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COMPARATIVE ANALYSIS OF THE ENVIRONMENTAL LOAD OF NATURAL REFRIGERANT (R290)

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Abstract

Due to the detrimental environmental consequences of synthetic refrigerants, natural refrigerants have gained renewed interest as alternative refrigerants for a variety of applications due to their minimal ozone depletion potential (ODP) and insignificant global warming potential (GWP). This study compares the performance characteristics of R32-based Air Source Heat Pump (ASHP) to those of R290 and R410A refrigerants. In this study, analyses of the cooling effect, heat output, compressor work input, and coefficient of performance (COP) for various refrigerants will be undertaken. Additionally, the environmental consequences of R32, R410A, and R290 are discussed. The results indicate that R290 is the most efficient refrigerant in terms of performance coefficient, followed by R410A and R32. Considering environmental protection aspects, R290 is a favorable substitute medium.
Keywords: *ASHP, COP, refrigerant, R290, enviromental load*

TERMÉSZETES HŰTŐKÖZEG (R290) KÖRNYEZETTERHELÉSÉNEK ÖSSZEHASONLÍTÓ ELEMZÉSE

Összefoglalás

A szintetikus hűtőközegek káros környezeti hatásai miatt a természetes hűtőközegek egyre nagyobb érdeklődésre tettek szert. Mint alternatív hűtőközegek elsősorban minimális ózon lebontási potenciáljuk (ODP) és nagyon kismértékű globális felmelegítő hatásuk (GWP) miatt lettek népszerűek. Ez a tanulmány összehasonlítja az R32 alapú levegős hőszivattyú (ASHP) teljesítményjellemzőit az R290 és R410A hűtőközegekkel. Elemezzük a különböző hűtőközegek hűtőhatását, hőteljesítményét, kompresszor energiafelhasználását és teljesítménytényezőjét (COP) ezzel összefüggésben az R32, R410A és R290 környezeti hatásait is tárgyaljuk. Az eredmények azt mutatják, hogy a teljesítménytényező szempontjából az R290 a leghatékonyabb hűtőközeg, ezt követi az R410A és az R32. Környezetvédelmi szempontokat figyelembe véve az R290 egy kedvező helyettesítő közeg.
Kulcsszavak: *hőszivattyú, COP, hűtőközeg, R290, környezetterhelés*
JEL kód: *Q53*

Introduction

Nowadays, the world's biggest challenge is how to live comfortably while maintaining the environment. According to EN ISO 7730, a comfortable situation exists when two conditions are met. The individual's heat balance is balanced without putting too much effort on his self-regulating mechanisms. There are no local discomforts caused by: the sensation of a draft; the asymmetry of radiation; the vertical temperature gradient; or the temperature at ground level. Air quality, lighting, and acoustics are all part of what is referred to as "the indoor environment," as is thermal comfort. (OLESEN et al., 2002)

To acheive this confort, thermal machines were invented and had proven a great fonctioning. As this technology advances, the world faces significant environmental challenges, the question of reducing the ozone layer becomes increasingly pressing, given that the refrigerating fluids used in these pumps, namely *CFC* (chlorofluorocarbon) R12 refrigerants and *HCFC*s (hydro chlorofluorocarbons) *R22*, destroy and deplete the ozone layer. This is why the Montreal Protocol of 1987 and the Copenhagen Accord decide to limit production of the latter. Years later, according to European Regulation 1005/2009, the use of virgin *HCFC*s has been prohibited since January 1, 2010. (CALM, 2007) If this indicates anything, it is the persistence of decisions that prevent certain types of refrigerants from being used with further research.

Alternative refrigerants are becoming increasingly necessary. In the early stages of refrigeration, natural refrigerants were utilised and due to their poor coefficient of performance (COP), these refrigerants have become obsolete. Following their replacement, *CFC*, *HCFC*, and *HFC* refrigerants were employed. All of these forms of refrigerants contribute to global warming, though. Although environmentally friendly HFO refrigerants have been produced, they are too expensive to replace conventional refrigerants. (ABAS et al., 2018)

Many investigations of the performance analysis of heat pumps by the operation of various refrigerants have been done. MESSINO – PANNO (2012) had showed a practical example of a cascade refrigerantion system working with *R410A* and *R134a* in hightemperature circuit, and, respectively, propane (*R290*), ammonia (*R717*), *R404A*, butane (*R600*), and carbon dioxide (*R744*) in low-temperature circuit. The results demonstrate that a cascade refrigeration system employing natural refrigerants is a promising replacement for synthetic refrigerant-based systems.

DALKILIC – WONGWISES (2010) have conducted an experimental study of a traditional vapor compression refrigeration system performance with refrigerant ratios based on R134a, *R152A, R32, R290, R1270, R600* and *R600a* compared to *R12, R22, R134a* as possible alternatives. This study has demonstrated that natural refrigerants and low GWP refrigerants ratios: Blends of *R290/R600a* (40/60%) and *R290/R1270* (20/80%) are found to be the most efficient refrigerant ratio in terms of COP compared to *R12* and *R22*.

HALIMIC et al. (2003) have proved in their paper, where they compared the operating performance of a vapor compression refrigeration cycle using *R410A, R290* and *R134A* comperad to *R12*, that *R290*, which is a natural gaz (Propane), showed the best performance compared to other refrigerants. In this study, we will compare the performance of the natural refrigerant *R290*, and *R410A*, with that of an *R32*-based *ASHP*.

Material and methods

The primary objective of this study is to analyze the possible performance of thermodynamic cycles using different substances with different environmental impact as refrigerants: *R290*, *R410A* and *R32*. The applications of these thermodynamic cycles are numerous, whether in refrigeration or heat production (domestic, commercial or industrial). Within the restricted framework of this paper, we focused on the usual thermal applications in the building, namely the heating of buildings.

The test procedure

The refrigerant test bench is a chamber located within the Energetics and Building Services laboratory of the Hungarian University of Agriculture and Life Sciences.

In the case of employing a heat pump for house heating, the inside of this chamber symbolizes the external environment with a low temperature, while the exterior of this chamber often depicts the interior that we want to heat. It is an air/air heat pump composed of the components shown in Figure 1.

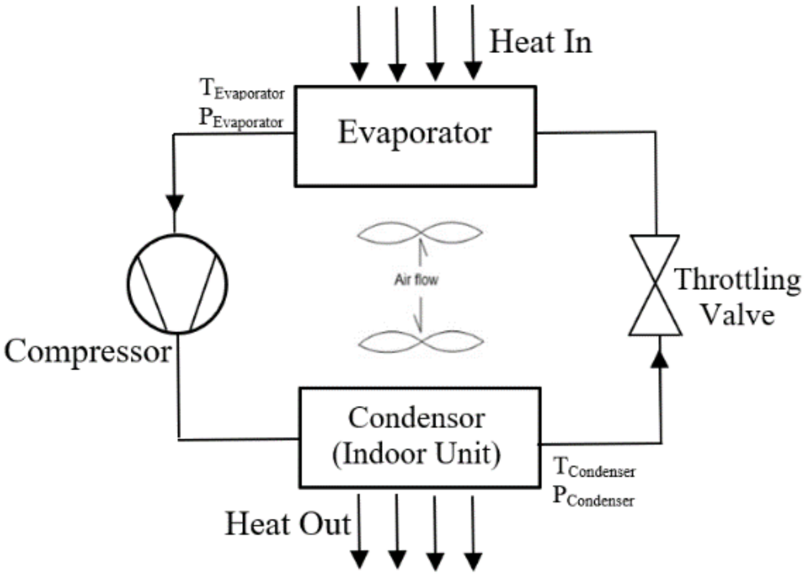

Figure 1. Schematic diagram of the studied *ASHP*

The sensors used in this expirement are represented in the following table:

Table 1. Sensors range and accuracy

Sensor Type	Parameter	Quantity	Range	Accuracy
DS18B20	Temperature	24	-55°C to +125°C	±0.5°C
DHT11	Humidity	2	20 to 80%	±0.5°C
TestoSmart Probe 549i	Pressure	2	0 to 60 bar	0.5% of full scale value

A steam generator installed inside the chamber produces steam that is used to to maintain the chamber's desired temperature. A water container is needed to the well function of the steam genrators, it is installed outside the chamber, and it requires a constant supply of water in order to function; the container itself displays a minimum water level required for operation. The steam generator will automatically turn off if the water level drops below that point.

A temperature regulator, is mounted outside the chamber and is controlled by the thermocouples located inside to maintain a constant temperature within it.

Although it was determined that the heat pump's load would be fixed at $T = 30°C$ for the interior environment to achieve constant maximum power operation, it was left to vary the simulated outdoor temperature. In order to test the energetic and exergitic parameters of each heat pump component for each refrigerant, we set it to -10°C, -5°C, 0°C, 5°C, and 10°C. In order to acquire more reliable findings, each test takes an average of 4 hours to complete. Because of the experiment's schedule, the tests were not conducted on the same day each week; rather, they were spread out over the months of January, February, and March.

The data gathered from the experiment were collected using an Internet of Things device called IMRe, and uploaded to the Internet. The collected data can be accessed and evaluated over the Internet through the use of the website http://v9y.emonitor.hu/feed/list/. They can also be exported as csv file with specific date and time information. The monitoring interface during an experiment is depicted in Figure 2.

Figure 2. Monitoring interface of the „CKmeres" web site during an experiment

Description of the used refrigerants

The section that follows provides information regarding the refrigerants utilized in this project. They include an *HFC* (*R32*), a hydrocarbon propane (*R290*), and a commercially available double refrigeration mixture designated *R410A.*

R290

Propane as a refrigerant carries the industry designation *R290*. When *CFC* refrigerants were available, hydrocarbons were abandoned due to a number of safety and technological concerns. They are compatible with the components and lubricants of conventional refrigeration systems. Hydrocarbons have great qualities as refrigerants, occur naturally in the environment, and neither deplete the ozone layer nor contribute significantly to global warming (see Table 2).

The most essential aspect of hydrocarbons as refrigerants is their flammability. (RICHARD - SHANKLAND, 1992; RITTER, 1996) It has been stated that even in systems with small charges, such as household refrigerators, the explosion risk of hydrocarbon refrigerants is horrifying. (VIDAL, 1992; KEEBLER, 1993) This, however, has been refuted by the work of MISSENDEN – JAMES (1992), who tested many freezers containing *R290* for the bomb-in-cabinet occurrence. In all refrigerators examined, the measured amount of refrigerant was less than 40g, and even in the worst-case scenario, the explosion and flames were incapable of igniting the combustible liner.

There are now defined protocols and standards for refrigeration safety, such as the *BS4434* from 1995. HERMANUCZ et al. (2018) suggested capping the amount of refrigerant in a home unit to 200g to prevent an explosive buildup of hydrocarbons in case of a leak.

R32

The *R32* refrigerant, also called difluoromethane, is a hydrofluorocarbon (*HFC*) that is commonly used in air conditioning systems. With a lower Global Warming Potential than other gases like *R410A* and *R407C*, this gas is set to become the industry standard. It has the molecular formula of CH_2F_2. It is a colorless gas and liquid that poses no health risks to humans or animals, is non-flammable, non-toxic, non-irritating, and does not corrode the metals typically used in refrigeration systems.

R410A

R-410A is a blend of difluoromethane (CH_2F_2, also known as *R32*) and pentafluoroethane (C_2HF_5, also known as *R125*) that is used as an air conditioning refrigerant. It is widely used because, unlike many haloalkane refrigerants, it does not contribute to ozone depletion. In 1996, Carrier Corporation was the first firm to market a household air conditioning unit with *R410A*. *R410A* has replaced *R22* as the preferred refrigerant for household and business air conditioners in Japan and Europe. However, its high *GWP* prompts the industrial world to seek out alternate solutions, particularly after the *EU F*-gas Regulation restrictions take effect on January 1, 2020.

Table 2: Environmental impact of refrigerants

Refrigerant	ODP	GWP
R32	0	675
R410A	0	2090
R290	0	<3

To experimentally evaluate the energetic parameters of the heat pump using the refrigerants that we will identify later, we need to measure the Coefficients of Performance (*COP*) of heat pump cycles using these refrigerants. We want to compare different refrigerants and several definitions of *COP* are possible depending on the limits we define for the system. The *COP* of the refrigerant cycle $COP = \Delta h_{Condenser}/\Delta h_{Compressor}$ would be the most suitable because it is independent of the efficiencies of the exchangers and the auxiliaries (pumps, etc.). In the rest of this text, this *COP* will be referred to as "*COP* cycle". However, the enthalpies of refrigerants are not always accessible, as shown in the previous chapter. In order to be able to compare the refrigerants on the same machine, we use the *COP* defined below, by measuring the thermal power supplied to the air divided by the electrical power of the compressor (including its control electronics):

$$COP = \frac{m_{air} * C_{p\,air} * \Delta T_{air}}{P_{abs}} \quad (1)$$

In the following, this *COP* will be referred to as "machine COP".
So, we need to measure:
m_{air}: The mass flow of water to the gas cooler, in kg/s.
$C_{p\,air}$: The heat capacity of air, in kJ/kg. K. As this varies with temperature.
ΔT_{air}: The temperature differential of the heated air, between the inlet and the outlet of the high-pressure condenser of the heat pump, in kelvins.

Results

All of the components in the process were regarded as a control volume in the thermodynamic simulations. Assumptions were made based on the following factors:

(1) Interprocess pressure and heat loss are considered negligible.

(2) 75% of the compression process is isentropic.

(3) Each component's processes are assumed to be in a steady state, with no significant fluctuations in potential or kinetic energy.

(4) Ambient temperature is 27°C.

R32 refrigerant measurement at a 10°C evaporation temperature is listed in Table 3, while R290 and R410A primary properties are showed in figure (3-4). The values of enthalpy, entropy and density are calculated using COOLPROP package in excel.

According to Table 3, an extensive energy analysis was conducted for ASHP and its components.

Table 3. R32 refrigerant measurement at 10°C

R32 at 10°C	**Temperature (K)**	**Pressure (Pa)**	**Enthalpy (KJ/Kg)**	**Entropy (KJ/Kg-K)**	**Density (Kg/m³)**
Evaporator	280	434000	535,650	2,3176	0,01043
Compressor	359,28	2900000	573,050	2,1708	0,06310
Condenser	322,1	2900000	514,598	1,9983	0,08596
Expansion valve	276,61	434000	509,218	2,3060	0,01059

It is shown in Figure 3 how each refrigerant's coefficient of performance changes with evaporating temperature. For all refrigerants, the COP rises as the evaporation temperature rises, regardless of the type of refrigerant. When it comes to condensing temperatures, R290 is by far the most efficient, followed by R410A and R32.

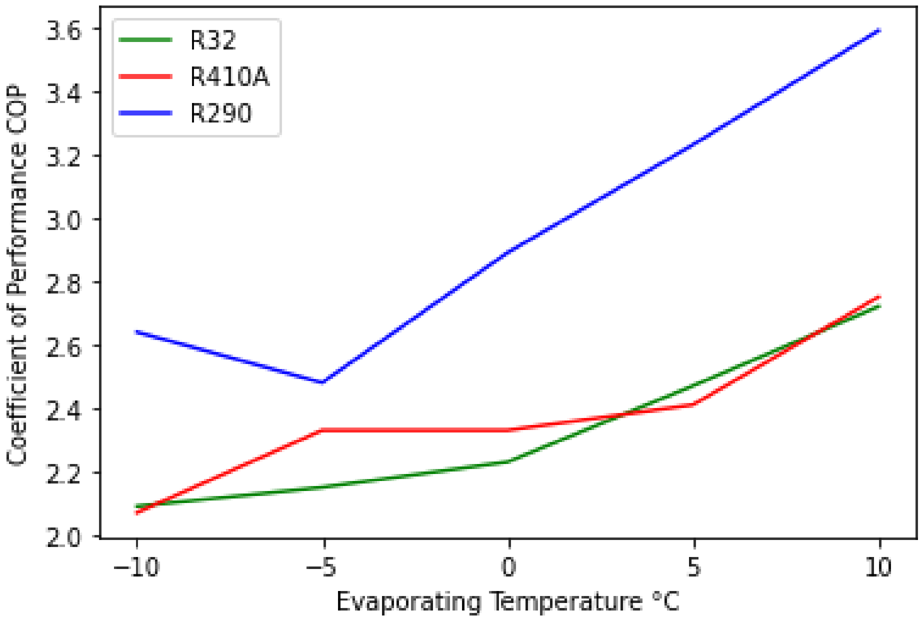

Figure 3. Variation of coefficient of performance with evaporating temperature at a condensing temperature of 30°C

According to the evaporation temperature, compressor consumption is depicted for each refrigerant in Figure 4. With a mean value of 0.98kW, R290 has demonstrated the bare minimum compressor's functionality. By comparison, R410A and R32's compressor have demonstrated a similar pattern of behavior, with a mean value of about 1.8kW.

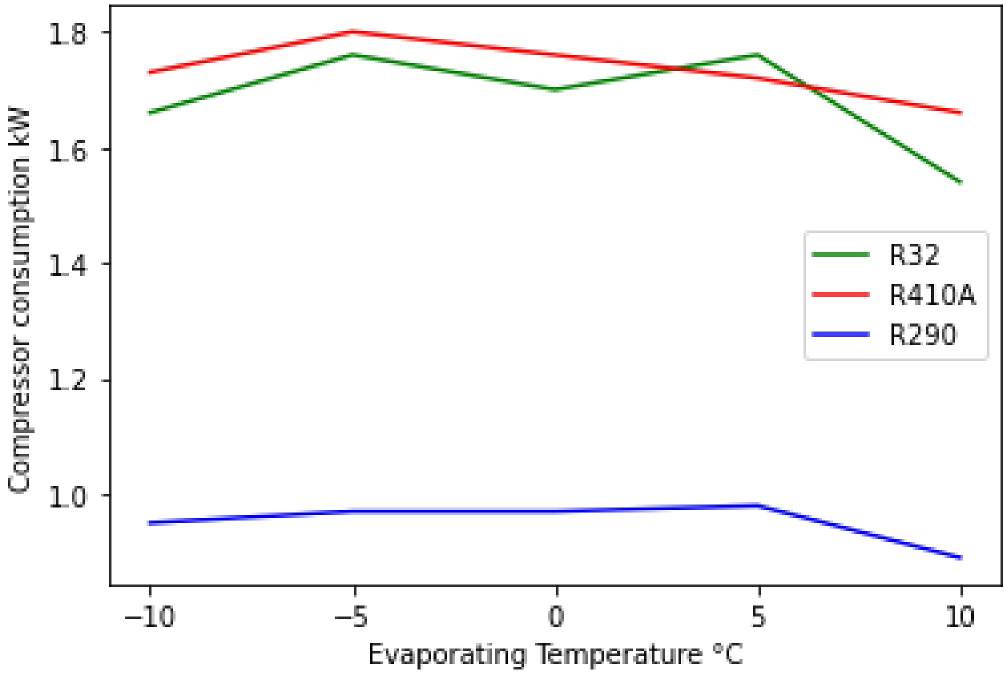

Figure 4. Compressor power consumption of refrigerants

Conclusion

The results of the current analysis show that:

- R290 (Natural refrigerant) may be a great replacement for HFC refrigerants when used in accordance with the procedures and guidelines for refrigeration safety, such as BS4434.
- R290 has demonstrated an effective function of the ASHP due to the 0.98kW consumption of the compressor.
- R32 and R410A displayed similar ASHP behavior, but when considering their effects on the environment, R32 is preferred.
- R290 is the favored refrigerant when environmental issues are taken into account because it has the lowest GWP and ozone depletion potential among the alternative refrigerants, as indicated in Table 2.

References

ABAS, N. – KALAIR, A.R. – KHAN, N. – HAIDER, A. – SALEEM, Z. – SALEEM, M.S. (2018): Natural and synthetic refrigerants, global warming: a review. *Renew Sustain Energy Rev*, 90, 557–569. DOI: https://doi.org/10.1016/j.rser.2018.03.099

BS4434 (1995): Specification for Safety and Environmental Aspects in the Design, Construction and Installation of Refrigeration Appliances and Systems, *BSI Standards*, London

CALM, J.M. (2007): The next generation of refrigerants – Historical review, considerations, and outlook. *International Journal of Refrigeration*, 31(7), 1123–1133. DOI: https://doi.org/10.1016/j.ijrefrig.2008.01.013

DALKILIC, A.S. – WONGWISES, S. (2010): A performance comparison of vapour-compression refrigeration system using various alternative refrigerants. *International Communications in Heat and Mass Transfer*, 37(9), 1340–1349. DOI: https://doi.org/10.1016/j.icheatmasstransfer.2010.07.006

HALIMIC, E. – ROSS, D. – AGNEW, B. – ANDERSON, A. – POTTS, I. (2003): A comparison of the operating performance of alternative refrigerants. *Applied Thermal Engineering*, 23(12), 1441–1451. DOI: https://doi.org/10.1016/S1359-4311(03)00081-4

HERMANUCZ, P. – BARÓTFI, I. – GÉCZI, G. (2018): Environmental and healthcare risks of refrigerants. *Mechanical Engineering Letters,* 17, 28–34.

JAMES, R.W. – MISSENDEN, J.F. (1992): The use of propane in domestic refrigerators. *International Journal of Refrigeration*, 15(2), 95–100. DOI: https://doi.org/10.1016/0140-7007(92)90033-Q

KEEBLER, J. (1993): Cold Fact: AC gas Danger. *Automotive News,* 45p.

MESSINO, A. – PANNO, D. (2012): Performance evaulation of cascade refrigeration systems using different refrigerants. *International Journal of Air-Conditioning and Refrigeration,* 20(3). DOI: https://doi.org/10.1142/S2010132512500101

OLESEN, B.W. – PARSONS, K.C. (2002): Introduction to thermal comfort standards and to the proposed new version of EN ISO 7730. *Energy and Buildings*, 34(6), 537–548. DOI: https://doi.org/10.1016/S0378-7788(02)00004-X

RITTER, T.J. (1996): Flamability-hydrocarbon refrigerants. *Proceedings of the Institute of Refrigeration Conference,* London 1996.11.21.

RICHARDS, R.G. – SHANKLAND, I.R. (1992): Flammability of alternative refrigerants. *ASHRE Journal*, 34(4), 22–24.

VIDAL, J. (1992): The Big Chill. *The Guardian* (November 19, *1992*), p.2.

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