Bulletin of the *Transilvania* University of Braşov
CIBv 2015 • Vol. 8 (57) Special Issue No. 1 - 2015

CONTRIBUTIONS REGARDING ENERGETIC AND ENVIRONMENTAL PERFORMANCES OF REFRIGERANTS USED IN HEAT PUMPS

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Abstract: *The present energetics of buildings within the context of EU Directives impose the use, at an ever growing measure of energy produced on the basis of renewable resources along with diminishing environmental pollution. In this respect, an increase of heat pumps performances is required in order to provide the heat energy to buildings. An important role is played by the refrigerants of heat pumps. The present paper analyses the energetic and environmental performances of refrigerants employed with heat pumps equipment and installations.*

Key words: *refrigerant, heat pump, coefficient of performance, ozone layer greenhouse gas.*

1. Introduction

Europe and the whole world are, at present confronted with two major problems: energy and reduction of environmental pollution. In conformity with the European Union Directives, the energetic and environmental policies are focused on diminishing energetic consumption based on classic fuels and the use, in an even greater measure, of energy obtained from renewable sources. In this respect an essential role is played by heat pump installations which are the only equipment that effect the “heat pumping” from a low heat level (corresponding to renewable heat sources level) to a high level corresponding to domestic heat energy consumers.

So, a major role is played by the working fluids of heat pumps, namely, the refrigerants working in high performance equipment both energetically and environmentally.

2. The Evolution and Characteristics of Refrigerants Used in Heat Pumps

Since, nearly 40 years, the action of protecting the ozone layer and reduction of greenhouse effect has represented one the principal challenges of the world.

Adopted in 1987, the Montreal Protocol, for the protection of ozone layer, has stimulated the actions for gradually stopping the production and consumption of certain substances, potentially responsible for diminishing the ozone layer [11], substances that were later regulated at EU level by Regulation (EC) No 2037/2000 and Regulation (EC) No 1005/2009.

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In conformity with Montreal Protocol and subsequent amendments, the international regulations have imposed the stopping of chlorofluorocarbons (CFS-s) production and their utilization (1.01.2000) and the banning of hydrochlorofluorocarbon (HCFC-s) from 1.01.2015 [13,14].

The action of refrigerants upon the ozone layer is rendered by ODP indices (Ozone depletion potential) and as reference value ODP=1 is considered for R-11(CFC).

The most extensively used refrigerants in the heat pumps, were R-12, R-114 (ODP=1) from the CFC category, respectively R_{22} (ODP=0.055) from HCFC category [9].

Possible replacements of CFS-s and HCFC-s are represented by hydrofluorocarbon (HFC) type refrigerants which, due to eliminating the chloride from the molecule do not contribute to the destruction of the ozone layer being characterized by an index ODP=0. To this category belong R-134a and its mixtures (R-407c, R-410A, R-404A) in heat pump installations.

Another alternative of replacing of CFC and HCFC agents within heat pumps is represented by the natural agents (R-744, R-290), with the same zero impact upon ozone layer.

As the impact upon environment is concerned, the refrigerants act both upon the ozone layer and greenhouse effect.

In order to limit the disastrous effects of climatic changes, worldwide, measures were taken to reduce greenhouse effects emissions which are being considered the main factors for climatic changes.

In conformity with Kyoto Protocol (1997), Protocol to the United Nations framework Convention on climate change, for first commitment period (2008-2012) a reduction of greenhouse gas emissions (GHG) of at least 5% of the 1990 level was amendments and regulations, the following established, and after the subsequent targets have been imposed along with a program of reducing GHG emissions:

- reduction by 20% of GHG emissions until 2020 as compared with 1990 level;
- reduction by at least 80% of GHG emissions until 2050 as compared with 1990 level [15].

In conformity with annex A of Kyoto Protocol the following gases with greenhouse effect are considered: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_{20}), hydrofluorocarbons (HFC-s), perfluorocarbons (PFC-s) and sulphur hexafluoride (SF_6) [10]. HFC, PFC and SF6 are referred to as fluorinated greenhouse gases (F-gases).

The contribution of F-gases to intensifying greenhouse effect is given by GWP index (Global warming potential) which represents "the climatic warming potential of a greenhouse gas relative to that of carbon dioxide, calculated in terms of the 100-year warming potential of one kilogram of a greenhouse gas relative to one kilogram of CO_2" [15].

The impact of the major refrigerants of heat pumps upon the environment, as the global heating and ozone layer destruction potential is concerned, is given in table 1.

Taking into account the two actions of refrigerants upon environment within the context of international regulations of protecting the environment, a stress will be lain on replacing agents HFC with ODP=0 and high GWP with agents characterized by a minimum impact upon the ozone layer (ODP=0) and of clime (GWP low), a hierarchization of these refrigerants is being presented in Figure 1.

In conformity with Figure 1, is highlighted agents R-407c, R-134a, R-32, R-152a with GWP< 2000 and R-290, respectively R-744 with GWP minimum.

The effect of refrigerants of heat pumps upon the environment [7, 8, 14,15] Table 1

Refrigerant	**GWP (100 yr)**	**ODP**
CFC		
R-12	10900	1
R-114	10000	1
HCFC		
R-22	1810	0,055
HFC		
R-152a	124	0
R-32	675	0
R-134a	1430	0
R-407c	1774	0
R-410A	2088	0
R-404A	3922	0
Natural fluid		
R-290	3	0
R-744	1	0

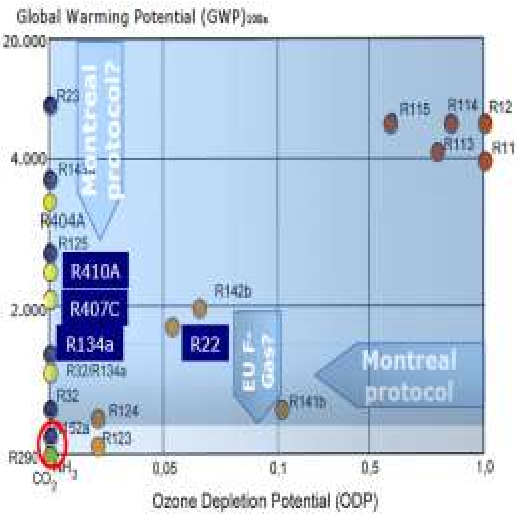

Fig. 1. *Ozone Depletion Potential and Global Warming Potential [12]*

3. The Analysis of Energetic and Environmental Performances of Refrigerants Used in Heat Pumps. Case Study.

The selection of refrigerants in heat pump installations will have to take into account the following requirements [1, 3]:

- chemical stability;
- impact upon the environment, health and safety: uninflammable, non-toxic, unharmful for atmosphere;
- thermodynamic properties: low vaporization temperature, the critical boiling point temperature should be proper for application, high vaporization capacity, low viscosity, reasonable working pressure in view of limiting costs;
- practical characteristics: solubility

with oils, compatibility with installation materials, low costs.

The main physical and thermodynamics properties most extensively used refrigerants of heat pumps (related to R-22) are presented in Table 2.

At present, the most extensively used refrigerants in heat pumps equipment are the following [3]:

- for air-air heat pumps: R-410A, R-407c;
- for air-water heat pumps: R-134a, R-407c, R-410A, R-404A, R-290, R-744;
- for brine/water-water heat pumps: R-134a, R-407c, R-410A.

Table 2

Thermodynamic properties and safety classifications of main refrigerants used in heat pumps related to R-22 [5]

Refrigerant	Chemical formula/ composition	Boiling point at 101325 Pa [^oC]	Critical temperature [^oC]	Critical pressure [bar]	Safety group
R-22	CHClF2	-40.81	96.145	49.9	A1
R-134a	CH2FCF3	-26.074	101.06	40.593	A1
R-407C	R-32/125/134a (23/25/52)	-43.627	86.034	46.298	A1
R-410A	R-32/125 (50/50)	-51.443	71.358	49.026	A1
R-404A	R-125/143a/134a (44/52/4)	-46.222	72.046	37.289	A1
R-290	C3H8	-42.09	96.675	42.471	A3(highly flammable)
R-744	CO2	-78.4	30.978	73.773	A1

A proper replacing of CFC agents and the HCFC transition ones implies, on one hand securing equivalent or higher energetic performances and the reduction of negative impact upon environment (ODP=0, GWP minimum) on the other hand.

In order to set into evidence the performant alternatives, from energetic and environmental point of view, of replacing the CFC and HCFC agents, more types of heat pumps were analyzes, with various refrigerants such as:

- case 1: air-water heat pump (A2/W35): R-134a, R-407c, R-404A, R-410A, R-290;
- case 2: water-water heat pump (W10/W35): R-134a, R-407c,R-410A, R-290;
- case 3: brine-water heat pump (B0/W35): R-134a, R-407c, R-410A, R-290.

For a comparative analysis a heat pump with mechanical vapor compression of 6.1 kW for heating the water la 35 ^{0}C was considered.

R-12 for CFC and R-22 for HCFC were considered as reference agents.

The analysis of thermodynamic cycles and determining the coefficient of performance (COP) for each case the Cool Pack program was used (see Fig.2).

The results of energetic performances for the three types of heat pumps (A2/W35, W10/W35, B0/W35) and various refrigerants used are presented in figures 3,4 and 5.

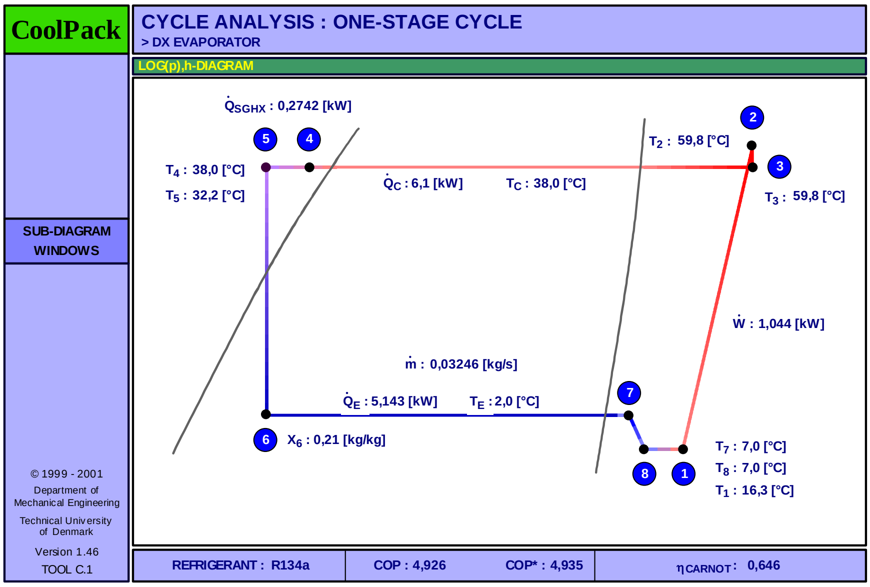

Fig. 2. *Detail of the cycle analysis for a water-water heat pump (W10/W35) with R134a [6]*

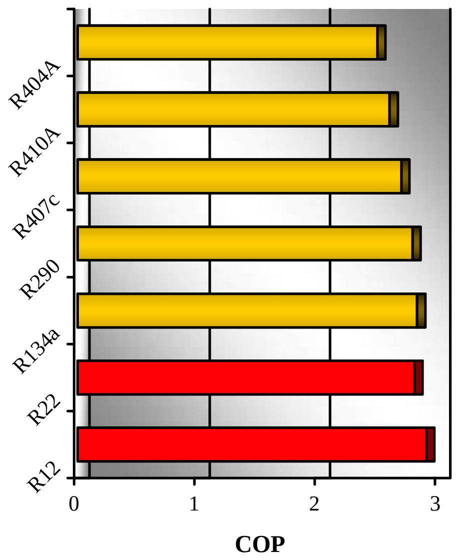

Fig. 3. *COP values for different refrigerants for an air-water heat pump (A2/W35)*

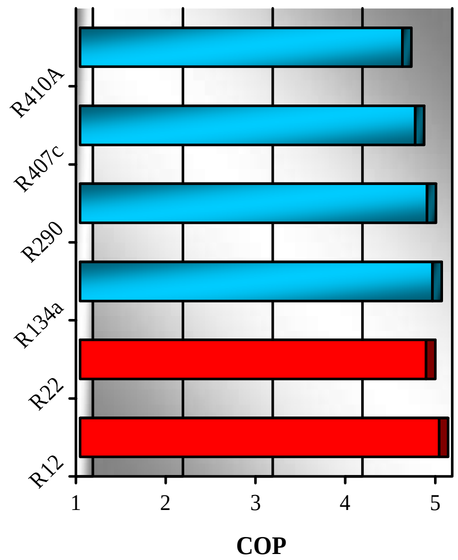

Fig. 4. *COP values for different refrigerants for a water-water heat pump (W10/W35)*

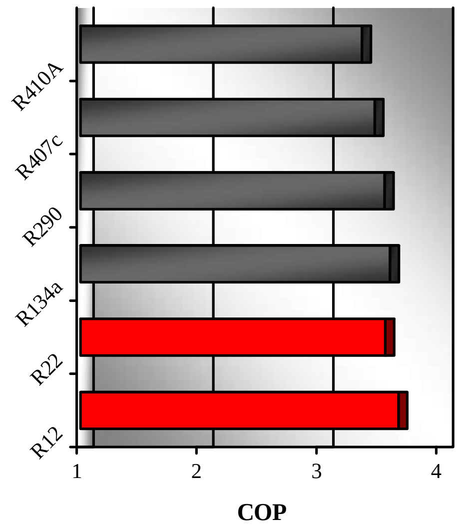

Fig. 5. *COP values for different refrigerants for a brine-water heat pump (B0/W35)*

In accordance with analyses with reference to thermo physical properties one notices that R-134a is a good replacement of refrigerant R-12, the COP being almost equal, for all three types of heat pumps.

As replacing R-22 is concerned a first version is presented by R-290, as a result of almost identical COP-s but taking into accounts the inflammable character and the need for safety measures, a second alternative hints at refrigerants R-134a, R-407c and R-410A. In the case of refrigerant R-134a improved energetic performances were obtained as compared with R-22 by 0.78…1.46%. By replacing refrigerant R-22 with R-407c the performance dropped by 2.48…3.89% and in the case of using R-410A, by 5.43…7.39% (see Fig.6). In the case of air-water heat pumps, by replacing refrigerant R-22 with R-404A, 11% lower performances were obtained.

As energetic performances are concerned the best solution of replacing refrigerants CFC and HCFC is with R-134a and R-290 and with mixtures the case is with R-407c.

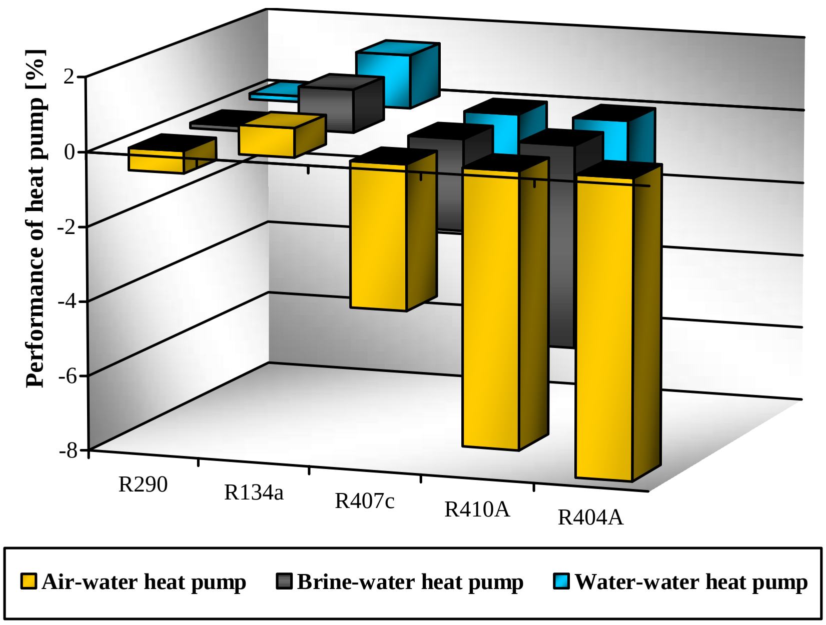

Fig. 6. *The performance of different heat pumps as compared with those using R-22*

In order to evaluate the impact on global heating of heat pumps, as greenhouse emission effects, have over a whole working life (until the agents are eliminated) index TEWI (Total equivalent warming impact) is used [4]. By means of index TEWI both the direct contribution of refrigerants and the indirect one, while producing working energy is evaluated [4]:

$$TEWI = (GWP \cdot m \cdot L_{annual} \cdot n + GWP \cdot m \cdot (1 - \alpha_{recovery})) + (E_{annual} \cdot \beta \cdot n) \quad (1)$$

where: GWP is Global Warming Potential of refrigerant, relative to CO_2;

m – refrigerant charge, [kg];

L_{annual} – leakage rate per year;

n – system operating life, [years];

E_{annual} – energy consumption per year, [kWh];

α_{REC} – recovery/recycling factor;

β – indirect emission factor [$kgCO_2$/kWh].

For determining index for each case analyzed we have considered: the heat pump operating life of 20 years, the leakage rate per year of 2%, the number of working hours of 2400h/year and the CO_2/kWh emissions for producing the electric energy 0.4166 (for Romania [2]). After determining and analyzing indices TEWI (see fig.7) we noticed that: R-290 exerts the lowest impact on global heating, followed by de R-134a, R-407c, R-410A, while R-404A presents the highest index, owing to the high GWP index (3922); R-134a and R-407c exhibit the most appropriate values of index TEWI.

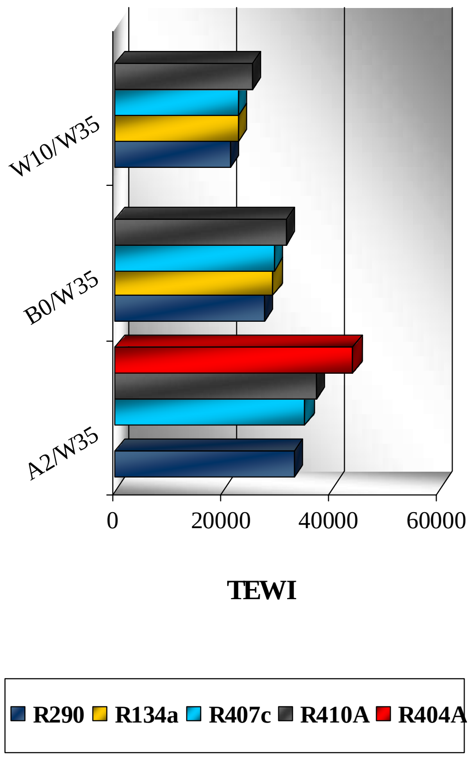

Fig. 7. *The values of index TEWI for various refrigerants and different types of heat pumps*

4. Conclusions

In view of replacing refrigerants CFC and HCFC within the heat pumps, the emphasis will be set on the use of refrigerants HFC and of the natural ones aiming at obtaining some high coefficients of performance and a minimum impact upon the environment

(ODP=0 and TEWI as low as possible).

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