaining the updated cost value incurred during a defined calculation period, taking into account the residual values of equipment/elements with a higher service life.

The Global Cost Method, also known as the "cost-per-life of a construction" method, aims to improve the investment decision by reducing the risk of investing less today and to support higher future expenses tomorrow. The timing of the optimal decision is at the design stage. In this respect, life cycle cost analysis is a key component of establishing the feasibility of a construction project.

In order to perform a technical-economic calculation of the air-conditioning systems in the office buildings, several buildings from the city of Chisinau, built during the last 5-8 years, have been analyzed. Based on this study, it was found out that the most frequently used is the chiller-fan coil system. The new VRF system is on the market, but due to the initial cost, few owners accept it. As a result, in the present paper it was proposed to compare these two air-conditioning systems: the VRF system and the chiller-fan coil system according to the life cycle cost principle.

For the study, an office building in the city Chisinau was selected, where the VRF air conditioning system is provided; the chiller-fan coil system for the this building was designed for comparison [5, 6, 7].

Figure 1. Office building.

The selected building is a representative sample of the building fund in the Republic of Moldova in terms of form, size, characteristics and ways of using new buildings. From an architectural point of view, the building is built in a modernist style with a compact structure. The flat shape of the construction is quasi-rectangular with 7 levels, the building being designed to accommodate the commercial area coupled with offices on the ground floor. Because offices are given on rent, the air conditioning system is installed separately on each floor, so the calculation of the Global Cost of the air conditioning was done for a single level. For both air conditioning systems, the Global Cost was determined with the relation:

$$GC = I + (\sum C \cdot \sum k_a) \quad (1)$$

where: *I* - the total investment on the system (see "Table 1" and "Table 3");
$\sum C$- represents the amount of annual expenditure ("Eq.(4)");
K_a – the value of the update coefficient ("Eq.(8)").

For each of the compared projects, one and the same time interval (study period) of duration T, in which a whole number of Tsn lifetimes can be assigned, is accepted. The duration of study chosen for both variants is 20 years.

As a result of the development of the documentation estimate, the cost price for both versions of one-storey air-conditioning systems was determined. The calculations were made using the WinSmeta program, adapted and supplemented to the normative basis of the Republic of Moldova.

Variant A - VRF air conditioning system, the value of the cost estimate is:
Io = 1083518,98 lei.

Variant B - chiller-fan coil system, the value of the cost of conversion is:
Io= 935709,83 lei.

Additional costs are also included in determining the Global Cost, including: maintenance costs; current repairs; capital repairs; replacements and operating costs.

Because the analyzed building works, all engineering systems, including the VRF air conditioning system, are serviced by dedicated staff. From the data obtained directly from the owner of the building, maintenance of one-storey engineering systems for:

- service staff – $C_{ser.st.}$ (unskilled workers) during one month pay 2143 lei;
- and 1000 lei - for the engineering staff - $C_{eng.st.}$

It follows that the costs for the salary payment of maintenance personnel during one year are:

$$C_{ser.st.} = 2143 \cdot 12 \cdot 0.6 = 15428{,}4 \ lei/year (2)$$

$$C_{eng.st.} = 1000 \cdot 12 \cdot 0.6 = 7200 \ lei/year (3)$$

where: 0.6 - occupancy rate, service staff and engineering staff, with service conditioning.

Annually, air conditioning operations are provided, as well as operating costs. The type of works and their cost are specified in the contract for the provision of air conditioning operation services between the owner of the building and the service provider. The payment for the provision of this type of air conditioning system on one floor, referred to in the formulas as service installation costs, $C_{ser.ins.}$ - is 9400 lei / year.

Energy costs are mentioned as a separate cost category, although these are considered as part of operational costs. Energy costs are based on consumption, building size, current rates and price estimates and are directly related to the result of the energy performance calculation. This means that energy costs depend on the system's building characteristics.

Based on project data "Figure 2", the power consumption for the VRF system , which consists of two KXV and KXVI systems, and the chiller - fan coil system, was determined.

The KXV-VRF system comprises:

- ✓ two outdoor units: CMV-V400W / ZR1-B-40kW (refrigeration power) with an electric power of 11.05kW and second - CMV-V280W/ZR1-B-28kW with an electric power of 6.95kW ;
- ✓ and 10 indoor units - V36G (one unit) with an electric power of 0.058kW; V56 (2 units) with an electric power of 0.06kW; V71 (2 units) - with an electric power of 0.3kW; V80 (2 units) - with an electric power of 0.3kW; V90 (2 units) - with an electric power of 0,34kW; V120 (one unit) - with an electric power of 0,34kW.

The KXVI-VRF system comprises:

- ✓ two outdoor units: one CMV-V335W/ZR1-B-33kW (cooling power) with an electric power of 8.48kW and a second CMV-V280W / ZR1-B-28kW with an electric power of 6.95kW;
- ✓ 8 indoor units - V56 (one unit) with an electric power of 0.06 kW; V71 (one unit) with an electric power of 0.3kW; V80 (one unit) with an electric power of 0.3kW; V90 (5 units) with a power output of 0.34kW.

The VRV air conditioning system consumes 33.43kWh of electricity.

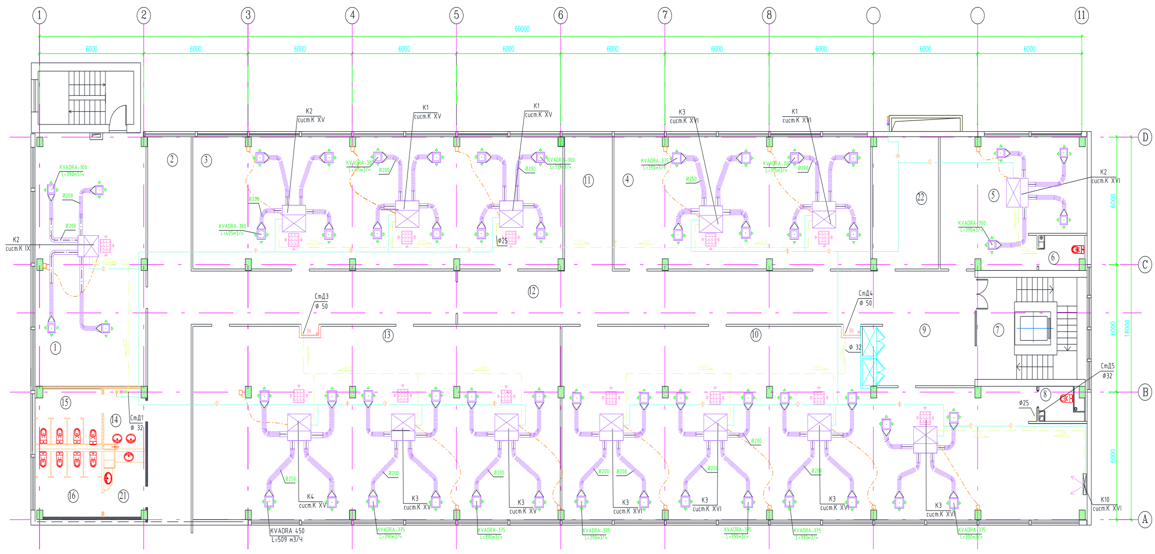

Figure 2. Plan of the office building with VRF system.

***The chiller - fan coil system* comprises**:

- ✓ a chiller Clint with a 161kW cooling capacity, and a 59 kWh with electricity consumption;
- ✓ the 18 indoor units (fan coils) have a electricity consumption of 2.66kWh:
  - CST-800P30 (6 units) with electrical power of 0.150kW;
  - CST-1000P30 (7 units) with electrical power 0.172kW;
  - CST-1200P30 (one unit) with electrical power 0.1949kW;
  - CST-400P30 (one unit) with electrical power 0,060kW;
  - CST-600P30 (3 units) with electrical power 0,106kW.

3. Results

The consumption and the cost of electricity during the cooling season are shown in Table 1.

Table 1

Electricity costs

Name- of the system	Electric power, kW	Number of working days per year, day	Number of working hours per year, h	Electricity consumption per year, kW / year	Electricity tariff lei / kWh	Costs for electricity, C_{elec}, lei/year
VRV	38,18	June - 15 days July - 22 days August - 21 days September - 10 days	544	20770	2,18	45279
Chiller-fan coil	61,66			33543		73124

The amount of annual expenses to determine with the relationship:

$$\sum C = C_{ser.st.} + C_{eng.st.} + C_{ser.ins.} + C_{elec}\ ,\ lei/\text{year} \quad (4)$$

where: $\sum C$ – represents the amount of annual expenditure;

$C_{ser.st.}$ – service staff, lei/year;

$C_{eng.st.}$ – engineering staff, lei/year;

$C_{ser.ins}$ – as service installation costs, lei/year;

C_{elec} –costs of electricity, lei/year.

$$\sum C_{VRF} = 15428{,}4 + 7200 + 9400 + 45279 = 77307{,}4\ lei/year$$

$$\sum C_{chiller-fan\ coil} = 15428{,}4 + 7200 + 9400 + 73124 = 105152{,}4\ lei/year$$

For a faster visual comparison, the chart in “Figure 3” was constructed, representing the cost of purchasing and installing conditioning equipment, the cost of servicing installations and the cost of electricity consumed during the operation of the conditioning system during one year Table 1.

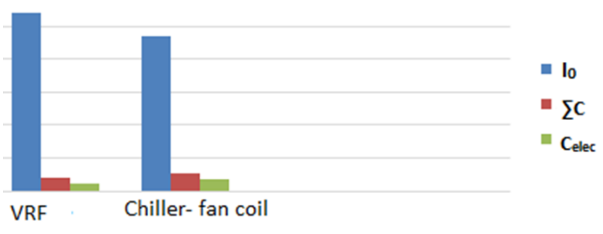

Figure 3. Graphical representation of the initial costs and subsequent servicing of air conditioning plants over a year, thousands of lei/year.

In addition to *initial investment costs* and *current costs*, regular **replacement costs** are introduced when determining the Global Cost, which is not considered as part of the maintenance costs, as occasionally for other cost structures. While smaller and consumable repair works are usually included in the maintenance cost category, periodic replacement refers to the required replacement of an entire element of the plant as a result of obsolescence, and therefore it is ensured that a separate category of costs. The period of periodic replacement depends on the life of the installation element. At the end of its lifetime, a replacement should be provided in the Global Cost calculation.

From the "Fixed assets and non-material assets catalog", as well as from the literature, the durations of use of components of air conditioning systems were identified, namely:

- ✓ water supply systems for steel pipes -15 years;
- ✓ copper freon pipes - 40 years;
- ✓ steel air ducts -10 years;
- ✓ air conditioning machines and apparatus fitted with a fan and electric motor and its own equipment for changing the temperature and humidity, including those for which the humidity cannot be adjusted separately - 8 years;
- ✓ compressors used in refrigerated machines with built-in fan - 12 years.

In “Figure 3” for example, alternative projects with different durations of use are represented.

The graph in “Figure 4a” - represents the VRF air conditioning system and in “Figure 4b” represents the chiller- fan coil system, where:

I_0 - represents the initial investment, which was determined with WinSmeta (“Table 2”, “Table 3”);

I_{1a} – represents the investment for the dismantling and replacing of indoor air conditioning units over 8 and 16 years respectively. I_1=I_8+I_{16};

I_{2a} – represents the investment in dismantling and replacing the air ducts over 10 years.
I_2 = I_{10};

I_{3a} – represents the investment in the dismantling and replacing of external conditioning units over 12 years. I_3 = I_{12};

I_{4a} – represents the investment in dismantling and replacing steel pipes over 15 years. I_4 = I_{15}.

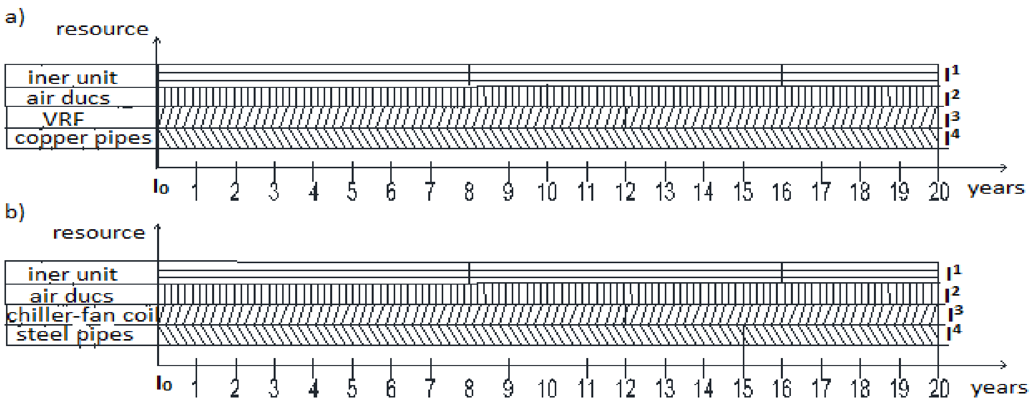

Figure 4. Graphic representation of the period of use of components of air conditioning systems.

Updating future cash flows (investments) (I_v) is made using the update coefficient (K_a):

$$I_a = I_v \cdot K_a. \tag{5}$$

where: I_v - future investments, which was determined with WinSmeta (“Table 2”, “Table 3”).

Choosing the discount rate (r) to assess the efficiency of investment projects is a challenge. The r rate varies from project to project and changes over time [1]. It depends on many factors such as: investor's financial condition, bank interest rate, tax structure and values, possible risk in economic activity, inflation, profitability of similar objectives, etc.

The discount rate must be higher than the rate of return in that sector. The update rate *r* values used in calculations for energy projects are between 10-12%. It is customary to consider *r* the constant value during the study period [1]. In the paper, the discount rate was accepted at 10% (*r* = 10%).

Table 2

Variant A. Determination of total investments for the VRF system

The system	The initial investment, I_o , lei	Elements of the system that are changed during the study period	Period of investment	Value of future investments, I_v lei	$K_a = \frac{1}{(1+r)^n}$	The updated investment, I_a, lei	Investment total on the system $I=I_0+(I_a^1+I_a^2+I_a^3)$, lei
VRF	1083518,98	Indoor unit I_a^1	I_8 I_{16}	dismantling: 31891,34 replacing: 326888,35	2,143 4,595	245499,82	1541369,53
		Air ducts I_a^2	I_{10}	dismantling: 6436,86 replacing: 145452,92	2,594	58554,27	
		External unit I_a^3	I_{12}	dismantling: 13180,27 replacing: 469432,92	3,138	153796,46	

for example:

$$I_a^1 = I_8 + I_{16} = (31891{,}34 + 326888{,}35)\frac{1}{(1+0{,}1)^8} + (31891{,}34 + 326888{,}35)\frac{1}{(1+0{,}1)^{16}} = 245499{,}82\ lei$$

Previously, the costs of maintenance and operation of air conditioning systems were determined. Their value was (Table 3):

Table 3

Variant B. Determination of total investments for the Chiller-fan coil system

The system	The initial investment, I_o , lei	Elements of the system that are changed during the study period	Period of investment	Value of future investments, I_v lei	$K_a = \frac{1}{(1+r)^n}$	The updated investment, I_a , lei	Investment total on the system $I=I_0+(I_a^1+I_a^2+I_a^3+I_a^4)$, lei

Ciller-fan coil	935709,83	Indoor unit I_a^1	I_8 I_{16}	dismantling: 31891,34 replacing: 138085,86	2,143 4,595	245499,82	1430210,03
		Air ducts I_a^2	I_{10}	dismantling: 6436,86 replacing: 145452,92	2,594	58554,27	
		External unit I_a^3	I_{12}	dismantling: 7258,38 eplacing: 514457,20	3,138	153796,46	
		Steel pipes I_a^4	I_{15}	dismantling: 15371,77 replacing: 137713,84	4,177	36649,65	

$$\sum C_{VRF} = 77307{,}4\ \ lei/year$$

$$\sum C_{chiller-fan\ coil}\ = 105152{,}4\ \ lei/year$$

The value of the update coefficient will be determined for a period of 20 years with the relationship (r=0,1):

$$\sum k_a = \ \frac{1}{(1+r)^1} + \cdots + \frac{1}{(1+r)^{20}} \tag{6}$$

$$\sum \mathrm{k_a} = 0{,}909 + 0{,}826 + 0{,}751 + 0{,}683 + 0{,}621 + 0{,}564 + 0{,}513 +$$

$$0{,}467 + 0{,}424 + 0{,}386 + 0{,}350 + 0{,}319 + 0{,}290 + 0{,}263 + 0{,}239 +$$

$$0{,}217 + 0{,}198 + 0{,}180 + 0{,}164 + 0{,}148 = 8{,}512$$

Finally, the value of the Global Cost for both variants of the air-conditioning system is determined:

1) The Global Cost of the VRF type air conditioning system is:

$$GC_1 = I + (\sum C_{VRF} \cdot \sum k_a) = 1541369{,}53 + (77307{,}4 \cdot 8{,}512) = 2199410{,}12 lei \tag{7}$$

2) The Global Cost of the chiller-fan coil air conditioning system is:

$$GC_2 = I + \left(\sum C_{chiller-fan\ coil} \cdot \sum k_a\right) = 1430210{,}03 + (105152{,}4 \cdot 8{,}512) =$$

$$= 2325267{,}26 le \tag{8}$$

4. Discussions

As a result of the calculations we have concluded that the GC_1 of the VRV is less than the GC_2 of the ciler-fancoil, 2 199 410,12 lei < 2 325 267,26 lei.

When comparing variants based on global cost, we can determine the economic effect as a result of selecting the more convenient version of the air conditioning system:

$$E_{eco} = CG_2 - CG_1 \ = 2325267{,}26 - 2199410{,}12 = 125857{,}14\ lei \tag{9}$$

The Global Cost as well as the value of the economic effect were determined for a single level, but because the building has 6 office levels, the economic effect for the entire office area will be:

$$GC_{1building} = 2199410{,}12 \cdot 6 = 13196460{,}72\ lei$$

$$GC_{2building} = 2325267{,}26 \cdot 6 = 13951603{,}76\ lei$$

$$E_{eco} = GC_{2building} - GC_{1building} = 13951603{,}76 - 13196460{,}72 = 755142{,}84\ lei.$$

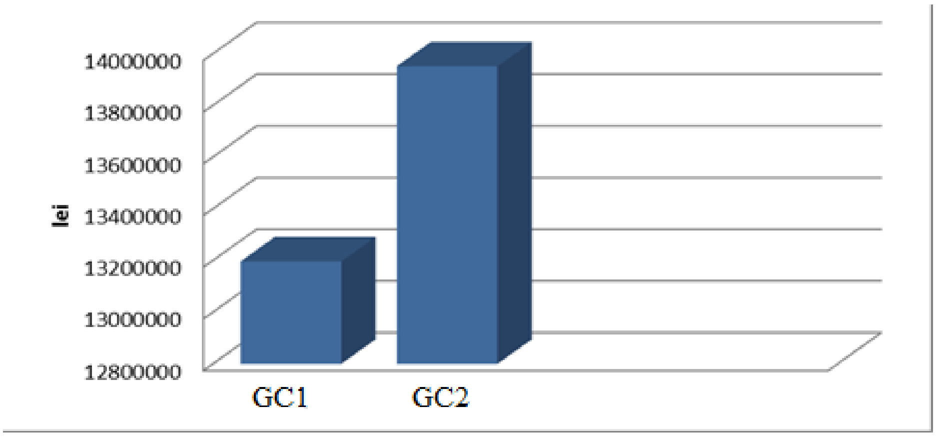

Figure 5. Comparison of the Global Cost of the VRF-type air conditioning and the chiller fan-coil system.

5. Conclusions

Following the study, it was found that:

- the Life Cycle Model will be useful both for developing concepts for energy-efficient buildings in new buildings and for renovating existing buildings;

- the Global Cost approach allows us to conclude that more expensive projects at the initial stage can become more lenient in the exploitation process over a long time horizon;

- as a result of the calculations, it can be mentioned that the VRV type air conditioning system is more efficient than the chiller – fan coil climate system. The Global Cost (the capital commitment for 20 years) after this variant is lower - a high-quality building offers not only better comfort but also a return on investment, thanks to the saving of operating costs;

- energy saving in the air conditioning system depends largely on building design solutions and the type of air conditioning system.

References

1. Arion V,V., Hlusov, V., Gherman, C., Șfeț,O. *Ghid privind evaluarea economică a proiectelor din domeniile eficienței energetice și energiei regenerabile* . Chișinău, 2014.
2. Albu, S., Albu, I., Usturoi L. *Management Investițional*. Chișinău, 2016.
3. Lambrache, S. *Principii de bază privind metodologie costurilor pe ciclu de viață a construcțiilor la nivel european.* București.Vol 2, Nr.2 In: Urbanism. Arhitectură. Construcții pp. 75-80. ISSN:2069-05.

4. Yang, L., Yan, H., Lam, J.C. Thermal comfort and building energy consumption implications. In: Applied Energy, 2014, 115, pp. 164–173.
5. Peeters, R., Hensen, J., D'haeseleer, W. Thermal comfort in residential buildings: Comfort values and scales for building energy simulation. In: Applied Energy, 2009, 86, pp. 772-780.
6. Xinqiao, Y., Da,Y., Kaiyu, S., Tianzhen, H., Dandan, Z. Comparative study of the cooling cnergy Performance of variable refrigerant flow systems and variable air volume systems in office buildings. In: Applied Energy, 2016, 183, pp. 725-736.
7. Yonghua, Z., Xinqiao, J., Xing, F., Zhimin, D. Optimal control of combined air conditioning system with variable refrigerant flow and variable air volume for energy saving. In: International Journal of Refrigeration, 2014, 42, pp. 14-25.
8. Behrouz, N., Simon, H., Qian, W., Adnan, P. Life cycle cost analysis of air preheating systems using wastewater and geothermal energy. In: REHVA European HVAC journal, 2019, 56, pp. 47-51.