Ecological and Energy Efficiency Study of Heat Pumps with Capillary Evaporators

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This study represents a research in the field of energy efficiency and environmental optimizations of heat pumps, analysing the comparative performances obtained by changing the refrigerant R407C with R290. For testing, an open circuit water-to-water heat pump was used, with capillary evaporators with an innovative spiral shape.

The simulations showed that the heat pump ensures an important reduction of the electricity consumption and Total Equivalent Warming Impact to an ordinary air conditioning system.

Keywords: Heat Pump, EER, COP, TEWI, Capillary Evaporators, Energy Efficiency.

Heat transfer performance is one of the most important areas of research in the field of thermal engineering. There is a large number of refrigerants used in compression refrigeration systems. Their use implies for each case some reservations in terms of environmental impact (Following the Montreal Protocol 1987 refrigerants CFCs "chlorofluorocarbons" were finally abandoned in 2000 and gradually replaced by HCFCs or HFCs and within it providing an opportunity for the development of substitutes), toxicity (NH_3), flammability (HC) or high pressure (CO_2), which gives them degrees of danger accordingly.

Ashok G. Matani et al. (2010), conducted an experimental study to observe the performance of different ecological refrigeration mixtures (HC and R401a mixture).

This innovative system can use a renewable energy resource, respectively groundwater, rivers or sea water and can achieve both the heating and cooling requirements of a location.

Method and international analysis

E. Halimic et al. (2011) tested the operation of a compression refrigeration system using R401a, R134a and R290 refrigerants. The results (**Figure 1**) indicated that the performance obtained with refrigerant R134a are close to those obtained with refrigerant R401a but lower than those obtained with refrigerant R290.

E. Navarro et al. (2012) conducted a comparative study between R1234yf, R134a and R290, using a piston compressor, with two operating speeds and vaporization temperatures from –20°C to 20°C, with the condensation temperature variation between 40°C and 65°C.

The measurements performed and the subsequent analysis led to the following conclusions:

- R290 has shown a significant improvement in volumetric efficiency, and heat losses are considerably lower than for the other two coolants. It should be noted that R290 has a significantly higher volumetric capacity than the other two refrigerants, which may reduce the size of this type of system (Brown, J.S., et al., 2010).
- The new refrigerant, R1234yf, has better efficiency compared to R-134a for pressure ratios greater than 8. It has less heat loss than R134a, but 20% more than R290 (Mathur, G.D., et al., 2010). From this study, was concluded that R1234yf and R290 can be good substitutes for R-134a.
- In terms of efficiency, R290 (**Figure 2**), demonstrated a better performance for the whole range of conditions tested (improvement on average by 30%

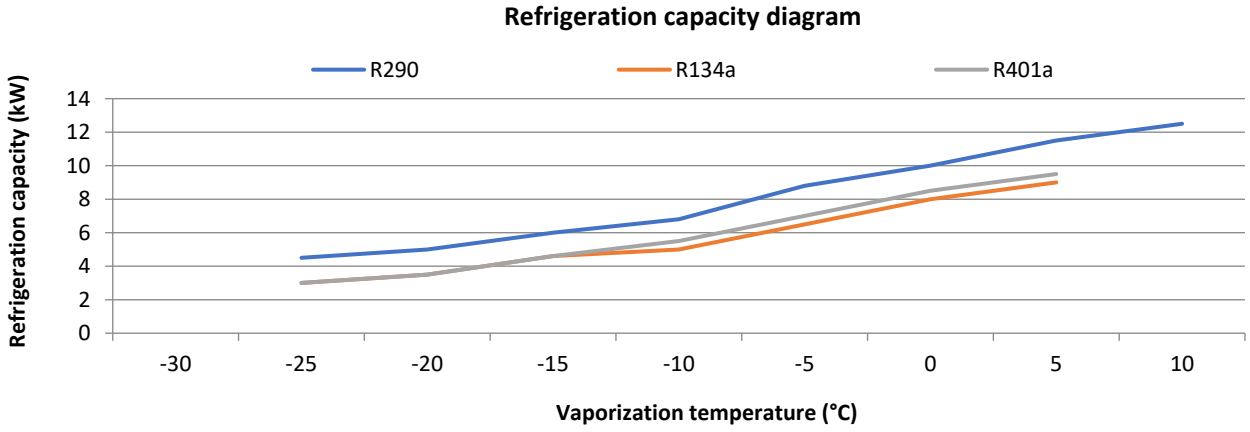

Figure 1. Refrigeration capacity analysis.

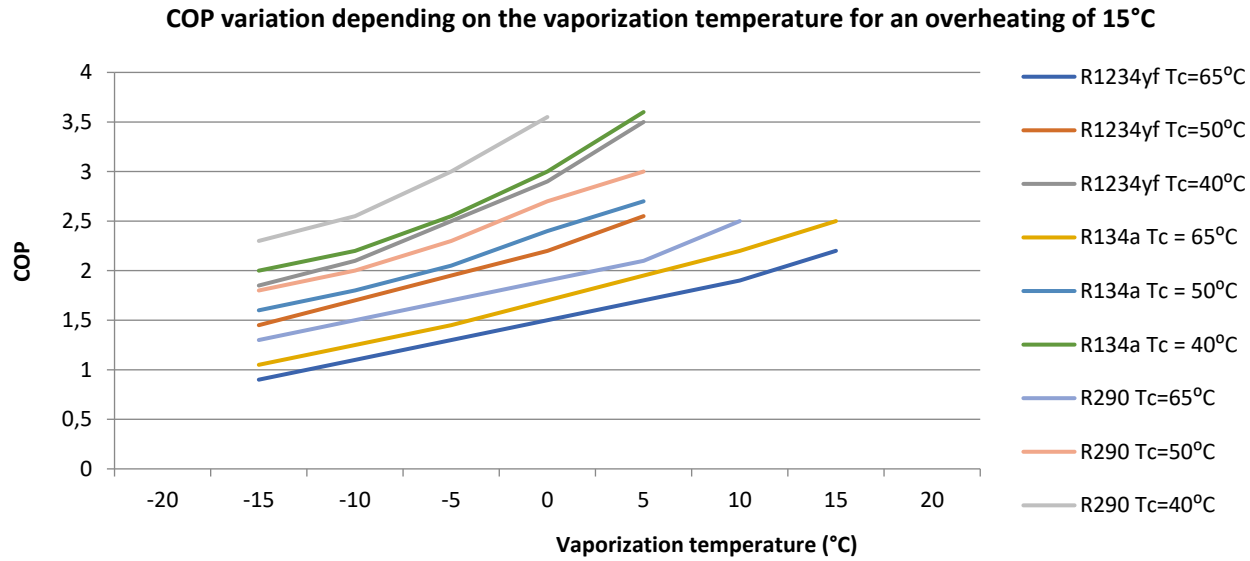

Figure 2. COP variation for tested refrigerants.

of volumetric efficiency and by 15% of compressor efficiency). R1234yf showed higher heat losses than R290, even with a significantly lower compressor discharge temperature.

Ki-Jung Park and others (2007), analysed the performance of two pure hydrocarbons and seven mixtures composed of propylene, propane, R152a and dimethyl ether in order to replace R22 refrigerant in residential air conditioners and heat pumps at evaporation temperatures and condensation of 7°C and 45°C, respectively. The test results confirmed a value of the performance coefficient of these mixtures up to 5.7% higher than in the case of operation with R22. The conclusions were that the mixtures used led to superior performance with reasonable energy savings, without any environmental problems and, consequently, can be used in the long term as alternatives for residential air conditioning and heating applications with heat pumps.

Ki-Jung Park et. al., (2007), analysed the thermodynamic performance obtained with two pure hydrocarbons and seven mixtures composed of propylene (R1270), propane (R290), R152a and dimethyl ether (R170) in order to analyse the possibilities of substituting R22 refrigerant in residential air conditioning installations.

The test results led to COP values up to 5.7% higher than when using R22 refrigerant.

K. Mani et. al., (2008) , analysed the operating parameters of a refrigeration system with steam compression using the R290 / R600 mixture (68% / 32%) in order to replace the R134a refrigerants.

In conclusion, the mixture R290 / R600a (68/32% by weight) can be considered as a substitute refrigerant R134a due to the real ecological advantages.

AS Dalkilic et al. (2010), studied the performance of a compression refrigeration plant using mixtures of R134a, R152a, R32, R290, R1270, R600 and R600a refrigerants combined in various ratios and the results were compared with the functional parameters of the same plant using refrigerants R22 and R134a.

The results show that all alternative refrigerants investigated in the analysis have a COP slightly lower than R22 and R134a for the condensation temperature of 50°C and the evaporation temperatures ranging from –30°C to 10°C.

The results have shown that the mixture of R290 / R1270 refrigerants (20% / 80% by weight) can replace refrigerant R22 with close energy results, having in view the ecological properties of these mixtures.

Vincenzo La Rocca et. al. (2011), analysed the performance of a refrigeration system with vapour compression using refrigerant R22 compared to those obtained by replacing this refrigerant with new refrigerants, HFC, respectively:

R417a, R422a and R422d. The conclusion was that the performances obtained with the new tested refrigerants were inferior to those achieved by operating with the R22 refrigerant.

Yunho Hwang et al. (2007), compared the operating performance of a refrigeration system using R404 and R410A refrigerants compared to R290. The conclusion was that the energy performance obtained with R290 refrigerant is lower than that obtained with R404 and R410A refrigerants but the ecological performance of R290 are absolute.

Venkataramana Murthy et al. (2014), considered the possibility of replacing refrigerant R22 with environmentally friendly refrigerants (R134a, R407C and R290) in order to comply with the provisions of the Montreal Protocol using for testing a refrigeration system equipped with a rotary encapsulated compressor using SUNISO4 oil and an air-cooled condenser. The evaporator used was a 2m long capillary.

The conclusion from all studies analysed in the first part of this article, was that the R290 refrigerant ensures a higher COP (**Figure 3**), compared to the R134a, R407C refrigerants and next chapter will show such results for a heat pump with original capillary evaporator.

Results and discussion

In order to determine the energy performance of the use of the R290 refrigerant compared to the R407C refrigerant for an innovative heat pump (HP) analysed in this paper, operation simulations were performed using specialized programs. The COP value was analysed for the entire usual range of condensation temperatures **Figures 4-9** represents the COP variation depending on the vaporization (Te) and condensation temperature (Tc).

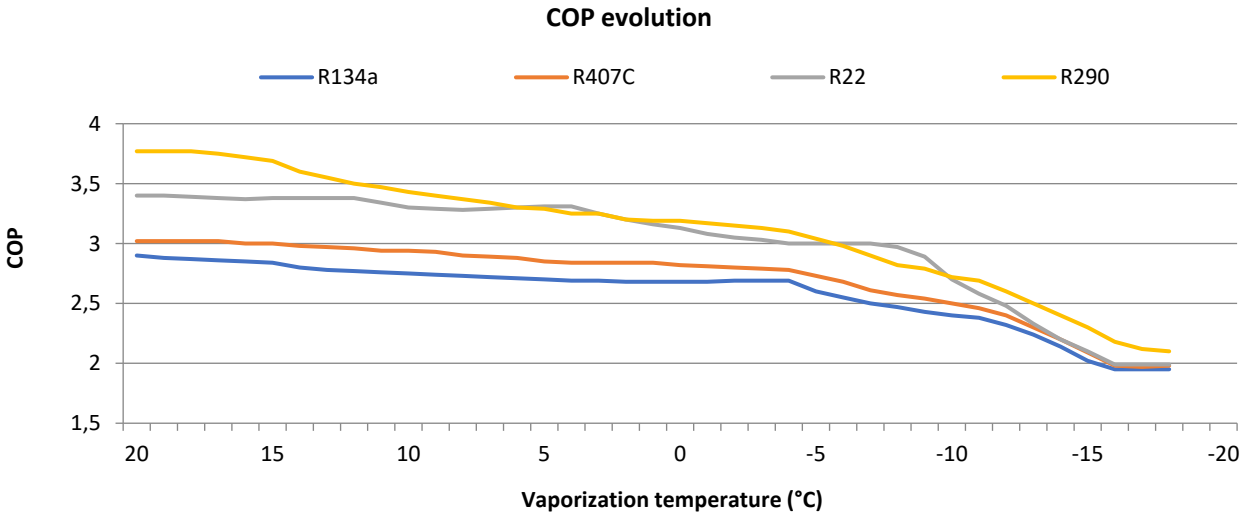

Figure 3. COP evolution for the refrigerants tested in the refrigeration installation.

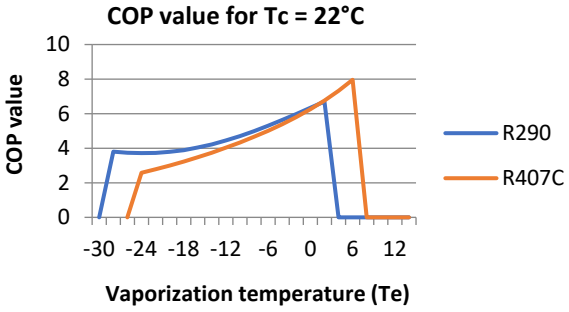

Figure 4. COP value for Tc = 22°C.

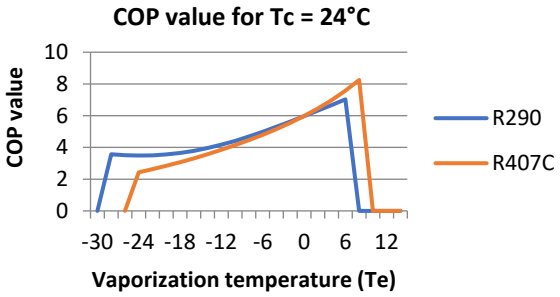

Figure 5. COP value for Tc = 24°C.

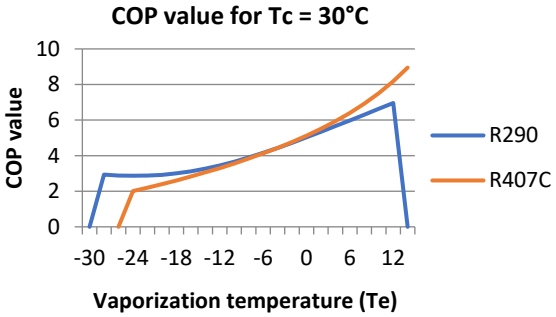

Figure 6. COP value for Tc = 30°C.

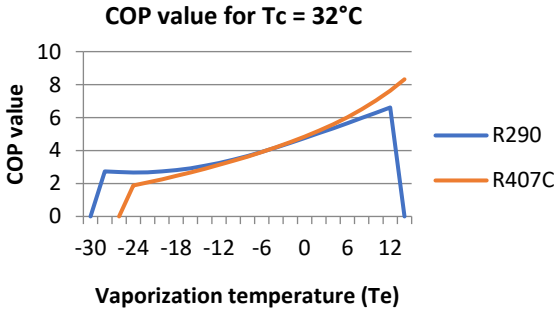

Figure 7. COP value for Tc = 30°C.

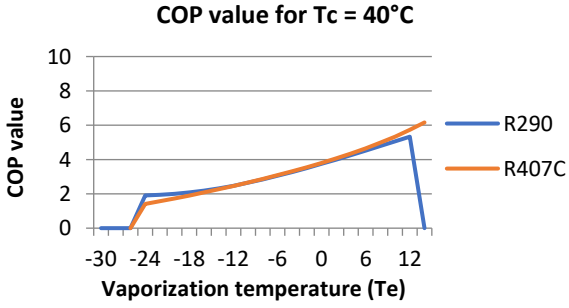

Figure 8. COP value for Tc = 40°C.

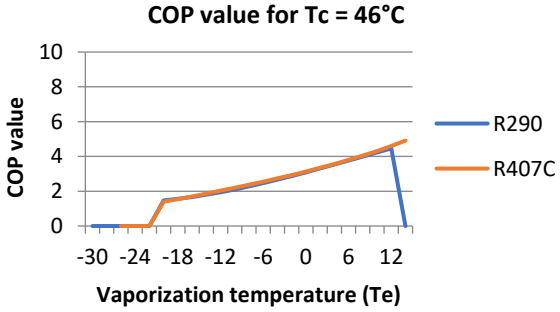

Figure 9. COP value for Tc = 46°C.

In his paper entitled "Comparing the energy efficiency and irreversibility of R22, R134a, R290 and R407C to replace R22 in an air conditioning system", published in the Journal of Mechanical Science and Technology (2013), the authors, Padmanabhan, VMV and Palanisamy , SK mentioned that the COP of R290 is higher compared to R22; R134a and R407C (**Figure 10**).

In conclusion, it is obvious that the refrigerant R290 has a better potential (except for the expansion process) and can be considered for substitution given by the superior parameters compared to other refrigerants, with the observation to take into account the increased flammability. of it, within the handling and storage operations Țârlea G. M et al. (2019).

In the **Table 1** it is shown the Total Equivalent Warming Impact calculation (see EN 378) for R407C and R290 and more than 40% ecological advantage of R290.

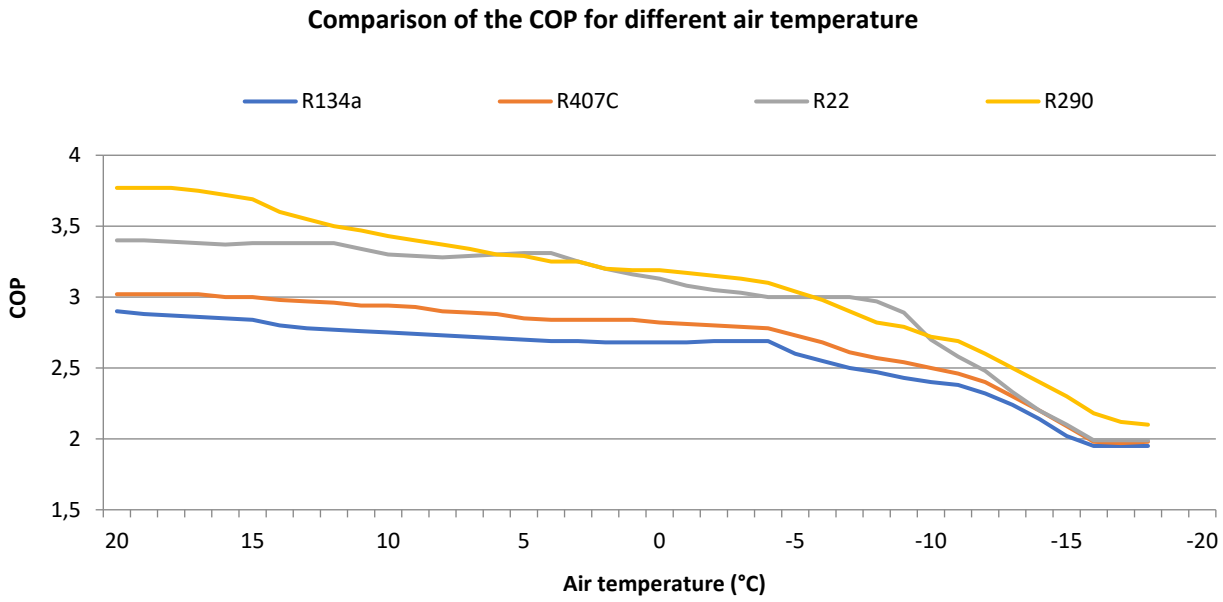

Figure 10. Comparison of the COP at different air temperatures.

Table 1. *TEWI calculation.*

	R407C	R290	Unit
GWP	1 620	3	–
Leakage	0.36	0.2	kg/year
Number	30	30	year
Mass	4.5	2.5	kg
α recover	0.8	0.8	–
E annual	2.462	2.462	kWh/year
B	0.28985	0.28985	kg/Kwh
GWP x L x n	17.496	18	–
GWP x m (1 – α recover)	1.458	1.5	–
n x E annual x β	21 408.321	21 408.321	–
TEWI (kg CO_2)	40 362.32	21 427.82	–
TEWI (tons CO_2)	40.36	21.42	–

Conclusions

For conclusions, the energetic, ecological and financial parameters were analysed comparing two systems that use respectively the R407C and R290 refrigerant, using the Pack Calculation program for an innovative HP (**Figure 11**).

The results offered by the program were the following:

1) For a year-long operation in climatic conditions in Bucharest, the average COP achieved by the heat pump system using the R407C refrigerant calculated by the program was 2.34 while the system using the R290 refrigerant provides an average COP of 3.03;
2) In front of the heat pump that uses the R407C refrigerant, the heat pump that uses the R290 refrigerant achieves an energy saving of 971kWh, which represents at the annual consumption level of the heat pump that uses the R407C refrigerant, a saving of 22%.
3) From the point of view of ecological analysis, during operation, the heat pump that uses the R407C refrigerant generates a higher TEWI (40,36 tons CO_2) compared to the heat pump that uses the R290 refrigerant (21,42 tons CO_2).

The operating time for the R290 refrigerant is much larger than for the R407C. From the point of view of condensation temperature, the R290 refrigerant operating tire starts at 16°C and ends at 68°C, while the R407C refrigerant operating tire starts at 22°C condensing and ends at condensation temperature of 64°C. From the point of view of vaporization temperature, the R290 refrigerant tire starts at –28°C and ends at 12°C. For condensation temperatures up to 36°C and low vaporization temperatures, between –26°C and –6°C the heat pump with refrigerant R290 ensures a higher COP than when using refrigerant R407C. For condensation temperatures between 46°C-48°C, the COP is identical for operation with both refrigerants over the entire range of usual values of the vaporization temperature. From the ecological point of view of the TEWI factor, operation with the R290 refrigerant is the ideal ecological option. ■

Figure 11. Heat Pumps with Innovative Capillary Evaporators.

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