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FLAMMABLE REFRIGERANTS IN BUILDINGS FROM FIRE SAFETY POINT OF VIEW

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ABSTRACT

The contribution is an introduction to a new trend in the assessment of buildings as concerns their fire safety, and namely assessing the refrigerating system with refrigerants as such, forming an important part of the technological equipment of the edifice. Down to the present day both refrigerants and refrigerating systems used to be in the background of considerations, being handled as mere component parts of the ventilation systems, or even totally left out of consideration in fire safety statements relating to buildings. However, a certain improvement is seen to have set in, thanks to which refrigerants are claiming due attention. The reason for focusing upon their problems lies in the fact that refrigerants with high GWP index are being gradually replaced with low GWP index preparations ever since 2015, and namely due to the legitimate requirement of environmental protection. High GWP index refrigerants are even going to be prohibited after 2020. The shady side of this process is the considerable flammability of the newly introduced refrigerants. This is also why these problems arouse increased interest in the domain of the fire safety experts of the building trade on the one hand side, and among those specialized in refrigerating systems on the other hand side. This paper offers an outline of ways helping to solve the situation having set in. The aim of the paper is to point out the new situation in buildings where there are refrigerating systems with flammable refrigerants and the necessary measures resulting from the given situation, such as reducing the amount of refrigerant and the need to ventilate the space using cooling.

INTRODUCTION

The fire safety of a building facility is its ability to protect the life and health of persons in case of fire and further, if case be, to prevent the loss of property [ČSN 730802, 2009]. Within the Czech environment this requirement is ensured by legal and standardizing regulations [Act No. 133/1985] followed by the Fire Code, namely a set of standards governing the fire safety of buildings [Regulation No. 23/2008]. The appropriateness of a proposed building project shall be checked as early as in the design phase by the so-called fire safety solution of the building whose single steps are binding [Regulation No. 246/2001]. One of the prescribed steps is also the assessment of the technological equipment of a given building involving, e.g., the assessment of air conditioning or ventilation systems. The consideration of refrigerant systems, actually in many cases immediately following the ventilation issue, has been hidden in this step almost down to the present day. Prior to 2015 the assessment of cooling systems did not attract special attention, since the majority of used refrigerants were not flammable.

Since 2016 the following standard has been valid on the Czech territory: EN 378 [ČSN EN 378-1, ČSN EN-2, ČSN EN-3, ČSN EN-4, 2016]. These legal documents reflect the strict requirements relating to the reduction of the GWP (global warming potential) index. GWP assesses the capacity to catch heat in the

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atmosphere, and possibly to refract it back to the surface of the Earth, i.e. it evaluates gaseous matter with regard to its effect upon its impact upon the creation of greenhouse gas whose consequence lies in the warming-up of the Planet. As has been mentioned, preferred refrigerants are those with low GWP index comprising, however, also an adverse aspect – the prevailing majority of them are flammable. These newly preferred refrigerants are proposed both to form part of new cooling systems, and to replace the former not flammable refrigerants in the existing ones.

The above problems inspire the efforts to create a system enabling to assess the utilization of flammable refrigerants in buildings. This endeavor is supported also by the present day situation in the building trade where the necessity of creating user friendly environment within the houses leads to fulfilling of the targets, at the one hand, by appropriate design of the facility and, on the other hand, by top quality building services, including the systems for cooling down [Kitanovski, 2015]. A working group consisting of experts from both participating fields, namely fire safety and refrigeration, have been processing this task now arriving at its objective in form of a methodology determining limit condition for the application of flammable refrigerants in buildings.

The primary task consisted in the determination among what type of matter these media should be classified. Further this assessment had to comprise all statements that had already been determined for the utilization of refrigerants by standard EN 378 [ČSN EN 378-1, ČSN EN-2, ČSN EN-3, ČSN EN-4, 2016]; the strictness of these boundary conditions makes them preferable also for further application in fire safety statements.

METHODS

Accordingly, the first phase required us to classify the refrigerant as a certain type of matter, which is not that easy, as we are going to show. The general division of material is into solids, liquids and gaseous matter. Each of these forms has its given system, classifying the respective reaction to high temperatures occurring in the course of a possible fire. This classification is called the fire technical characteristics of material. These are measurable or classifiable values enabling either classification or passing the decision about recommending or forbidding them for the use in a certain environment.

With regard to the domain of the fire safety of buildings the building products are divided into combustible and not combustible ones. The respective evaluation criterion is their class of reaction to fire, namely the reaction of a given building material or artefact to high temperatures. The used differentiation consists of seven classes of reaction to fire, class A1 and A2 involve not flammable building products, whereas classes B to F flammable ones. Solids are mentioned only to make the overview complete, since refrigerants do not fall among solid matter.

Flammable liquids are evaluated by indicating their hazard class, see Tab. 1 [ČSN 650201, 2003, 2006]. The hazard class of a flammable liquid is defined by its point of ignition, i. e. according to such lowest temperature under which the volume of steam generated over the flammable liquid under normal pressure catches fire through air by approaching a flame for a short time, but does not continue burning upon withdrawing the flame. Low boiling liquids with boiling point less than 21°C, e. g. ether, are classified as flammable liquids of the first hazard class. Under certain conditions most refrigerants are liquids.

Table 1. Hazard class of flammable liquid

HAZARD CLASS	POINT OF IGNITION **[°C]**
I.	from 21°C inclusive
II.	from 21°C to 55°C inclusive
III.	from 55°C to 100°C inclusive
IV.	more than 100°C

Flammable gazes are classified by the explosion range wherein explosions of gas blended with air occur under the effect of high temperature. This range is delimited by explosive limits (the upper and lower one), indicating the concentrations of flammable gas in g/m^3, under which explosions of the mixture already/still occur, see Fig. 1. Refrigerants in current environments are gaseous matter.

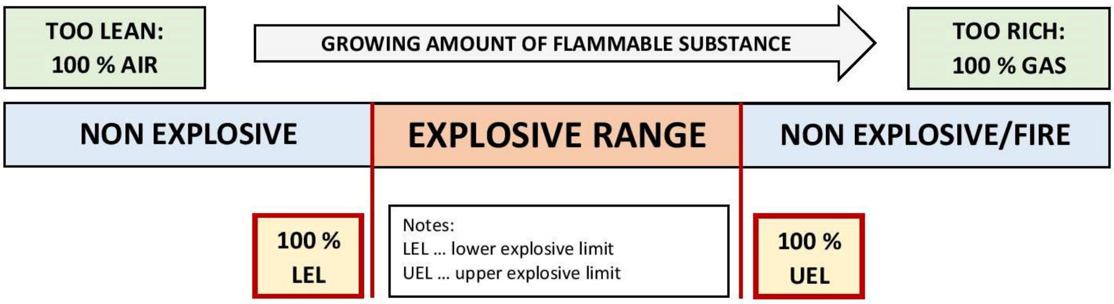

Figure 1. Explosive limits

Most refrigerants exist in two states of matter. If the refrigerant mixture is closed in the cooling circuit under the determined pressure, it behaves as a liquid. If the refrigerant escapes into the environment with normal temperature and atmospheric pressure, it turns in gas in most cases. However, there are exceptions when a refrigerant remains in liquid state even after having left the cooling circuit.

Under the concept of refrigerant in a special machine appliance serving as cooling circuit, a substance is understood that is used for the transfer of heat from one environment to another, the resulting temperature in one of them dropping consequently under the environmental temperature [ČSN EN 378-3, 2016]. Within the cooling circuit the refrigerant is a liquid with boiling temperature under 0 °C. Most refrigerant media are heavier than air, exceptions being methane, ethane and ammnonia. As mentioned above, most refrigerants convert to gas under current pressure and temperature, remaining in liquid state only by way of exception (e.g. R11 refrigerant). Refrigerants are characterized by the impact of GWP, the global warming index, by their toxicity and flammability. Toxicity and flammability of a refrigerant are decisive for its safety classification. In addition to that also the maximum volume of refrigerant fill is defined as its practical limit. This classification is prescribed [ČSN EN 378-1, 2016].

As indicated above, GWP being the governing aspect for the choice of refrigerant at the present day, the low GWP index refrigerants are preferred [European Regulation No. 2038, 2002, European Regulation No. 517, 2014]. GWP assesses the ability to get hold of heat in the atmosphere, and possibly to reflect it back to the surface of the Earth, i.e. the possibility of warming-up of the Planet. The limit of refrigerant applicability from the viewpoint of the impact of warming-up of the Planet is GWP = 2500 [Brož, J., 2017]. Any refrigerant exceeding this value will be prohibited after 2020. Unfortunately, the preferred refrigerants having favourable GWP values between 450 and 650 are all more or less flammable.
Refrigerants are classified according to their toxicity upon the basis of their long-time limit of exposure, the PEL classification see Tab. 2.

Table 2. Classes of refrigerants according to their flammability

CLASSES OF REFRIGERANTS	LFL [$kg.m^{-3}$]	index of spread of fire [cm/s]	PCL [MJ/kg]
Class 1	Without origin of flames		
Class 2	> 0,10	-	< 19
Class 2L	-	< 10	-
Class 3	< 0,10	-	> 19

The bottom limit of flammability with the LFL limit is used to assess refrigerants according to their flammability. The flammability classes of refrigerants depend both upon the LFL index [kg.m^{-3}] and upon the amount of burned heat PCL [MJ/kg], see Tab. 2. Toxicity and flammability serve for dividing refrigerants into safety classes, as shown by Tab. 3.

Table 3. Safety classes of refrigerants

REFRIGERANT FLAMMABILITY	REFRIGERANTS with low toxicity		REFRIGERANTS with high toxicity	
	mark	refrigerant	mark	refrigerant
Class 1	A3	hydrocarbons	B3	doesn´t exist
Class 2	A2	R152	B2	R30
Class 2L	A2L	R32, HFO	B2L	R717
Class 3	A1	CO_2, synthetic	B1	R123

Another indicator, maximum fill of refrigerant, is given by PED (Pressure Equipment Directive), determining groups that define the type of gas related to the respective classification of liquids according to PED, namely groups 1 and 2 [European Regulation No. 68, 2014]. The first group comprises dangerous liquids characterized by problematic features – flammable, explosive, toxic and causing oxidation. The second group involves safe liquids not mentioned in group 1. The highest amount of a certain refrigeration fill in a given system and environment is determined by the practical limit of refrigerant. Considering the options of emplacing a certain refrigerant system and refrigerant medium in a certain environment requires the knowledge of refrigerant properties, its flammability, toxicity and safety class, the location of the cooling equipment (direct, indirect, outside of the occupied spaces or in their interior), the categories of approach to the occupied spaces and some further aspects (such as the respective volume). Then the maximum amount of the gaseous refrigerant in the occupied space is determined so as to avoid any subsequent requirements relating to the evacuation of the place. Examples of classifying refrigerant media to the respective practical limits are shown by Tab. 4.

Table 4. Practical limit

REFRIGERANT	SAFETY CLASS OF REFRIGERANT	PRACTICAL LIMIT [kg.m^{-3}]	LFL [kg.m^{-3}]
R22	A1	0,3	non-flammable
R32	A2L	0,061	0,307
R1234yf	A2L	0,058	0,289

Other circumstances to be assessed comprise the occupied space, namely the space within the building facility that is enclosed by structures (walls, ceiling, building envelope) wherein persons can appear for a considerable time. These can be also rooms accessible to the public, including uninformed persons, e.g. in hospitals. Another category contains rooms with supervision, used by persons repeatedly, such as production areas. The last option to be mentioned are rooms accessible to authorized persons whose instruction can be anticipated, e.g. specialized laboratories. The fire safety of buildings does not recognize this categorization that can be considered as rather strict. The last important note concerns the sealing of refrigerating systems. There are namely, besides open types of equipment, also two groups of sealed ones [ČSN EN 378-3, 2016]. A semi sealed system is a cooling system where all parts containing refrigerant are sealed by welding, by brazed joints, pressing, threaded connections, flange joints; it can be provided with capped valves and with covered service openings, thus enabling repairs, if need be, or liquidation, and where the tested amount of escape of one joint lies under 5 g per year under the pressure of at least one fourth of the maximum permissible pressure A sealed system is a cooling system where all parts containing refrigerant are sealed by welding, by brazed joints or similar not dismountable connections; it can be provided with capped valves and with covered service openings, thus enabling repairs, if need be, or liquidation, and where the tested amount of escape of one joint lies under 3 g per year under the pressure of at least one fourth of the maximum permissible pressure.

EXPERIMENT – DETERMINATION OF MAXIMUM REFRIGERANT FILL AND FIRE SAFETY EVALUATION

At the present day flammable refrigerants A2 and A2L are getting ever broader popularity. The following example will show the necessity to aerate the occupied rooms wherein they are located. It is necessary to consider proper ventilation of occupied spaces, i.e. rooms where the presence of persons can be anticipated, as early as in the design phase. If it holds that Q x RCL/10 < 1, the through-flow of air shall be drafted under the following equation [ČSN EN-3, 2016]:

$$m = -\frac{10 \times V}{Q} \times ln\left(1 - \frac{Q \times RCL}{10}\right) \quad (1)$$
, where:

m refrigerant fill [kg],
V volume of the refrigerated space [m^3],
10 expected maximum nominal escape [m^3/h],
Q flowing air passage by ventilation [m^3/h],
RCL limit refrigerant concentration [kg/m^3] under [ISO 817, 2014].

In the opposite case the relation changes to take the form:

$$Q = \frac{10}{RCL}, \quad (2).$$

The above makes it obvious that the fill of refrigerant is a function of the volume of the cooled space, the through-flow of air by ventilation and the RCL value. The latter amounts, e.g. for refrigerant R1234yf, RCL = 0,058 $kg.m^{-3}$. This linear dependence, see Fig. 2, enables the determination of the refrigerant fill for a certain volume of the room. Values of fill that have been calculated can be converted to fire charge [Regulation No. 23/2008], where 1 l of flammable liquid stands for 2,5 $kg.m^{-2}$ fire charge, see Tab. 5.

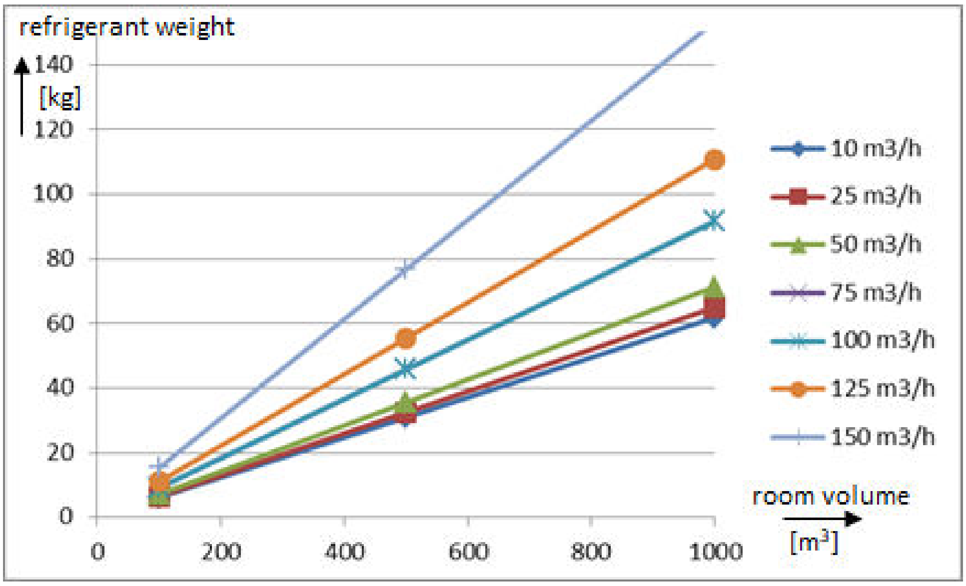

Figure 2. Dependence of refrigerant charge R1234yf on the volume of occupied space at different air through-flow ventilation values.

Table 5. Determination of refrigerant fill for a given air flow by ventilation Q [m^3/h] and fire load resulting of this fill for refrigerant R1234yf at space´s volume V = 100 [m^3]

Q [m^3/h]	Calculated refrigerant fill [kg]	Fire risk of given amount of refrigerant
50	7,13	17,825
25	6,50	16,250
10	6,18	15,450

DISCUSSION

Supposing that the occupied space are rooms of office character with given fire risk 42 kg.m^{-2} [ČSN 730802, 2009], the values characterizing the fire load in such area can be assessed as high. Taking into account that in the case of escaping R1234yf into current environment the substance in question is a gas already, it is not clear where such load should be accounted for within the refrigerated space. Let us underline that the cooling apparatus is a sealed system, namely one with joints that are hermetically tight and not dismountable. Under conditions of current operation the prerequisite can be accepted that the refrigerant medium remains within the circuit and need not be reflected in the calculation of the fire risk of the refrigerated rooms.

CONCLUSIONS

Flammable refrigerants are difficult to classify from the viewpoint of the fire safety of buildings. It is obvious that a cooling circuit shall be considered as a closed technological apparatus. An option to classify flammable liquids was left out of consideration in the course of processing the problems, accordingly, the issue relates to flammable gases. Their occurrence within the space will continue to be limited by maximum fill, as stipulated by standard [ČSN EN 378-1, 2016] and regarding the fire safety of buildings the space will be monitored in accordance with the amount of flammable refrigerant on the appropriate level of technical safeguards (independent detectors, detection combined with electrical fire alarm system). After all, the application of flammable refrigerants is still at its beginnings and their integration into the system of evaluating the fire safety of buildings can be expected to develop further.

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