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The role of environmental metrics (GWP, TEWI, LCCP) in the selection of low GWP refrigerant.

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Abstract

Based on increasing contribution of refrigeration systems to climate change it is necessary to use environmentally friendly refrigerants to mitigate the global warming. Different environmental metrics are used to facilitate decision-making process of selection of refrigerant with low global warming potential. Three conventional environmental metrics - global warming potential (GWP), total equivalent warming impact (TEWI) and life cycle climate performance (LCCP) – are used in this study as tools to select the most environmentally friendly refrigerant for 30 kW air/water heat pump system. The uncertainties in use of all these environmental metrics are discussed. The study concludes with the selection of the refrigerant and discusses the suggestions to facilitate further studies on selection of the low GWP refrigerant with low contribution to global warming.

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Keywords: refrigerant, LCCP, TEWI, GWP, heat pump

1. Introduction

Environmental concerns have always been the driven force in the developments of environmental friendly refrigerants. Active research in fields of system design optimization, energy efficiency increase, search of the new refrigerants and efficient use of the old systems is important for both heat pump and refrigeration systems. While human influence on the climate system is clear [1], it is important to have transparent and easy to use methods when designing an energy system with low environmental impact.

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Nomenclature	
GWP	Global Warming Potential
TEWI	Total equivalent warming impact
LCCP	Life-cycle climate performance

Three environmental metrics are mostly used in the process of refrigerant selection: GWP, TEWI and LCCP. While each serves similar aim of quantifying the impact of refrigerants to global warming, their usage can lead to different conclusions. In this study, the selection of the refrigerant for 30 kW air/water residential heat pump system is made in order to reach the lowest possible environmental impact.

2. System description and refrigerant candidates selection

Refrigerant selection for a 30 kW air/water heat pumps for retrofitting multi-family houses and commercial buildings is in focus of this study. The potential refrigerant candidates were selected based on a number of criteria, including GWP upper limit of 150 (for 100-year time horizons). After applying all the necessary criteria, four refrigerant options have been selected for detailed environmental performance analysis: two hydrocarbons (R290, R1270) and two hydrofluorocarbons (R152a, R1234yf). The refrigerant R410A is used as a reference refrigerant.

Different environmental metrics are used to quantify the impact of refrigerant to global warming. Below three methods are shortly described and compared to each other.

2.1 Global Warming Potential (GWP)

GWP is perhaps the most commonly used environmental metric. GWP is the index, which compares the global warming impact of an emission of a greenhouse gas in relation to the impact from the emission of similar amount of CO_2. The impact is estimated during a time horizon. A time horizon of 100 years is most adopted and normally assumed when no information on time horizon is given (including the values cited in this paper). GWP is an easy metric to use. The smaller the GWP, the lower contribution of a substance to the global warming. Based on GWP criteria the R290 (Propane) and R1270 (Propene) can be considered as the most environmentally friendly refrigerants while the R1234yf is less favorable. R152a, in turn, is the least environmentally friendly refrigerant out of the four candidates, but still its contribution to the global warming is much lower than that of the reference R410A (see Table 1).

Table 1. GWP values of refrigerant candidates

Refrigerant	R290	R1270	R1234yf	R152a	R410A
GWP [2] [3]	3,3	1,8	4	124	2088
% of R410A	0.16%	0.09%	0.19%	5.94%	100.00%

2.2 Total equivalent warming impact (TEWI)

In addition to the direct impact of the refrigerant (which is conveniently estimated by GWP), any system or process, which requires energy input, indirectly affects the environment. This impact is originated from CO_2 emissions from the energy production processes.

In order to indicate the overall environmental impact from a refrigeration system during it operation, another environmental indicator, named TEWI, is used. TEWI accounts for the global warming impact from both direct and indirect emissions and calculated as a sum of both: direct effect of refrigerant released during the lifetime of the equipment and the indirect impact of CO_2 emissions from fossil fuels used to generate energy to operate the equipment throughout its lifetime. TEWI can be calculated using the equation below (UNIDO 2009):

$$\text{TEWI} = \text{direct emissions} + \text{indirect emissions} = (GWP \times L \times N) + (Ea \times \beta \times n), \quad (1)$$

where L – annual leakage rate in the system, kg (3% of refrigerant charge annually),
N – life of the system, years (15 years),
n – system running time, years (based on weather data, 4910 hours),
Ea – energy consumption, kWh per year (modelled for each refrigerant),
β – carbon dioxide emission factor, CO_2-eq. emissions per kWh (165 g CO_2/kWh).

In terms of TEWI, the most environmentally friendly refrigerant is the R152a with total lifetime CO_2 equivalent emissions of 37,522 kg. TEWI values of R1270a and R290 are close to that of R152a (see Table 2). R1234yf refrigerant shows the worth TEWI value out of four refrigerant candidates under consideration and therefore it is not a preferable option. R410A, in turn, have high TEWI value that is mostly due to high contribution of direct effects caused by its high GWP value.

Whereas direct effect of R410A is nearly 10% of total TEWI value, for the refrigerants with low GWP direct effect is negligible compared to the indirect effect. Therefore, the result of refrigerant comparison based on TEWI will be greatly affected by the performance of the energy consumption data of refrigeration system, which is affected by the system efficiency.

Table 2. TEWI values of refrigerant candidates and share of direct emissions in total TEWI value

Refrigerant	R290	R1270	R1234yf	R152a	R410A
TEWI, kg CO_2-eq	37,775	37,706	40,027	37,522	43,351
% of R410A	87.14	86.98	92.33	86.55	100.00
Direct emissions contribution to total TEWI, %	0.01	0.00	0.02	0.54	9.42

2.3 Life-cycle climate performance (LCCP)

TEWI metric is more indicative than the GWP, but it is not taking in account all the relevant indirect emissions involved into refrigerant life cycle such as emissions related to the manufacture and transportation of the system and refrigerant. Hence, another indicator is used to account for all GWP related to the refrigeration system operation, including environmental impact of substances emitted during the process of refrigerant production and transportation. This environmental effect, together with environmental effects already accounted in TEWI, is known as the life-cycle climate performance (LCCP) and intended for providing holistic picture of environmental impact of different refrigerants. In practice, the LCCP is more complex than TEWI metric to calculate, and an additional contribution of LCCP compared to the TEWI is negligible (Table 3).

In terms of LCCP, the most environmentally friendly refrigerant is the R1270 with total lifetime CO_2 equivalent emissions of 37,708 kg CO_2-eq. emissions. R290 and R152a are very close to the values of R1270, whereas R1234yf refrigerant shows the worth TEWI value out of four refrigerant candidates and therefore not a preferable option.

Table 3. TEWI values of refrigerant candidates

Refrigerant	R290	R1270	R1234yf	R152a	R410A
LCCP, kg CO_2-eq	37,780	37,708	40,039	37,839	45,398
% of R410A	83.22	83.06	88.20	83.35	100.00
% to TEWI	+0.01	+0.01	+0.03	+0.84	+4.72

3. Conclusion

LCCP is a holistic metric to quantify the effect of the refrigerant on the total lifetime system emissions. However, in practice, the LCCP is more complex than TEWI and the contribution of additionally accounted emissions is negligible. GWP is useful metric to compare different refrigerants. However, it may to overestimate the benefits of low GWP refrigerant to environment, as it does not take into account many other affecting factors.

While the results given by each of the environmental metrics were different from one metric to another, TEWI as an environmental metric is simpler to use than LCCP and more correct than GWP in the selection of an environmentally friendly low GWP refrigerant. TEWI is sensible to the energy performance of a system. Thus, the efficiency of the refrigeration system, shown for every refrigerant candidate, is the most important parameter when estimating impact of a system to the environment. Other parameters, if varied within reasonable limits, play less important role in comparative analysis of refrigerant options based on TEWI. Current study shows that refrigerants R152a, R290 and R1270 can be considered equally good from environmental point of view in the heat pumps.

Acknowledgements

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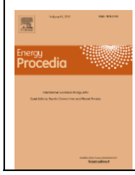

Biography

Pavel Makhnatch is a PhD student in Energy Technology with particular research interest in sustainability aspects of refrigeration technology and focus on new low global warming potential refrigerants.