Ventilated Enclosures for Flammable Refrigerants

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If your heat pump application needs almost 5 kg of R-290 or 40 kg of R-32 to be placed indoors, then the safety standards offer the option of placing the system in an enclosure, and ventilating it to the outdoors.
In this article we will look at the requirements for a ventilated enclosure and what variations of this concept that may be relevant for the heat pump industry.

Introduction

In previous papers in the HPC Newsletter, the author has given an overview of the trends, legislation and standards for flammable refrigerants [1] and an overview of charge limits for heat pumps with flammable refrigerants [2]. However, the concept of "Mechanical Ventilation Within the Appliance Enclosure" or simply "Ventilated Enclosure" was not covered, as it is a complex topic and so important that it needs its own paper.

The first part of this paper is a brief introduction to the standards governing the domestic and light industrial heat pumps, with focus on the EU. This is followed by a description of the formal requirements for mechanical ventilation within the appliance enclosure, valid also for areas outside of the EU. The paper ends with a description of how the risk assessment approach can be used to modify the requirements from the system standards for a ventilated enclosure while still ensuring that the resulting system is safe.

Standards for heat pumps

The international application standard for domestic and light industrial heat pumps is IEC 60335-2-40 edition 5.1 from 2016 (this is the version from 2013 plus an amendment). In Europe, an older version of this standard is used with small modifications as EN 60335 -2-40, and is harmonised to both the EU Machinery Directive and the EU Low Voltage Directive. Unfortunately, at the time of writing, the EN version is still based on the IEC 60335-2-40 edition 4 from 2002; although the EN version has been amended multiple times it is outdated in several aspects. Work is ongoing to create a new EN version, but has been delayed for several reasons. Still this author hopes that 2017 will be the year that a new EN 60335-2-40 will be published.

ISO 5149 is another international standard, which in principle covers all systems, including heat pumps. However, it is preferred to use the application-specific standard EN or IEC 60335-2-40. Still, it is worthwhile

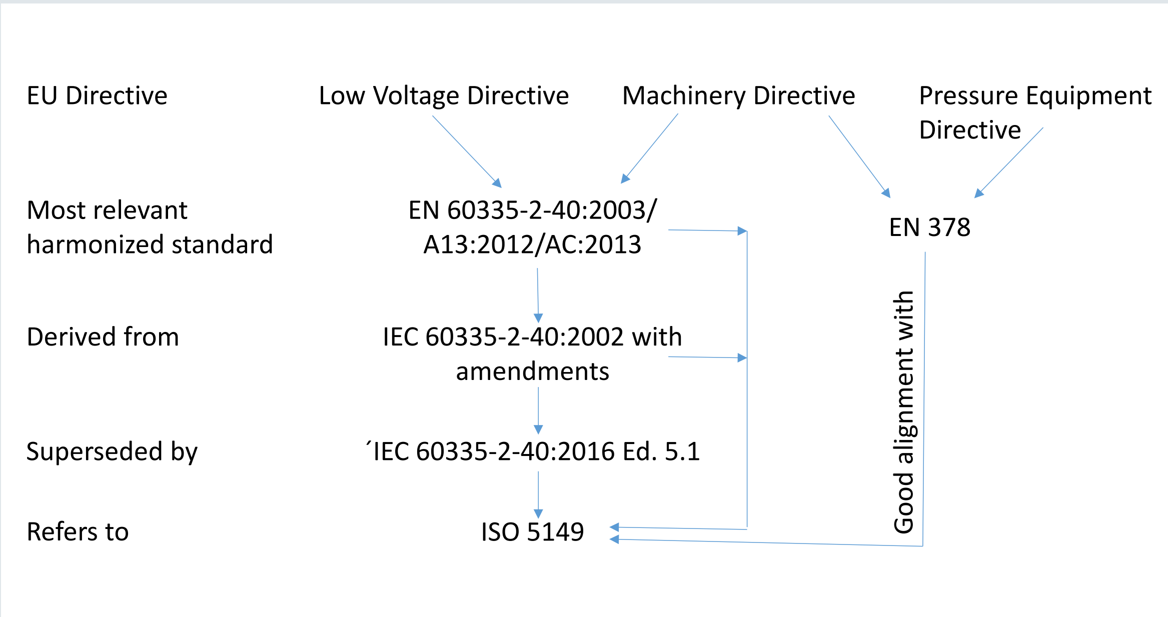

Figure 1. Relation between the standards and EU legislation.

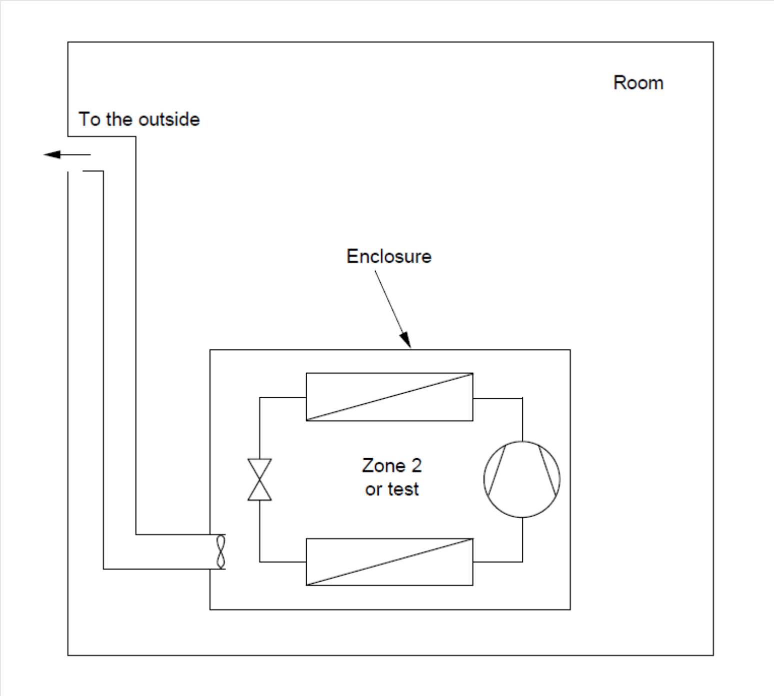

Figure 2. Illustration of ventilated enclosure from IEC 60335 2 40.

to consider ISO 5149, and in some cases it is even required by EN or IEC 60335-2-40. EN 60335-2-40 requires safety requirements of ISO 5149 to be followed as part of the clause on mechanical strength. The newer IEC 60335-2-40 is a bit more specific, as it only requires ISO 5149 to be followed for construction strength and for aspects not already covered by the IEC standard.

In the EU, there is also the EN 378 which covers all systems, such as the ISO 5149. EN 378-2 is harmonized to the EU Pressure Equipment Directive and for flammable refrigerants. Systems with pipes greater than DN25 or vessels with volume times maximum allowable pressure greater than 50 bar·l typically need to comply with the Pressure Equipment Directive. The easiest way to comply with the Pressure Equipment Directive is typically to follow EN 378-2.

The conclusion is that the primary standard to consider is EN or IEC 60335-2-40, but both EN 378 and ISO 5149 may be relevant. Luckily, the requirements of the three standards are quite similar, and especially the EN 378 and ISO 5149 are well aligned.

Mechanical ventilation within the appliance enclosure

EN and IEC 60335-2-40 use the term "mechanical ventilation within the appliance enclosure" to cover a box surrounding the refrigerating system which is ventilated through a ventilation duct to the outside and prevents air from moving from the refrigerating system to the room outside the box. EN 378 and ISO 5149 do not use this term, but simply call it a "ventilated enclosure".

The reason for using this ventilated enclosure is that leaking refrigerant is much less dangerous if it is ventilated to the outside, and the system builder is rewarded by being allowed 5 times larger flammable refrigerant charges than would normally be allowed indoors in very large rooms. This is enough to cover most heat-pump applications.

The charges allowed is one of the issues where EN 60335-2-40 does not agree with IEC 60335-2-40. The charges depend on the LFL, the Lower Flammability Limit of the refrigerant, which is the lowest concentration of refrigerant in air which can be ignited. Below the LFL, the air/refrigerant mixture is too thin to be flammable. The allowed charges also depend on the flammability class, which is either 3 for higher flammability, 2 for flammability or 2L for lower flammability. These flammability classes are normally written together with the toxicity class, and in this article we will only consider toxicity class A, lower toxicity. The safety classes are therefore A3 (for instance R-290), A2 (for instance R-152a), or A2L (for instance R-32 and R-1234ze).

EN 60335-2-40 allows charges up to 130 m^3 × LFL for A3, A2 and A2L refrigerants. IEC 60335-2-40 along with ISO 5149 and EN 378 also allows charges up to 130 m^3 × LFL for A3 and A2, but up to 195 m^3 × LFL for A2L refrigerants.

For A3 refrigerants (such as hydrocarbons) the charge is typically just below 5 kg (e.g., for R-290 the LFL is 0.038 kg/m^3 and 130 m^3 × 0.038 kg/m^3 is 4.94 kg). For A2L refrigerants (like R-32 and R-1234ze(E)) the charge according to EN 60335-2-40 is typically just below 40 kg, but according to IEC 60335-2-40, ISO 5149 and EN 378 it is typically just below 60 kg.

To allow larger charges, there needs to be a ventilation duct leading to the open air. For some heat pumps, such as typical sanitary hot water heaters or heat pumps reclaiming waste heat, this is not an issue, while for other heat pumps this adds an extra complication to the installation of the heat pump. ISO 5149 also allows the ventilation to go to a sufficiently large room, although for most applications this option is not of interest.

To ensure that the refrigerant does not leak out of the enclosure, the ventilation needs to create a pressure at least 20 Pa below atmospheric pressure and the ventilation rate needs to be high enough to remove the total refrigerant charge within 1 minute, and not less than 2 m^3/h. For 0.988 kg R-290 (density 1.80 kg/m^3) this is 33 m^3/h, while for 5 kg R-32 (density 2,13 kg/m^3) it is 131 m^3/h and for a R-1234ze(E) (density 4.66 kg/m^3) chiller with a charge of 50 kg it is 645 m^3/h.

The ventilation has to either run continuously or be started by a signal from a gas detector. The ventilation needs to be monitored, and if the ventilation fails, then the compressor needs to be switched off. If the ventilation is controlled by a gas detector, any failure needs to result in the system going into a safe-mode. The safe mode is not described in detail in the standards, and is left for the system builder to define.

From a practical point of view, today's energy efficiency requirements make continuous ventilation difficult. Even for sanitary hot water heaters and heat pumps with heat reclaim, where ventilation air is fed through the heat pump, it can be difficult to maintain ventilation when heating is not needed. This leads to either choosing the gas detector option, or to consider alternatives with a risk assessment. More on this later.

Both EN 378 and ISO 5149 require the room where the appliance is installed to be at least 10 times the volume of the appliance and with sufficient make-up air to replace any air exhausted. This is, however, not a requirement in the application standards EN and IEC 60335-2-40, but the need to replace any air exhausted is fundamental if air is taken from the room where the appliance is installed. A practical solution to this is often to have two ventilation ducts, one letting air from the outside into the appliance, and another one for the exhaust air. In this case, the risk of air re-entering from the air exhaust to the air intake needs to be considered.

Ignition sources are not allowed where leaked refrigerant could be ignited. This means that there should not be any ignition sources inside the enclosure or in the ventilation duct. Avoiding ignition sources can be achieved by selecting ATEX or IECEx components. There are other alternatives in EN and IEC 60335-2-40 clause 22.116 which may be cheaper when mass-producing components or systems.

Variation with risk assessment

Often it is easy for systems to match most of the requirements of standards, but on a few points the requirements can be impractical or do not fit with the conditions of the specific application. In these cases it is usually permissible to apply a risk assessment to cover these last requirements.

In the EU system, the logic is that the safety directives such as the Low Voltage Directive, Machinery Directive, and Pressure Equipment Directive give a list of "essential requirements", where the manufacturer has to comply with those which are applicable for the product. As shown in Figure 3, there are two pathways to complying with the applicable essential requirements. The most commonly used is to comply with a harmonized standard, but it is also allowed to use any other specification, for instance the manufacturer's own specification. When using another specification, the manufacturer cannot presume conformity with the essential requirements; instead the manufacturer has to show, through a risk assessment, that the specification covers the essential requirements.

The essential requirements of the directives are sometimes written very broadly, and it is difficult to prove that the specification used actually covers a specific essential requirement. For instance, the Low Voltage Directive requires "that persons and domestic animals are adequately protected against the danger of physical injury or other harm which might be caused by direct or indirect contact", which is not an easy thing to prove. In these cases the preferred approach to using an "other specification" is to follow a harmonized standard except for the few details which are impractical or do not fit. For these few details a thorough risk assessment is created to ensure that the solution actually used is safe.

For ventilated enclosures, the risk assessment approach can for instance be used if the required ventilation rate or the required sub-atmospheric pressure cannot be achieved without too large an impact on the energy efficiency or cost of the system.

When choosing a risk assessment to replace a requirement in a standard, the first step is to identify the purpose of the requirement. In the case of ventilation rate and negative pressure the purpose has to be to keep any leaking refrigerant from getting into the room surrounding the enclosure to create a sufficient concentration to be ignited. See Figure 3.

A manufacturer is free to choose a way of making the system safe with less ventilation, and the below should be seen as an inspiration list rather than a limited set of choices.

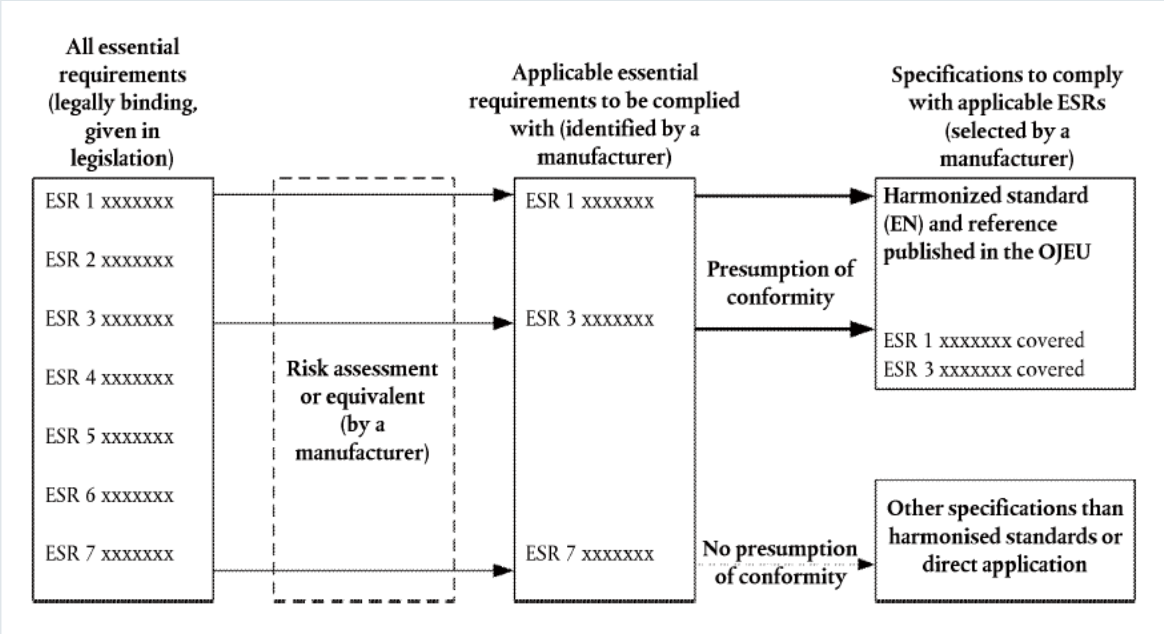

Figure 3. Product safety requirements from EU Blue Guide.

An option would be to simulate the airflow inside the enclosure with Computational Fluid Dynamics (CFD) to prove that the lower ventilation rate will keep a refrigerant leak inside the enclosure. The simulation can also be replaced with tests where refrigerant or a gas with similar density is leaked inside the enclosure (R-290 and CO_2 happen to have the same density).

For these simulations or tests it is necessary to use a relevant leak rate. The leak rate used for small systems in the safety standards are the full charge leaking in 4 minutes. For most systems this leak rate is too high, but rather too high than too low. If the "4 minute leak rate" is too high, then tests on the system can be used to determine what a realistic worst case is.

Another option would be to make the enclosure very tight, and have make-up air coming through a ventilation duct. The risk of refrigerant leaking to the room is handled by the tightness of the enclosure, so the purpose of the ventilation is only to ensure that the leaked refrigerant does not create a permanent flammable atmosphere inside the enclosure. The ventilation rate can be very low, and the ventilation "ducts" could have a very small diameter. In this case the enclosure would need to be tested for tightness at a small pressure differential to the surroundings.

Other options which may be considered are the ability to replace the gas detector with an algorithm monitoring the pressures and temperatures in the system and detecting leakage that way, or showing that the amount of refrigerant leaking from the enclosure is too small to present a hazard, or feel free to come up with your own ideas.

What is important is that a thorough risk assessment is carried out. The details of doing risk assessments are outside the scope of this article, but the reader needs to keep in mind that a risk assessment is a team effort, where risks are identified, categorised and addressed. The process is normally facilitated by tools and involves considering the whole lifecycle of the system. The difficult point in risk assessments is typically to determine when a risk is sufficiently small to be ignored. A good rule of thumb is that two or more unlikely events at the same time can be ignored, but not without first considering whether they really are that unlikely.

Conclusions

The concept of mechanical ventilation within the appliance enclosure, or simply ventilated enclosure, is important for heat pumps as it allows up to 5 kg hydrocarbon refrigerant or 40 kg or more of A2L refrigerant.

According to the safety standards, the ventilation rate needs to be high enough to create a pressure at least 20 Pa below atmospheric pressure and high enough to remove the complete refrigerant charge in 1 minute. The ventilation can either be continuous and monitored, or it can be triggered by a gas detector.

If specific requirements are either impractical or do not fit the application, then it is possible to replace them with a risk assessment of the actual specifications used. This allows the use of lower ventilation rates with sufficient evaluation of safety.

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[7] IEC 60335-2-40:2016 Ed. 5.1. *Household and similar electrical appliances* – Safety – Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers.

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