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Safety aspects for the R290 (propane) as working medium in small air conditioning installations

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Abstract

Following the entry into force of the Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006, the scope of refrigerants, which have so far been commonly used is very limited. All preferred refrigerants are mostly flammable and explosive, and they include R32, R1234yf, R1234ze, R290 (propane), R600a (isobutane), R717 (ammonia). However, it should be noted that refrigerants such as R32, R1234yf, R1234ze are classified as mildly flammable and has been created for them, in accordance with ISO 817 standard, special group called A2L. It is also worth noting that the new classification moved ammonia to the group B2L - that means is toxic and mildly flammable. The article focuses on defining the conditions in which there is possible to build safely split installation in which the propane is a refrigerant. It turns out that small splits are devices which can be used safely with R290 in most cases.

Keywords: refrigeration, refrigerant, propane, R290.

1 Introduction

In 2014, a new regulation of the European Parliament and of the Council came into force on refrigerants from the group called f-gases - certain fluorinated greenhouse gases [18]. The use of currently available refrigerants has once again been reduced [19]. This regulation is related to the direction of the development of the European Union's climate actions, which aims to continuously reduce emissions of CO2 and other greenhouse gases. [1]. The Global Warming Potential (GWP) coefficient was adopted as the parameter determining the greenhouse effect potential). Table 1 lists the GWP coefficients for current and prospective refrigerants.

Table 1 clearly shows that the refrigerants used today have a high level of GWP. This leads to a situation where, in the coming years, further refrigerants commonly used in air conditioning systems, heat pumps and refrigeration equipment will be phased out. The European Commission is moving towards the use of natural refrigerants [11]. In the coming years, only refrigerants such as: ammonia, carbon dioxide, propane, isobutane will be approved for use, from the group of hydrofluoroolefins there will be allowed only R1234ze, R1234yf [20]. All these natural refrigerants have been known in refrigeration for over 100 years, however, due to their flammability and explosiveness, they have lost the competition to synthetic agents such as R12 or R22, which are neither flammable nor toxic [3, 4] and do not cause corrosion of the installation [25]. R32, R1234ze, R1234yf refrigerants are included in the newly created A2L group, non-toxic and moderately flammable substances [21, 24, 27]. Fig. 1 shows the minimum ignition energy and the lower explosion limit in air for prospective refrigerants.

Figure 1 shows that the refrigerants from the A2L group pose a risk of explosion when their concentration is several times higher than in the case of propane, methane or isobutane, and in most cases they also require much more energy to ignite. It should also be added that the R1234ze refrigerant is non-flammable at temperatures below 30 ^oC [14]. Other parameters important from the point of view of the explosion hazard are the burn rate and the heat of combustion - these are defined as the potential damage that can be caused by gas ignition after leakage from the installation. These values for refrigerants are presented in Fig. 2. In this case also the factors from the A2L group

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Table 1. GWP coefficient for selected refrigerants

Refrigerant	GWP
R1234ze	7
R1234yf	4
R134a	1430
R22	1810
R290 (propane)	3
R32	675
R404A	3922
R407C	1770
R410A	2018
R600a (isobutane)	3.3
R717 (ammonia)	0
R744 (carbon dioxide)	1

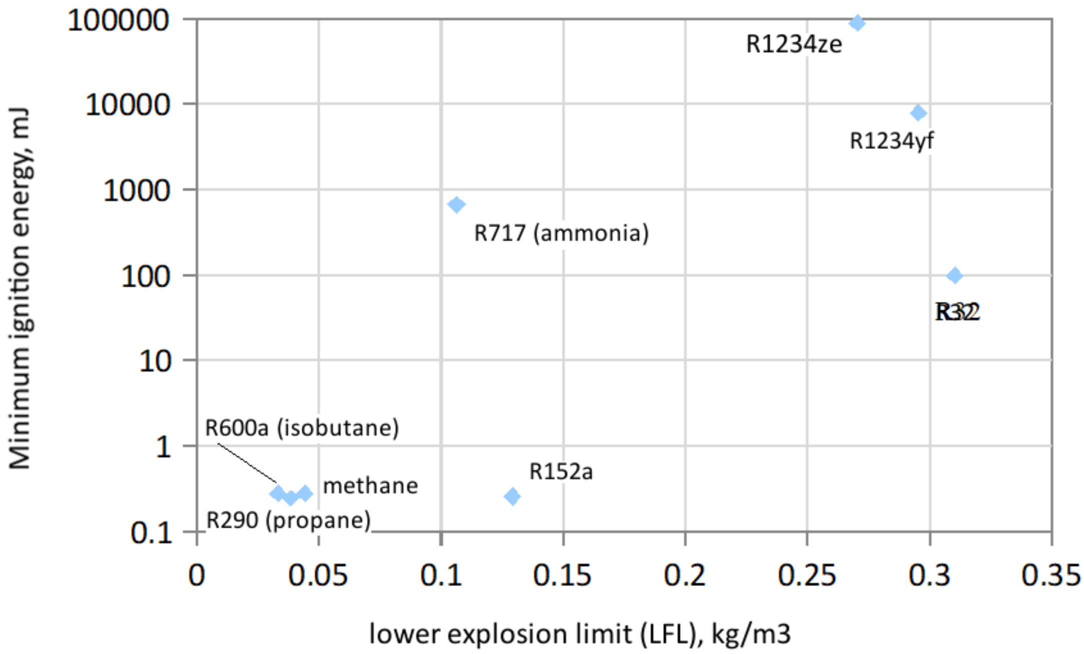

Figure 1. Minimum ignition energy as a function of the lower explosion limit (LFL) for flammable refrigerants.

fare much better. Potential leakage and ignition will not cause as much damage as leakage and ignition of propane or isobutane

The only refrigerant that is safe in terms of explosion hazard is R744 - carbon dioxide CO2, but it has other limitations:

- low temperature of the critical point (30.4^{o}C) - significantly reduces the use of carbon dioxide in typical cooling and air-conditioning installations;
- high operating pressures (condenser work over 100 bar);

Refrigerants from the hydrocarbon group (HC) are not a solution that is not available in refrigeration industry

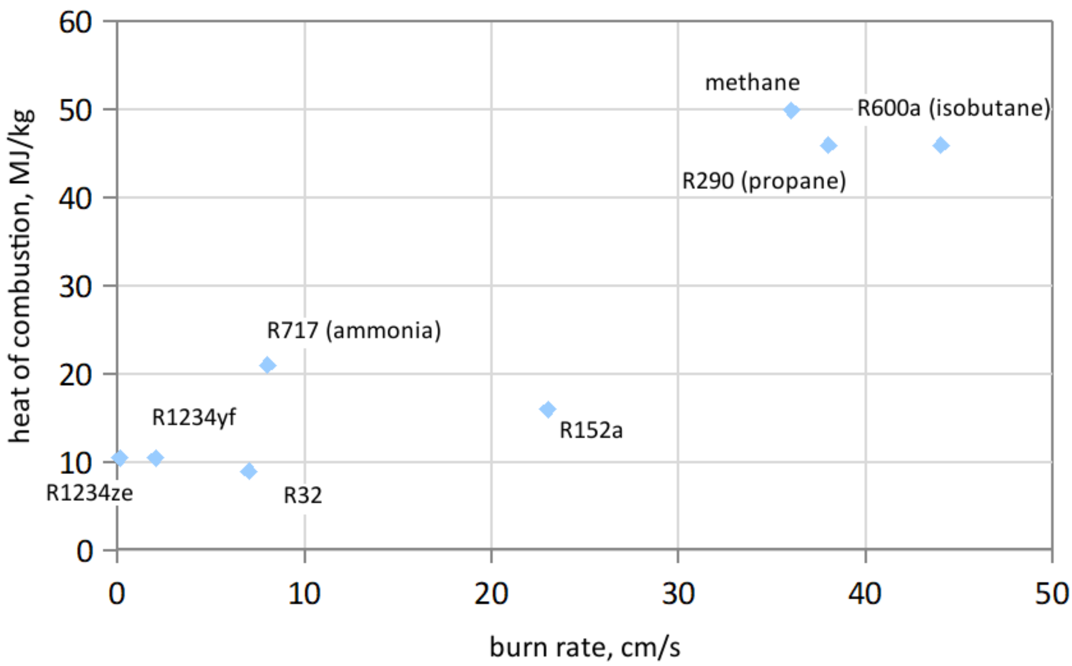

Figure 2. Combustion heat as a function of the combustion speed of refrigerants.

today. Isobutane has been the main refrigerant used in fridges in the European Union since the 1990s (over 90% of the market) [11, 12]. Propane is often found in large industrial installations. On the other hand, ammonia can often be found in large installations of the food industry.

The new regulations favor the development of other technologies related to the reduction of energy consumption[2, 10, 13, 16, 17], less dust emissions [15, 26], or the construction of non-compressor refrigeration equipment. In recent years, many absorption and adsorption cooling installations have been built [7] or with the use of the ejectors [23].

2 Legal acts and standards regulating the use of propane in split air-conditioning systems

Nine documents (legal acts and standards) are listed that should be taken into account in the aspect of construction and operation of devices and installations containing propane [5, 8]. These documents are listed in table 2. After careful analysis of the documents, it turns out that in most cases, due to the small amount of the refrigerant, which is propane, in split units, the documents do not apply to them. The EN 378 standard turns out to be the most important.

The EN 378 standard says that devices with a filling capacity of less than 150 grams can be used anywhere. However, in larger installations, the standard defines the concept of the maximum charge with the working medium, which is calculated in accordance with the formula:

$$M = 2.5 \cdot LFL^{1.25} \cdot h \cdot A^{0.5} \tag{1}$$

where:

M - maximum filling of the installation with the refrigerant, kg;

LFL - lower explosive limit, kg/m^3; for propane LFL is equal to 0.038 kg/m^3.

h - unit installation height, m (0.6 - floor unit, 1.0 - window unit; 1.8 - wall unit; 2.2 - ceiling unit);

A - floor area, m^2;

Table 2. Legal acts and standards concerning flammable materials as refrigerants

Act	Description
ISO 817:2014	Refrigerants — Designation and safety classification
EN 378	Refrigerating systems and heat pumps - Safety and environmental requirements
EN 60079	Explosive atmospheres
EN 60335	Safety of household and similar electrical appliances
ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road
Dz.U. 2003 nr 86 poz. 789	Act of March 28, 2003 on rail transport
Dz.U. 2010 nr 138 poz. 931.	Regulation of the Minister of Economy of 8 July 2010 on the minimum requirements for occupational health and safety related to the possibility of an explosive atmosphere in the workplace.
Dz.U. 2015 poz. 881	Act of 15 May 2015 on substances that deplete the ozone layer and some fluorinated greenhouse gases
Regulation (EU) No 517/2014	Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 .

These restrictions apply only to devices located in the zone of continuous human habitation. For industrial installations - other regulations listed in Table 2 also apply.

3 Propane in air-conditioning installations

There are three types of air conditioning systems:

- split systems - one evaporator is located inside the room, one condenser with a compressor is located outside the building.
- multisplit systems, VRV , VRF - outside the building there is a central unit with a condenser / condensers and a compressor / compressors, the refrigerant is supplied to the building and then distributed to individual evaporators;

- brine systems - secondary fluid systems - the so-called ice water generator (chiller) is located outside the building - while only chilled water (or brine) is supplied to fan coils inside the rooms.

In the case of VRV systems, the amount of refrigerant is so large that it is not practicable to maintain safety in air-conditioned rooms - hence, in these solutions it is not possible to use hydrocarbons as refrigerants. In the case of systems with chilled water generators, despite the fact that the actual cooling system has no connection with the air-conditioned space, the standard EN 378 [9], in the case of air conditioning for people's comfort, it requires the same limits as in the case of so-called direct evaporation installations. Installations with chilled water generators are usually large systems - this means that in these installations it is also impossible to use hydrocarbon refrigerants in accordance with applicable regulations.

For this reason, the split system used for air conditioning the room will be analyzed in the further part of the work. A device of this type is presented in Figure 3. A typical split device for cooling apartments or office spaces will be used for the analysis. The analysis will cover the replacement of the working medium with propane [22]. A typical 2.7kW split uses approximately 700 grams of R410A refrigerant. The cooling capacity of 2.7 kW is sufficient to air-condition rooms with an area of about 20 m2 when the windows are facing south or west, and when the windows are facing east or north - the area of the rooms can reach up to 40 m^2. Calculations will be made for rooms with a smaller area - i.e. 20 m^2. Split devices are most often installed in the wall or ceiling mode - this is due to the favorable air circulation. Thus, assuming a wall positioning, a maximum level filling is achieved:

$$M = 2.5 \cdot 0.038^{1.25} \cdot 1.8 \cdot 20^{0.5} = 0.338kg \tag{2}$$

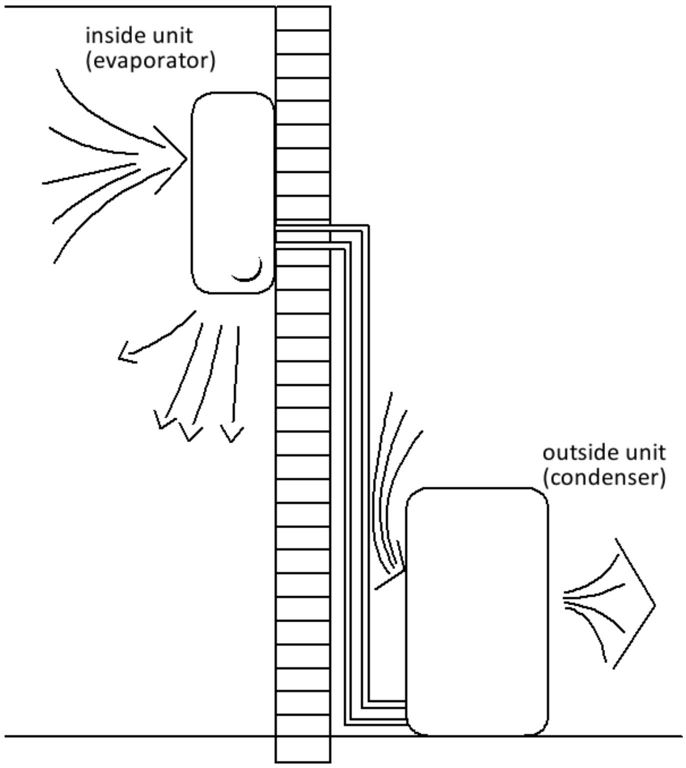

Figure 3. Split air conditioning unit with wall-mounted indoor unit.

In order to compare the difference between the charging of the same system with R410A refrigerant and R290, ln p-h graphs were prepared for both refrigerants (Fig. 4 and 5). At characteristic points, propane, compared to R410A, has an average density of 2.59 times lower, which means that it can be estimated that in a device with 700 grams of R410A there will be just 271 grams of propane. The presented estimate is indicative, because for each system this number should be determined experimentally, as it depends on the size of the heat exchangers, the size of the compressor and the length of the pipelines between the evaporator and the outdoor unit.

Experimental studies for refrigerants such as R22, R404A, R407C show that the amount of propane compared to the original refrigerant is reduced by 4 to 5 times [6]. This suggests that in a system where R410A was replaced

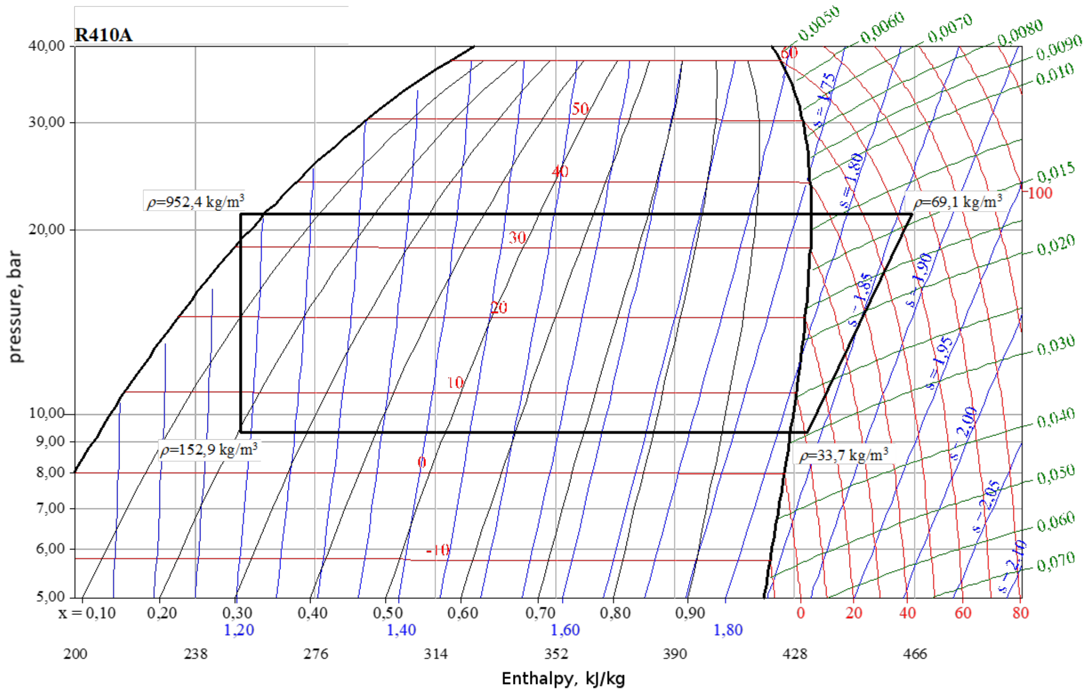

Figure 4. The lnp-h cycle of R410A refrigerant for the considered case

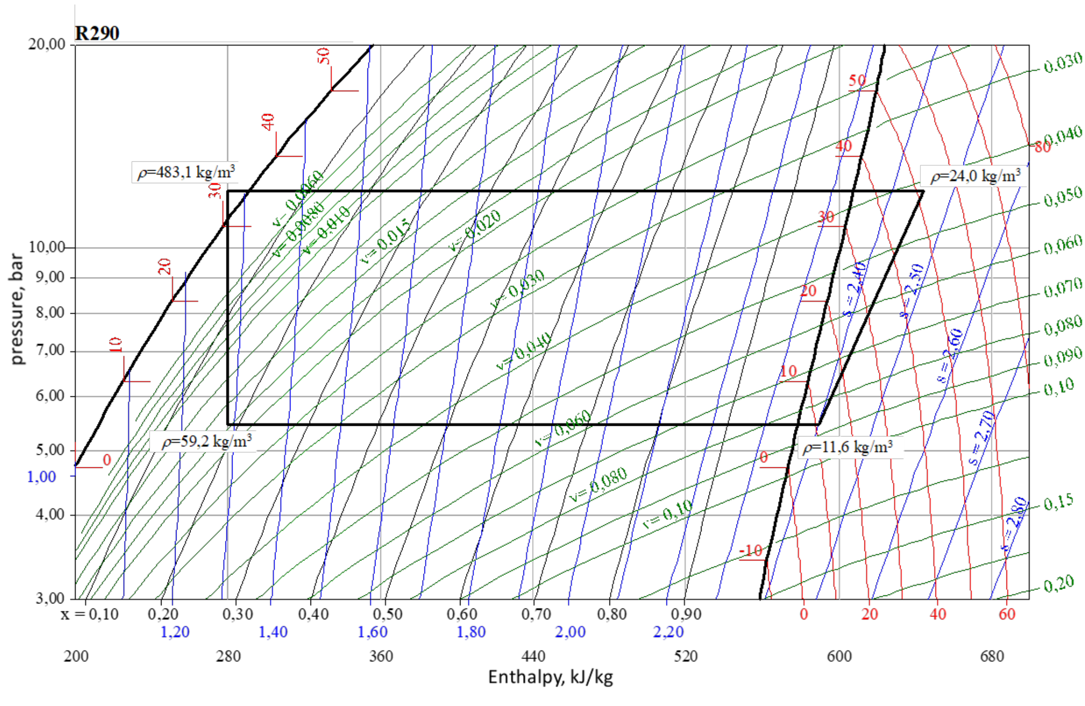

Figure 5. The lnp-h cycle for R290 (propane) for the considered case

with propane, its amount will be even less than the estimated 271 grams. The R410A refrigerant unit with a cooling capacity of 2.7 kW has a compressor volumetric capacity of 1.6066 m^3 / h. If it is planned to replace the refrigerant in an operating system with R290, the volumetric capacity of the compressor will remain the same - it results from the design of the compressor. However, for the same volumetric capacity of the compressor, only 1.601 kW of cooling power can be obtained in the system with R290. For a propane system, replace the compressor with one with a higher volumetric capacity to obtain the same cooling capacity. The sizes of the heat exchangers can remain unchanged. This is because propane's thermal conductivity is greater than that of R410A. This fact means that the amount of refrigerant after replacing the compressor may also remain unchanged at 271 grams.

4 Conclusions

The conducted analysis shows that in small split air-conditioning systems, it is safe to use a refrigerant such as propane, because even the leakage of the entire amount of gas does not pose an explosion hazard. However, there is always a risk that the gas will ignite locally during service or disposal, so these activities should be performed only by qualified personnel. The amount of refrigerant in the installation, compared to the refrigerants currently used, is reduced by 2 to 5 times. In the case of the analyzed installation, 700 grams of R410A can successfully replace 271 grams of propane. However, a simple exchange of the refrigerant with one to another in an operating installation causes a reduction of the cooling capacity by 41%. Due to this phenomenon, the cooling capacity may not be sufficient to maintain thermal comfort in the room. Due to the high thermal conductivity of propane, the heat exchangers are of sufficient size. Only the compressor per unit with higher volumetric capacity needs to be replaced. Another important consideration when replacing the refrigerant with propane is that propane has a density lower than that of oil. As a result, the oil transport will be different than in standard systems with synthetic agents. In large installations it would require reconstruction of pipelines and exchangers, in the case of split devices there is no such need.

References

1. Bartela, L., Skorek-Osikowska, A. & Kotowicz, J. An analysis of the investment risk related to the integration of a supercritical coal-fired combined heat and power plant with an absorption installation for CO2 separation. *Applied Energy* **156,** 423–435 (2015).
2. Baryłka, A. The impact of fire on changing the strngth of the underground shelter structure. *Rynek Energii* **146,** 71–75 (1 2020).
3. Bohdal, T., Charun, H. & Sikora, M. Empirical study of heterogeneous refrigerant condensation in pipe minichannels. *International Journal of Refrigeration* **59,** 210–223 (2015).
4. Bohdal, T., Widomska, K. & Sikora, M. The analysis of thermal and flow characteristics of the condensation of refrigerant zeotropic mixtures in minichannels. *Archives of Thermodynamics* **37,** 41–69 (2 2016).
5. *BRA: Guide to Flammable Refrigerants* (2012).
6. Colbourne, D. & Huhren, R. *Operation of split air conditioning systems with hydrocarbon refrigerant. A conversion guide for technicians, trainers and engineers. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH - German International Cooperation -Programme Proklima* (Eschborn, Germany, 2011).
7. Cyklis, P. Two stage ecological hybrid sorption-compression refrigeration cycle. *International Journal of Refrigeration* **48,** 121–131 (2014).
8. *Dz.U. 2010 nr 138 poz. 931. Rozporządzenie Ministra Gospodarki z dnia 8 lipca 2010 r. w sprawie minimalnych wymagań, dotyczących bezpieczeństwa i higieny pracy, związanych z możliwością wystąpienia w miejscu pracy atmosfery wybuchowej*
9. *EN 378: Refrigerating systems and heat pumps — Safety and environmental requirements*
10. Gourbi, A., Bousmaha, I., Brahami, M. & Tilmatine, A. Numerical Study of a Hybrid Photovoltaic Power Supply System. *Journal of Power Technologies* **96,** 137–144 (2 2016).
11. Grzebielec, A. Europa zmierza w kierunku naturalnych czynników chłodniczych. *Chłodnictwo* **9,** 42–46 (2010).
12. Grzebielec, A. & Rusowicz, A. Kierunki rozwoju syntetycznych czynników chłodniczych w Europie. *Polska Energetyka Słoneczna* **1-4,** 45–49 (2012).
13. Harmanti, N., Folić, R., Magyar, Z., Drazić, J. & Kurtowić-Folić, N. Building envelope influence on the annual energy performance in office buildings. *Thermal Science* **20,** 679–693 (2 2016).
14. Honeywell. Solstice ze refrigerant (HFO-1234ze). The Environmental Alternative to traditional refrigerants (2014).
15. Kukfisz, B., Półka, M. & Salamonowicz Z.and Woliński, M. Badania inertyzacji mieszanin pyłowo powietrznych. *Przemysł Chemiczny* **93,** 103–106 (1 2014).
16. Laskowski, R. Relations for steam power plant condenser performance in off-design conditions in the function of inlet parameters and those relevant in reference conditions. *Applied Thermal Engineering* **103,** 528–536 (2016).
17. Owczarek, M., Owczarek, S., Baryłka, A. & Grzebielec, A. Measurement Method of Thermal Diffusivity of the Building Wall for Summer and Winter Seasons in Poland. *Energies* **14.** ISSN: 1996-1073 (2021).
18. *Rozporządzenie Parlamentu Europejskiego i Rady (UE) nr 517/2014 z dnia 16 kwietnia 2014 r. w sprawie fluorowanych gazów cieplarnianych i uchylenia rozporządzenia (WE) nr 842/2006*

19. Rucinski, A., Rusowicz, A., Grzebielec, A. & Jaworski, M. Wycofywanie czynników chłodniczych i ich bezpieczna utylizacja. *Logistyka* **1,** 116–22 (2016).
20. Ruciński, A., Rusowicz, A. & Grzebielec, A. Czynniki chłodnicze w transporcie samochodowym - aspekty prawne i techniczne. *Logistyka* **5,** 1303–1309 (2014).
21. Rusowicz, A., Grzbielec, A. & Ruciński, A. Ocena zagrożeń związanych z wykorzystywaniem naturalnych czynników chłodniczych. *Logistyka* **5,** 1310–1316 (2014).
22. Rusowicz, A. & Grzebielec, A. Aspekty prawne i techniczne zmiany czynników chłodniczych w instalacjach chłodniczych i klimatyzacyjnych. *Czasopismo Inżynierii Lądowej, Środowiska i Architektury, JCEEA* **32,** 359–367 (62 2015).
23. Smierciew, K., Butrymowicz, D., Kwidzyński, R. & Przybyliński, T. Analysis of application of two-phase injector in ejector refrigeration systems for isobutane. *Applied Thermal Engineering* **78,** 630–639 (2015).
24. Spatz, M. & Minor, B. *HFO-1234yf A Low GWP Refrigerant For MAC* in. Honeywell / DuPont Joint Collaboration. SAE World Congress - Detroit, Michigan, April 14-17 (2008).
25. Szczucka-Lasota, B. Opracowanie stanowiska do przeprowadzenia testów korozyjnych. *Aparatura Badawcza i Dydaktyczna* **19,** 303–308 (2014).
26. Szwast, M. & Szwast, Z. A Mathematical Model of Membrane Gas Separation with Energy Transfer by Molecules of Gas Flowing in a Channel to Molecules Penetrating this Channel from the Adjacent Channe. *Chemical and Process Engineering* **36,** 151–169 (2 2015).
27. *The Japan Society of Refrigerating and Air Conditioning Engineers: Risk Assessment of Mildly Flammable Refrigerants, April* 2014.