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Research Paper

Evaluation of Low GWP Refrigerants R452B and R454B as Alternative to R410a in the Heat Hump Systems

Ragıp Yıldırım[1], Afşin Güngör[2], Kazım Kumaş[3], Ali Akyüz[4, *]

[1] Burdur Mehmet Akif Ersoy University, Bucak Emin Gulmez Technical Sciences Vocational School, Burdur, Turkey; [2] Akdeniz University, Faculty of Engineering, Antalya, Turkey; [3] Burdur Mehmet Akif Ersoy University, Bucak Emin Gulmez Technical Sciences Vocational School, Burdur, Turkey; [4] Burdur Mehmet Akif Ersoy University, Bucak Emin Gulmez Technical Sciences Vocational School, Burdur, Turkey,

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Abstract. In this study, energy and environmental analyses of R410A and its alternative refrigerants (R452B and R454B) in the heat pump system were performed. Environmental analyses of refrigerants were performed as stated by life cycle climate performance. The heating performance coefficient of R452B and R454B was approximately 1.20% higher than R410A. LCCP values of R452B and R454B refrigerants were slightly lower than R410A (about 1.20%). R452B and R454B GWP rates are quite low compared to R410A or and their energy performance is slightly higher than R134a. A low GWP ratio of refrigerants is not the solution alone in reducing the carbon footprint of the heat pump system. In order to lessen the total carbon footprint of the heat pump, increasing the efficiency of the heat pump and environmentally friendly energy sources (wind, solar, geothermal energy sources, etc.) must be used.

Keywords: *Heat pump, Climate change, Global warming, LCCP*

Introduction

Various legal regulations have been made to reduce the total carbon footprint of cooling and heating systems. In this context, it is necessary to reduce using and production of refrigerants with high global warming potential (GWP). For example, in the European Union F-gas regulation 842/2006 CE) and 2014 F-gas regulation (517/2014 N) change with HVAC-R systems have imposed restrictions on refrigerants used in (EEA, 2014). It is not enough to use low-GWP refrigerants to reduce the carbon footprint of vapor compression systems. For this reason, the energy efficiency of steam compression systems should be increased, and renewable energy sources should be used.

With the development of technology, heat pumps are widely used, and their popularity is increasing every day. R410A refrigerant is one of the most commonly used refrigerants in heat pump systems. The ozone depletion potential of the R410A refrigerant is zero, but the GWP ratio is high (1924) (Heredia-Aricapa *et al*., 2020). In order to minimize the upshots of refrigerants on global warming, scientists focused on low GWP ratio refrigerants with systems that would reduce the amount of refrigerant charge (Poggi et al. 2008).

In this study, R452B and R454B refrigerants with low GWP, which are alternatives to R410A in heat pump systems, were theoretically examined. In the study, energy and environmental impact of refrigerants were analysed and compared.

Materials and Method

The properties of R410A, R452B and R454B refrigerants are given in Table 1. All refrigerants can be obtained by mixing R32 with others. GWP ratio of R452B and R454B, which are alternative refrigerants, is quite low compared to R410A. The reason for this is that the mixture of R452B and R454B contains the refrigerant R1234yf. The GWP ratio of R1234yf is less than 1. Comparison of GWP ratios of refrigerants is given in Figure 1 (Schultz, 2016; Sieres et al. 2021).

*Corresponding Author: E-mail: aakyuz@mehmetakif.edu.tr, Tel: +90 2482138207; Fax mail: +90 2482138210

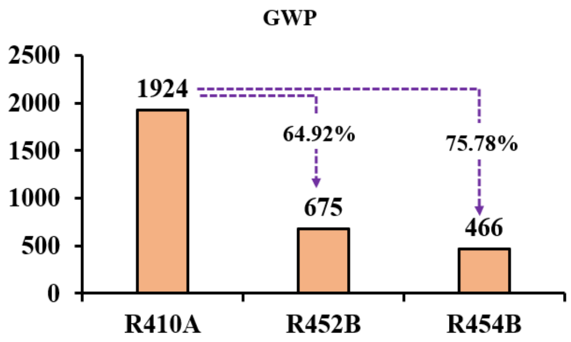

Figure 1. Comparison of GWP value of R452B and R454B relative to R410A

Theoretical energy analysis was performed for a heat pump system operating according to a single-stage vapour compression cooling cycle. The admissions for analyses are given below:
* Evaporator temperature is 0 ºC.
* Condenser temperature is 45 ºC.
* Superheat and subcooling temperature is 5 ºC.
* Compressor isentropic efficiency is 0.70.
* Compressor sweep volume is 10.80 cm^3 / rev.

Table 1. The properties of R410A and alternatives (R452B and R4545B) with zero ODP (Sieres et al. 2021)

Refrigerants	Composition (% mass)	T_b, ºC	T_c, ºC	GWP	ASHARE safety
R410A	R32/R125 (50/50)	-51.40	71.30	1924	A1
R452B	R32/R125/R1234yf (67/7/26)	-50.00	77.10	675	A2L
R454B	R32/R1234yf 68.90/31.10)	-50.50	78.10	466	A2L

Results and Discussion

According to the results of theoretical energy analysis, the refrigerant flow of R410A is higher than R452B (about 16%) and R454B (about 18%). In Table 2, the results of theoretical energy analysis of refrigerants are given. Heating capacity of R452B and R454B is lower than R410 by 1.16% and 1.94% respectively. R410A's compressor energy consumption is higher than R452B and R454B by 2.38% and 3.17% respectively. The heating performance coefficient of R452B and R454B is approximately 1.20% higher than R410A. As can be seen from the results of the theoretical analysis, R452B and R454B can be used as low GWP refrigerants.

Table 2. Energy performance of R410A and two alternatives (R452B and R454B)

Refrigerants	Heating capacity (W)	Power consumption (W)	Heating COP (-)	Mass flow rate (g/s)
R410A	1682.26	397.93	4.23	7.98
R452B	1662.76	388.46	4.28	6.74
R454B	1649.55	385.29	4.28	6.57

In the case of using R410A and its alternative R452B and R454B refrigerants in the heat pump, the environmental impact analysis was performed as stated by LCCP. LCCP analysis is similar to total equivalent warming impact (TEWI) analysis. LCCP covers each of emissions over the life of a system (from cradle to grave). In Figure 2, the LCCP analysis of a heat pump is given schematically. As can be seen in Figure 2, LCCP is examined in two main categories: (I) Direct emissions and (II) indirect emissions (Yıldız and Yıldırım, 2020).

Direct emissions contain the effects of the refrigerant given into the atmosphere during service life of the unit (loss of refrigerant caused by leakage, loss of refrigerant caused by the life of the system, losses caused by the breakdown of refrigerant in the atmosphere, etc.). Indirect emissions include emissions from use over the life of the unit, such as electricity, material and refrigerant production, disposal (Yıldız and Yıldırım, 2020; Choi et al. 2017).

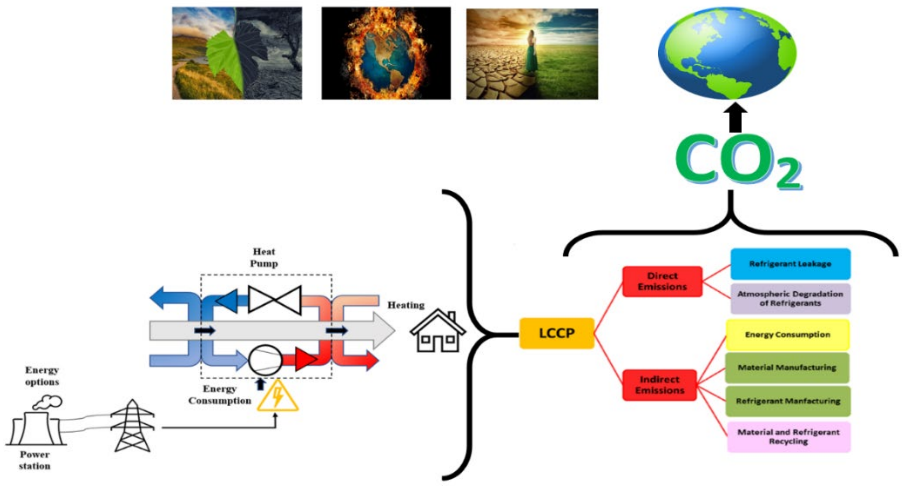

Figure 2. LCCP of heat pump

In the literature, it has been observed that vapour compression systems consist of approximately 80% to 95% of LCCP emissions from indirect emissions. As an example of this situation, data taken directly from the studies of Choi et al. (2017) and Yıldız et al. (2020) are given in Figure 3 and Table 3. The vast majority of these indirect emissions are due to energy consumption (Aprea et al. 2018). Therefore, emissions from energy consumption were calculated in LCCP analysis in this study.

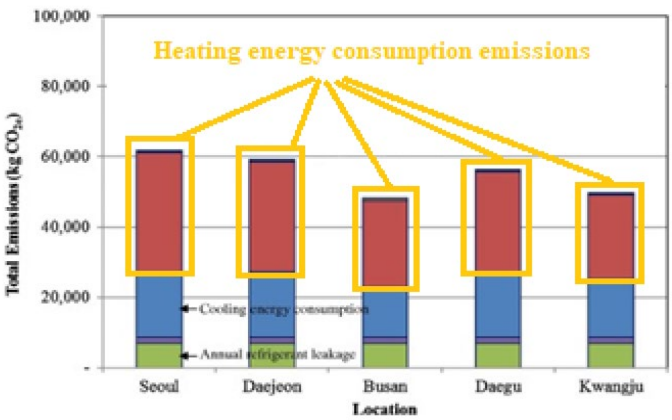

Figure 3. LCCP evaluation with the heat pump in Korea (Choi et al. 2017)

Table 3. Asumptions and equation for LCCP (Atilgan & Azapagic, 2016)

Heating capacity	5 kW
L (Device life)	15 year
EM (Electricity generation emission value)	0.532 kgCO_2/kW
AEC (Annual energy consumption)	kWh/year
Energy consumption emission = L. AEC. EM	

Table 4 was used to calculate emissions from energy consumption. LCCP analysis of refrigerants is given in Figure 4. As shown in Figure 4, the LCCP values of R452B and R454B refrigerants are slightly lower than R410A (about 1.20%). As can be seen from Figure 4, it is not enough to use only refrigerants with a low GWP ratio or reduce the amount of refrigerant charge to reduce the total emissions of vapour compressed systems. Because they only reduce the direct emissions of vapour compression systems. But as described above, in the LCCP analysis of steam compression systems, most emissions are by reason of energy consumption. For this reason, the efficiency of vapour compression systems should be increased, and the electrical energy required for these systems should be generated from renewable energy sources.

As in other countries, fossil fuels have been largely used in electric power production in Turkey. According to data for 2018 in Turkey, coal, natural gas, hydroelectric energy, wind energy, solar energy and geothermal energy in total electricity production rates respectively 37.7%, 29.8%, 19.8%, 6.6%, 2.6% and 2.5% (ETKB, 2018).

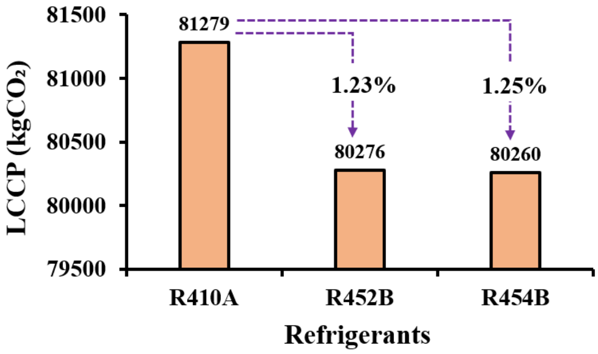

Figure 4. Comparison of LCCP of R452B and R454B relative to R410A

Table 4. Analogy of LCCP of refrigerants for a heat pump (Yıldız & Yıldırım, 2021)

Emission category	R134a		R513A		R1234yf	
	Emissions	Percentage of total emissions	Emissions	Percentage of total emissions	Emissions	Percentage of total emissions
Direct emissions	**410**	**0.89**	**149**	**0.38**	**1**	**0.00**
Annual refrigerant leakage	293	0.64	107	0.27	1	0.00
End-of-life refrigerant leakage	117	0.25	43	0.11	0.29	0.00
Indirect emissions	**45,651**	**99.11**	**39,262**	**99.62**	**38,165**	**100**
Refrigerant manufacturing	4	0.01	7	0.02	8	0.02
Material recycling	72	0.16	72	0.18	72	0.19
Material manufacturing	355	0.77	355	0.90	355	0.93
Heating energy consumption	45,219	98.17	38,828	98.52	37,728	98.85
LCCP	**46,061**	–	**39,412**	–	**38,166**	–

Bold values indicate subtotal of direct and indirect emissions and total LCC values

The average electricity emission value of Turkey was 0.523 kgCO2 / kWh (Atilgan & Azapagic, 2016). Electricity generation emission value is important for LCCP analysis. It plays an important role in reducing emissions from electrical energy consumption. Emission values in electrical energy production of some energy sources are given in Table 5.

Table 5. CO_2 emissions for various energy sources (Varun et al. 2009; Kumaş & Akyüz 2020)

Source	CO_2 Emission ($kgCO_2$/kWh)
Hydro	0.0037 – 0.237
Wind	0.0097- 0.1237
Solar thermal	0.0136 – 0.202
Nuclear	0.0242
Biomass	0.035 – 0.178
Solar PV	0.0534 – 0.250
Coal	0.9753
Oil	0.7421

Let consider the impact of wind energy in the LCCP analysis to emphasize the importance of renewable energy. If the electrical energy required for the heat pump system is generated from wind energy, the total emission of the heat pump would be as in Figure 5. The emission value for wind energy was taken as 0.1237 kgCO2/kWh. As shown in Figure 5, there was a significant decrease in heat pump emission when wind energy was used (average 76%).

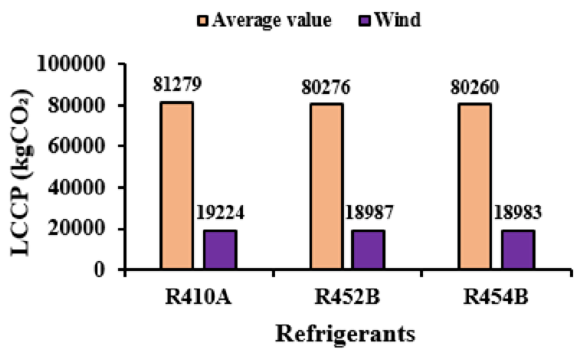

Figure 5. Comparison of LCCP according to average emissions value and wind energy

Conclusions

In this study, energy and environmental analysis of low GWP refrigerant R452B and R454B, which are alternatives to R410A in the heat pump system, were examined. Results from the study are given below:

- The heating performance coefficient (COP) values of R452B and R454B are almost the same and are approximately 1.20% higher than R410A.
- The GWP ratio of alternative refrigerants R452B and R454B is quite low compared to R410A.
- It is not enough to use low-GWP refrigerants to reduce the carbon footprint of vapour compression systems. For this reason, the energy efficiency of vapour compression systems should be increased and renewable energy sources should be used.

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