MONTREAL PROTOCOL

ON SUBSTANCES THAT DEPLETE

THE OZONE LAYER

UNEP

REPORT OF THE
TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL

MAY 2017

VOLUME 3

DECISION XXVIII/4 TASK FORCE REPORT
SAFETY STANDARDS FOR FLAMMABLE
LOW GLOBAL-WARMING-POTENTIAL (GWP) REFRIGERANTS

UNEP
May 2017 Report of the Technology and Economic Assessment Panel
Volume 3

Decision XXVIII/4 Task Force Report
Safety Standards for Flammable Low Global-Warming-Potential (GWP) Refrigerants

Montreal Protocol
On Substances that Deplete the Ozone Layer

Report of the
UNEP Technology and Economic Assessment Panel

May 2017

Volume 3

DECISION XXVIII/4 TASK FORCE:

SAFETY STANDARDS FOR FLAMMABLE
LOW GLOBAL-WARMING-POTENTIAL (GWP) REFRIGERANTS

The text of this report is composed in Times New Roman.

Co-ordination:	**TEAP and its XXVIII/4 Task Force**
Composition:	Roberto Peixoto and Fabio Polonara
Layout:	Fabio Polonara
Final formatting:	Ozone Secretariat
Reproduction:	UNON Nairobi
Date:	May 2017

Under certain conditions, printed copies of this report are available from:

UNITED NATIONS ENVIRONMENT PROGRAMME
Ozone Secretariat, P.O. Box 30552, Nairobi, Kenya

This document is also available in portable document format from:
http://www.ozone.unep.org/

Printed in Nairobi, Kenya, 2017

ISBN: 978-9966-076-28-1

UNEP
MAY 2017 REPORT OF THE
TECHNOLOGY AND ECONOMIC
ASSESSMENT PANEL
VOLUME 3

DECISION XXVIII/4 TASK FORCE REPORT
SAFETY STANDARDS FOR FLAMMABLE
LOW GLOBAL-WARMING-POTENTIAL (GWP)
REFRIGERANTS

DISCLAIMER

The United Nations Environment Programme (UNEP), the Technology and Economic Assessment Panel (TEAP) co-chairs and members, the Technical Options Committee, chairs, co-chairs and members, the TEAP Task Forces co-chairs and members, and the companies and organisations that employ them do not endorse the performance, worker safety, or environmental acceptability of any of the technical options discussed. Every industrial operation requires consideration of worker safety and proper disposal of contaminants and waste products. Moreover, as work continues - including additional toxicity evaluation - more information on health, environmental and safety effects of alternatives and replacements will become available for use in selecting among the options discussed in this document.

UNEP, the TEAP co-chairs and members, the Technical Options Committee, chairs, co-chairs and members, and the Technology and Economic Assessment Panel Task Forces co-chairs and members, in furnishing or distributing the information that follows, do not make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or utility; nor do they assume any liability of any kind whatsoever resulting from the use or reliance upon any information, material, or procedure contained herein.

Although all statements and information contained in this XXVIII/4 report are believed to be accurate and reliable, they are presented without guarantee or warranty of any kind, expressed or implied. Information provided herein does not relieve the reader from the responsibility of carrying out its own tests and experiments, and the reader assumes all responsibility for use of the information and results obtained. Statements or suggestions concerning the use of materials and processes are made without representation or warranty that any such use is free of patent infringement and are not recommendations to infringe on any patents. The user should not assume that all toxicity data and safety measures are indicated herein or that other measures may not be required.

ACKNOWLEDGEMENT

The UNEP Technology and Economic Assessment Panel and the XXVIII/4 Task Force co-chairs and members wish to express thanks to all who contributed from governments, both Article 5 and non-Article 5, furthermore in particular to the Ozone Secretariat and the Multilateral Fund Secretariat, as well as to a large number of individuals involved in Protocol issues, without whose involvement this Task Force report would not have been possible.

The opinions expressed are those of the Panel and its Task Force and do not necessarily reflect the reviews of any sponsoring or supporting organisation.

TEAP thanks PETRA Engineering Ltd of Jordan for hosting the TF meeting on 17 March 2017 where all the elements for this report were first discussed and Keiichi Onishi for hosting the TEAP meeting, 2-6 May 2017, where, after review, decisions were taken for the drafting of the final parts of the report before submission.

Foreword

The May 2017 TEAP Report

The May 2017 TEAP Report consists of 4 volumes:

Volume 1: 2017 TEAP Progress Report

Volume 2: CUN Interim Report

Volume 3: Decision XXVIII/4 Task Force Report on Safety Standards Relevant for Low GWP Alternatives

Volume 4: Decision XXVIII/5 Task Force Report: Assessment of the Funding Requirement for the Replenishment of the Multilateral Fund for the Period 2018-2020

The UNEP Technology and Economic Assessment Panel (TEAP):

Bella Maranion, co-chair	USA	Kei-ichi Onishi	J
Marta Pizano, co-chair	COL	Roberto Peixoto	BRA
Ashley Woodcock, co-chair	UK	Fabio Polonara	I
Paulo Alto	BRA	Ian Porter	AUS
Mohamed Besri	MOR	Rajendra Shende	IND
Suely Carvalho	BRA	Helen Tope	AUS
Adam Chattaway	UK	Dan Verdonik	USA
Marco Gonzalez	CR	Shiqiu Zhang	PRC
Sergey Kopylov	RF	Jianjun Zhang	PRC

UNEP
MAY 2017 REPORT OF THE
TECHNOLOGY AND ECONOMIC
ASSESSMENT PANEL

DECISION XXVIII/4 TASK FORCE REPORT
SAFETY STANDARDS FOR FLAMMABLE
LOW-GLOBAL-WARMING-POTENTIAL (GWP)
REFRIGERANTS

Table of Contents **Page**

Executive summary

ES.1 Introduction

In response to Decision XXVIII/4, this report provides the following information from TEAP:

- The progress in the revision of International safety standards relevant for flammable low-GWP alternatives by the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO) and other International Standards bodies.
- Information on risk assessments and their relevance to safety standards.
- The implications of International Standards for the implementation of the decisions of the Meeting of the Parties to the Montreal Protocol on the accelerated phase-out of HCFCs and HFC control measures, and gives recommendations to the parties.

In Sections ES2, ES3, ES4, ES5 and ES6, highlights and technical summaries of the report's five main chapters are provided. Section E7 includes the concluding remarks and the recommendations to parties.

ES.2 International Standards for R/AC&HP equipment (Chapter 2)

- There are four different types of safety standards: basic safety standards, group safety standards, product safety standards, and standards containing safety aspects.
- Within the R/AC&HP sector, there are currently nine main safety standards that cover whole systems, appliances, and products. Five are product safety standards and four are group safety standards.
- If a product safety standard is available for the specific product or equipment of interest, then it should be used in preference to a group safety standard. However, unless national legislation mandates a particular product safety standard, then the choice is voluntary.
- International safety standards do not override national legislation, however, safety standards are commonly referenced or copied into national legislation.
- Whilst the standards discussed are International Standards, these are seldom used directly. Most countries will adopt a standard nationally or regionally. For national adoption, many countries will include national modifications or deviations. In some instances national legislation may conflict with the text within the International Standard.
- The standards discussed in this chapter do not cover all aspects of the lifecycle. For example, the competences of the service technicians are especially important for the safety throughout the life cycle. To address the full lifecycle, the use of safety standards needs to be supplemented with a risk assessment.
- Standards are often expensive, complex and not available in the local language, and therefore cannot serve as a direct source of knowledge for technicians and contractors.
- Compliance with safety standards plays an important role when substantiating that the safety of a system is according to recognized good practice. This is important for companies for managing the legal risk associated with selling systems or services associated with systems.
- Since many enterprises operate internationally, there is a preference for the requirements of a standard to be universal, with national variations kept to the minimum.

ES.3 General composition and working procedures of International Standards (Chapter 3)

Important considerations on how and why ISO and IEC standard procedures are effective, however, also encounter limitations, include:

- Issues related to the global relevance of the International Standards.
- The working procedures and the formal stages for international standard developments.
- Opportunities for stakeholders to participate in the different standardization committees and working groups.
- Expert standardization work is time-consuming and expensive and often limited to large market participants, since sophisticated engineering knowledge and safety statistics are required.
- In some parties, expert participation in standardization committees is limited and / or expensive.

ES.4 Risk assessments and other technical work applicable to standards development (Chapter 4)

- The development of safety standards should be based on systematic consideration of refrigerant releases resulting in hazards, use and application characteristics of the R/AC&HP equipment, and the implications of the measures so as to minimise the likelihood of detrimental consequences to persons and property.
- ISO and IEC publish guidelines on how safety hazards should be handled when developing standards and a large part of this is through risk assessment approaches. When developing safety standards, the relevant literature can help to shape the requirements.
- When assessing the flammability aspects of refrigerants, the general areas of interest are: flammability characteristics, release/leakage characteristics, dispersion behaviour of leaked refrigerant, potential sources of ignition, consequences of ignition including formation of decomposition products and risk mitigation systems/functions, as well as the combination of these within overall risk assessment.
- The published literature these areas is fairly extensive and is increasing as interest in flammable alternative refrigerants grows. In addition to the material specifically related to R/AC&HP, there is a large body of literature related to general flammability risk of hydrocarbons.
- Many of the topics in the published literature are being taken into account in the development of amendments and revisions of the applicable standards.
- However, the value of technical literature can be limited by the subjective opinions of the participants involved in standards development which play a role in achieving consensus. Nevertheless, the evolution of understanding of the technical concepts related to flammability in R/AC&HP equipment should be reflected by improvements in the proposed requirements.
- Whilst the consequences of ignition of higher flammability substances such as hydrocarbons have been widely studied for many decades, work on fluorinated substances classed as A2L is in its infancy. As new research is carried out, understanding of their behaviour is evolving rapidly.
- Whilst small-scale experiments have previously shown that the severity of certain primary consequences of ignition is strongly dependent upon the relatively low laminar flame speed, some large/full scale experiments have yielded “unexpected” behaviour such as rapid pressure build-up and turbulent burning, which are indistinguishable over a range of laminar flame speeds. Accordingly it may be necessary to carry out more thorough investigations into unanticipated consequences. There are now several research projects planned which address some of these topics.

ES.5 Standards development and applicability to R/AC&HP sector (Chapter 5)

Chapter 5 describes the representation of countries in the committees responsible for R/AC&HP standards, as well as liaison and working groups (WG). A progress summary of the activities under the various standards is provided, where it concerns developments applicable to alternative refrigerants.

- At ISO and IEC level, there are at least five technical subcommittees responsible for the relevant safety standards, with working groups who are developing the major amendments and/or revisions of the safety standards that are concerned with alternative refrigerants.
- IEC SC61C is responsible for IEC 60335-2-24 (domestic refrigeration) and IEC 60335-2-89 (commercial refrigeration appliances). WG4 is developing an amendment to IEC 60335-2-89 to increase the charge limits for flammable refrigerants; it has 30 members from 16 parties (three are from Article 5 parties).
- IEC SC61D is responsible for IEC 60035-2-40 (air conditioners and heat pumps). WG9 is developing an amendment for extended applicability of A2L refrigerants; it has 32 members from 13 countries (two are from Article 5 parties). WG16 is developing an amendment for increasing allowable charge (relative to room size) for A2 and A3 refrigerants; it has 27 members from 12 countries (three are from Article 5 parties).
- ISO TC86 SC1 is responsible for ISO 5149 (the horizontal standard for all R/AC&HP systems). WG1 is working on a revision, which is hoped to include improvements for all flammable refrigerants; it has 52 members from 12 countries (one is from an Article 5 party). One non-industry NGO is joining with 4 experts.
- ISO TC22 SC34 is responsible for ISO 13043, but does not have any activities related to revising the standard (although it only addresses one flammable low GWP refrigerant, HFO-1234yf, and one other low GWP, R-744).
- ISO TC104 SC2 is responsible for ISO CD 20854, a new safety standard for reefer container using flammable refrigerants, describing requirements for design and operation.
- The projected publication dates for these amendments and standards is uncertain due to the nature of the process, but depending upon the WG, changes are expected between 2018 and 2030 for the horizontal standards and between 2018 and 2025 for product standards.
- Irrespective of the tasks of the WGs, most of these standards are subject to continuous improvements through regular (at least annual) amendments, albeit at a smaller scale.
- Relatively few stakeholders participate in the process for R/AC&HP safety standards, and an even smaller number effectively dominate the SC (Subcommittee) and WG activities. This is because of the way the standards development rules have evolved, as well as the onerous investment costs and resources needed for active participation.
- However, there are several options for interested parties to actively participate in relevant national committees and SCs, ranging from commenting on proposals and voting positions, participating in SC meetings, contributing to WGs, carrying out background technical work, etc. However, in some parties, membership of national committees can also be prohibitively costly or can be restricted and thus active participation in standard development may effectively be closed to some stakeholders.

ES.6 Assessment of the implications of International Standards for the implementation of MOP Decisions (Chapter 6)

Chapter 6 presents an assessment of the implications of the International Standards for the implementation of the decisions of the meeting of the parties to the Montreal Protocol on the accelerated phase-out of HCFCs and HFC phase-down control measures

- For non-Article 5 parties in relation to Decision XXVIII/1, the first 10% reduction by 2019 may be largely achieved by a reduction of controlled substance consumption combined with a conversion in non-R/AC&HP sectors, implying that little change in the selection of refrigerant types is needed in the short term. The usual process is that National Standards and regulations map onto the International Standards. However, a small number of countries have more stringent regulations than the international safety standards for flammable refrigerants. Such regulations may inhibit the local implementation of certain lower GWP alternatives.

- Accelerated revision of National Standards (and regulations) will facilitate the use of lower GWP refrigerants and assist non-Article 5 and Article 5 parties in achieving the agreed freeze and phase-down steps under Decision XXVIII/1.
- Given the typical 5-year lead time for product development, in the case of non-Article 5 parties in relation to issues under Decision XXVIII/1, international safety standards to be published in 2019-2020 will play an important role in the development of national regulations which should be applicable by 2024.
- Attention should be paid to the prescribed reduction percentages as these should be added to the market growth (in %, expressed in CO_2-eq.) as of the freeze year, yielding the total reduction required in a control step year. On the other hand, actions including reuse, recover and destruction are likely to have a positive impact on achieving the reduction percentage targets. These aspects are linked to the feasibility of achieving the required reductions in the different sectors within the context of the refrigerant choice and its safe application in the revised International Standards and national regulations.
- For Article 5 parties and the future reduction steps under Decision XXVIII/1, it is difficult to predict the aggregated HFC consumption levels during the period 2019-2024, with the accelerating technical developments in the different sectors (such as foam blowing, fire protection, technical aerosols and R/AC&HP). National regulations applicable by 2029 will have resulted from International Standards developed by 2024, with the possibility of several revisions of the current international safety standards.
- Article 5 parties with not yet converted R/AC&HP equipment manufacturing activities may be required to switch to HCFC alternatives to comply with Decision XIX/6. Currently, only HFC-32, HC-290 and possibly some of the new low and medium GWP A2L HFC/HFO blends are available options. Some Article 5 parties may find HFC-32 and the A2L HFC/HFO blends to be interim options since resulting GWP based consumption levels may affect their future compliance with Decision XXVIII/1. HFC-32, the HFC/HFO blends and HC-290 are all flammable to a certain degree, where current standards limit their application in larger than e.g. 5 kW room AC and multi split systems. Handling flammable refrigerants in Article 5 countries also requires significant quality improvement for manufacture, installation, service and end-of-life. Currently there are some gaps in addressing these aspects in the International Standards, particularly for the installation, service and end-of-life.
- A number of AC applications have a risk assessment combined with additional mitigation to allow the refrigerant charges needed. Work is ongoing in the standardisation organisations to allow the refrigerant charges needed provided a series of forms of mitigation are implemented. The timing of these updates and especially the speed of acceptance of these updates in national legislations will affect which technologies will be available to replace high-GWP refrigerants.
- A challenging question is when revisions of International Standards, which are currently underway (that will apply to the 40% reduction to be achieved in 2024 for non-Article 5 parties), will then have been transferred to Article 5 parties' National Standards and regulations. This would enable flexibility in the refrigerant choice for these parties with early selection of low GWP alternatives that could contribute to a lower CO_2-eq. total consumption and to a lower freeze level.

ES.7 Concluding remarks and recommendations to parties

- The current international safety standards impose varying degrees of restriction on the application of certain medium and low-GWP alternatives, depending upon the type of refrigeration system and the location of refrigerant in the equipment. Whilst it is “technically feasible” to use almost all class A flammable refrigerants in all applications, the critical issue is whether or not a given alterative can be used in a safe and cost-effective way using state-of-the-art system architectures.

- Broadly, there are four levels of constraints that the various international safety standards pose to flammable refrigerants: (i) the scope of the standard excludes the refrigerant(s) totally, or above a certain quantity; (ii) the technical requirements prohibit charges above a certain (absolute) quantity for a given type of system and/or place of installation; (iii) the requirements prohibit charges above a certain quantity in relation to a room size; and (iv) the requirements are sufficiently onerous that equipment costs would be commercially prohibitive. The severity of each level of constraint varies according to refrigerant, type of application and location of refrigerant in the equipment.
- Generally, the most critical situations concerning restrictions are:
    - A2 and A2L refrigerants in domestic refrigeration,
    - all flammable refrigerants in commercial refrigeration appliances,
    - A2 and A3 refrigerants in commercial refrigeration systems,
    - A2 and A3 refrigerants in small air conditioning and heat pump appliances and systems,
    - all flammable refrigerants in large air conditioning appliances, and
    - all flammable refrigerants (except HFO-1234yf) in MAC systems.

Parties may wish to consider:

- Funding and support for education and training of technicians handling and using flammable refrigerants
- Identifying what types of systems/equipment/applications are of national interest and determine whether technical limitations exist due to current safety standards.
- Encouraging and supporting national experts' participation at national and international level. Provide funding as and where necessary and try to ensure such funding is guaranteed on a long-term basis (recognising that effective interventions in the standards development process normally take many years).
- Actively supporting technical and research activities, data gathering, etc. to help contribute to new and/or improved requirements that reflect the national interests.
- Enabling rapid transfer of International-Standards for flammable refrigerants into national regulations. This would ensure that revisions of International Standards underway will apply to Article 5 parties' National Standards and regulations (where applicable). In this way the flexibility in the refrigerant choice for these parties could be improved, and this may then contribute to lower CO_2-eq. HFC consumption and to a lower (future) freeze level.
- Setting up mechanisms to avoid delays in introducing lower GWP substances e.g., quota credits for early implementation in one sector to balance against another sector where implementation is expected to be slower.
- Establishing ways to disseminate competence on safety standards within their programs for the education of competent personnel for service and maintenance. Currently the cost of standards and guidelines is prohibitive for technicians and contractors in Article 5 parties.

1 Introduction

1.1 Terms of Reference for the XXVIII/4 Task Force report

Decision XXVIII/4 of the Twenty-eight Meeting of the Parties requested the Technology and Economic Assessment Panel (TEAP) to prepare a report for consideration by the Open-ended Working Group at its 39th meeting in Bangkok in July 2017.

The text of Decision XXVIII/4 ("Establishment of regular consultations on safety standards"), as it relates to this report is as follows:

Decision XXVIII/4	*Noting* that parties recognize the importance of the timely updating of International Standards for flammable low-global-warming-potential (GWP) refrigerants, including International Standard IEC 60335-2-40 of the International Electrotechnical Commission (IEC), and support the promotion of actions that allow for the safe market introduction, manufacturing, operation, maintenance and handling of zero-GWP and low-GWP refrigerants that are alternatives to hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs),
	Aiming to support the timely revision of relevant standards in a manner that is technology-neutral to enable the safe use and market penetration of low-GWP alternatives,
	1. To request the Technology and Economic Assessment Panel to establish a task force that includes outside experts, as needed:
	(a) To liaise and coordinate with standards organizations, including IEC, to support the timely revision of IEC standard 60335-2-40 and ensure that the requirements for the A2, A2L and A3 categories are revised synchronously using a fair, inclusive and scientifically sound approach;
	(b) To submit to the Open-ended Working Group at its thirty-ninth meeting a report on safety standards relevant for low-GWP alternatives, including on the following: (i) Progress in the revision of international safety standards by the IEC, the International Organization for Standardization (ISO) and other International Standards bodies; (ii) Information concerning tests and/or risk assessments and their results relevant to safety standards; (iii) Assessment of the implications of International Standards for the implementation of the decisions of the Meeting of the Parties to the Montreal Protocol on the accelerated phase-out of HCFCs and HFC control measures, and recommendations to the parties;
	(c) To provide relevant findings to the standards bodies;
	2. To request the Ozone Secretariat to organize a workshop on safety standards relevant to the safe use of low-GWP alternatives back to back with the thirty-ninth meeting of the Open-ended Working Group, within existing resources;
	3. To urge parties to consult and work with their industries and standards bodies to support the timely completion of the processes for developing new standards, harmonizing existing standards and revising current standards that would facilitate the adoption of additional environmentally friendly alternatives to HCFCs and HFCs and the broader deployment of existing such alternatives and allow for their use with a goal of completing such efforts by the end of 2018;
	4. To invite parties to submit to the Ozone Secretariat by the end of 2016

	information on their domestic safety standards relevant to the use of low-GWP flammable refrigerants;
	5. To encourage parties to strengthen connections and cooperation between national and regional standards committees and national ozone units;
	6. To request the Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol to consider maintaining or, if required, increasing the Fund’s technical and capacity-building assistance, in particular through the United Nations Environment Programme's Compliance Assistance Programme, with a view to improving cooperation between national authorities in charge of implementation of the Montreal Protocol and national and regional standards committees;
	7. To consider holding regular consultations on international safety standards with the Ozone Secretariat and relevant International Standards bodies, including IEC and ISO, and regional standards bodies, including the European Committee for Standardization , the European Committee for Electrotechnical Standardization, UL (formerly known as Underwriters Laboratories), the American National Standards Institute, the American Society of Heating, Refrigerating and Air-Conditioning Engineers and others, taking into account the outcomes of the processes mentioned in the present decision.

1.2 Composition of the Task Force

Responding to point (1) of Decision XXVIII/4 TEAP established a Task Force, which composition is as follows:

Co-chairs

- Roberto Peixoto (Brazil, RTOC co-chair)
- Fabio Polonara (Italy, RTOC co-chair)

Members:

- Mohamed Alaa Olama, (Egypt, RTOC member)
- Adam Chattaway (UK, HTOC member)
- Leonilton Tomaz Cleto (Brazil, outside expert)
- Daniel Colbourne (UK, member RTOC)
- Richard DeVos, (USA, member RTOC)
- Sukumar Devotta (India, RTOC member)
- Martin Dieryckx (Belgium, member RTOC)
- Dennis Dorman (USA, member RTOC)
- Rod King (New Zealand, outside expert)
- Holger König (Germany, member RTOC)
- Jay Kohler (USA, outside expert)
- Lambert Kuijpers (The Netherlands, member RTOC);
- Hongqi Li (China, outside expert)
- Tingxun Li (China, RTOC member)
- Maher Mousa (Saudi Arabia, RTOC member)
- Alex Pachai (Denmark, RTOC member)
- Andy Pearson (UK, outside member)
- Brian Rodgers (US, outside expert)
- Dave Rule (US, outside expert)
- Stefano Vit (Italy, outside expert)
- Asbjørn Vonsild (Denmark, member RTOC)
- Hiroichi Yamaguchi (Japan, RTOC member)

1.3 Scope and coverage

This report responds to the Decision XXVIII/4, taking into account the fact that the development of safety standards should be based on systematic consideration of refrigerant hazards, use and application characteristics of the R/AC&HP equipment and implications of the measures so as to minimise the likelihood of detrimental consequences to persons and property:

As a result, the following chapter layout has been followed for this XXVIII/4 Task Force report:

- **Executive Summary**
- **Introduction**, with the co-chairs acting as Chapter Lead Authors (CLAs).
- **International Standards for R/AC&HP Equipment**, with Asbjorn Vonsild as CLA.
- **General Composition and Working Procedures of International Standards,** with Holger König as CLA.
- **Risk assessments and other technical work applicable to standards development**, with Daniel Colbourne as CLA.
- **Standards development and applicability to R/AC&HP Sector**, with Daniel Colbourne as CLA.
- **Assessment of the implications of International Standards for the implementation of MOP decisions** with Martin Dieryckx and Lambert Kuijpers as CLAs.
- **Concluding Remarks and Recommendations to Parties**, with co-chairs and Lambert Kuijpers as CLAs.

1.4 Recommendations for points (1)a and (1)c of the Decision

Parties may wish to consider the following:

- providing additional guidance to TEAP on the establishment of regular consultations on relevant international safety standards with a view to support the timely revision of such standards.
- that the report is formally forwarded to the relevant International Standards bodies, including the IEC and ISO and to establish a consultative/exchange of information process in particular with respect of:
  - the Decision of the Parties to the Montreal Protocol related to enabling the safe use of alternatives in the phase down of HFCs under the Montreal Protocol,
  - the information that TEAP could assess/review to inform the process of revision of the relevant safety standards by those institutions to achieve the objectives of the Montreal Protocol.

2 International Standards for R/AC&HP equipment

2.1 Introduction

The intention of this chapter is to give an overview on the safety standards that are applicable to air conditioning, refrigeration and heat pump (R/AC&HP) systems and equipment.

There are a number of standardisation organisations that produce standards that are applied within more than one country. Several of these organisations include R/AC&HP safety standards within their output. However, only those from International Organisation for Standardisation (ISO) and International Electrotechnical Commission (IEC) will be discussed, not only because they are effectively true international organisations but also to retain some continuity.

The overview of this chapter will not cover current general risk assessment standards (basic safety standard as defined in IEC/ISO Guide 51) such as ISO 12100.

Safety standards do not override national legislation, however, standards are commonly referred to from or copied into national legislation.

Compliance with safety standards also plays an important role when substantiating that the safety of a system is according to recognized good practice. This is important for companies for managing the legal risk associated with selling systems or services associated with systems.

2.2 Overview of main R/AC&HP safety standards

The structure of safety standards is built on the following types of standard (IEC/ISO Guide 51):

- basic safety standard (also known as framework standards), comprising fundamental concepts, principles and requirements with regard to general safety aspects applicable to a wide range of products and systems;
- group safety standard (also known as horizontal standards), comprising safety aspects applicable to several products or systems, or a family of similar products or systems, dealt with by more than one committee, making reference, as far as possible, to basic safety standards;
- product safety standard, comprising safety aspects for a specific product or system, or a family of products or systems, within the scope of a single committee, making reference, as far as possible, to basic safety standards and group safety standards;
- standards containing safety aspects, but which do not deal exclusively with safety aspects, making reference as far as possible to basic safety standards and group safety standards.

Within R/AC&HP sector, there are current nine main safety standards that cover whole systems, appliances, and products, and one more is under preparation. Five are product safety standards and four are group safety standards. These standards are listed in Table 1 and the applicable sub-sectors are identified, according to the classification within the 2014 RTOC Assessment report.

As a general rule, if a product safety standard is available for the product or equipment of interest, then it should be used in preference to a group safety standard. This is because the requirements are generally tuned to the particular characteristics. However, unless national law mandates a particular product safety standard, then the choice is still voluntary. In many cases it may in fact be appropriate to use a group safety standard, for instance, where:

- The requirements of the group safety standard are more mature or developed;
- The scope of the product safety standard excludes particular characteristics that are applicable to the product or equipment under consideration.

It is also possible to use one standard and adopt clauses or requirements from another provided there is no conflict with other parts and provided there is a risk analysis done.

Table 2-1: Scope of different international and regional safety standards for R/AC&HP systems

Sector	**Product safety standards**						**Group safety standard**			
	IEC 60335 -2-11	IEC 60335 -2-24	IEC 60335 -2-40	IEC 60335 -2-89	ISO 13043[1]	ISO 20854[2]	ISO 5149 -1	ISO 5149 -2	ISO 5149 -3	ISO 5149 -4
Domestic refrigeration		X					X	X	X	X
Commercial refrigeration				X			X	X	X	X
Industrial systems							X	X	X	X
Transport refrigeration							X	X	X	X
Air-to-air air conditioners & heat pumps			X				X	X	X	X
Water heating heat pumps			X				X	X	X	X
Heat pump tumble driers	X						X	X	X	X
Chillers			X				X	X	X	X
Vehicle air conditioning					X					X
Refrigerated containers						X	X	X	X	X

There is no overarching authority that can dictate which standard must be used in a given set of circumstances; the most important aspect is that a robust technical justification is provided.

All of the standards deferred in Table 1 give technical requirements and limitations for the safe application of refrigerants, including flammable refrigerants. The above standards do not cover all aspects of the lifecycle especially the competences of the service technicians is important for the safety throughout the life cycle. To address the full lifecycle, the use of safety standards needs to be supplemented with a risk assessment.

There are many other standards which are relevant for the application of lower-GWP refrigerants, for instance, ISO 817 "Refrigerants: Designation and safety classification", which lists the refrigerant data including flammability and toxicity data used in the safety standards.

---

[1] ISO 13043 only covers R134a, R744 and R1234yf, so all other alternative refrigerants are out of its scope. ISO 5149-1 and ISO 5149-2, specifically excludes mobile air conditioning (MAC) systems from its scope, and ISO 5149-3 is not applicable to MAC.
[2] ISO 20854 Thermal containers — Safety standard for refrigerating systems using flammable refrigerants – Recommendations Requirements for design and operation is under preparation.

In particular where it concerns application of flammable refrigerants, there are a series of standards that are related to the safety of potentially hazardous (flammable/explosive) atmospheres, most notably the IEC 60079 series.

Standards are typically purchased at the national standardisation organisation. As the number of supplementary standards, which are referred to from the safety standards of Table 1, is significant and standards are therefore often too expensive for technicians and contractors to be a direct source of knowledge. The lack of standards in local languages and the complexity of the standards can also be a technical limitation for the standards to be used by technicians and contractors. Technicians and contractors will therefore need industry guidelines and similar material.

2.3 Implementation of the safety standards

Whilst the standards discussed are International Standards, these are seldom used directly. Most countries will adopt a standard nationally or regionally.

In the case of national adoption, the name and number of the standard may be retained or changed to match the national numbering system. Significantly, many countries will include national modifications or deviations, such as where a national body objects to certain requirements, terminology, references, etc., or more often where there is national legislation that conflicts with the text within the international standard. On a regional basis – such as within Europe – the international standard may also be modified in this respect before it is adopted and then further nationally in the case of conflicts with specific national laws.

However, since many enterprises operate internationally, there is a preference to ensure that the requirements of a standard are as universal as possible applicable so that national variations are kept to the minimum.

In the “Annex to Chapter 2” the relation between “standards” and “legislation” in three countries (namely China, France and Japan) is presented, as an example on how the matter is handled throughout the world.

2.4 Relevant standards

IEC 60079 series	Explosive atmospheres
IEC 60335-2-11: 2008	Household and similar electrical appliances — Safety — Part 2-24: Particular requirements for tumble dryers
IEC 60335-2-24: 2013	Household and similar electrical appliances — Safety — Part 2-24: Particular requirements for refrigerating appliances, ice-cream appliances and ice-makers
IEC 60335-2-34:2012	Household and similar electrical appliances – Safety – Part 2-34: Particular requirements for motor-compressors
IEC 60335-2-40: 2016	Safety of household and similar electrical appliances — Part 2-40: Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers

IEC 60335-2-89: 2012	Household and similar electrical appliances — Safety — Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant unit or compressor
IEC 60335-2-104: 2003	Household and similar electrical appliances — Safety — Part 2-104: Particular requirements for appliances to recover and/or recycle refrigerant from air conditioning and refrigeration equipment
ISO 817: 2014	Refrigerants — Designation system and safety classification
ISO 5149-1:2014	Amendment A1:2015, Refrigerating systems and heat pumps — Safety and environmental requirements — Part 1: Definitions, classification and selection criteria
ISO 5149-2: 2014	Refrigerating systems and heat pumps — Safety and environmental requirements — Part 2: Design, construction, testing, marking and documentation
ISO 5149-3: 2014	Refrigerating systems and heat pumps — Safety and environmental requirements — Part 3: Installation site
ISO 5149-4:2014	Refrigerating systems and heat pumps — Safety and environmental requirements — Part 4: Operation, maintenance, repair and recovery
ISO 13043:2011	Road vehicles — Refrigerant systems used in mobile air conditioning systems (MAC) — Safety requirements
ISO CD 20854	Freight Container — Thermal containers — Safety standard for refrigerating systems using flammable refrigerants — Requirements for design and operation
ISO/IEC Guide 51:2014	Safety aspects — Guidelines for their inclusion in standards

3 General composition and working procedures of International Standards

The following section describes the ISO and IEC standard development procedures in general. The development of national or local standards is often comparable in terms of the procedures but is not addressed in this document.

3.1 Global relevance of International Standards

ISO (International Organization for Standardization) is an independent, non-governmental international organization with a membership of 162 National Standards bodies. The International Electrotechnical Commission (IEC) is a not-for-profit, quasi-governmental organization.

The ISO / IEC's members are National Committees, and they appoint experts and delegates coming from industry, government bodies, associations and academia to participate in the technical and conformity assessment work of standard development.

The aim of International Standards, such as ISO/IEC standards, is that the International Standards aims to represent a worldwide quasi consensus and responds to global market needs. In order to achieve this aim, it has been recognized by ISO/IEC that special measures are needed to ensure that the needs of developing countries are taken into account in ISO’s technical work. One such measure is the inclusion of specific provisions for “twinning”, i.e. partnerships between developed and developing countries, see ISO Supplement to the ISO/IEC Directives [ISO/IEC, 2016a] and ISO/IEC Directives, Part 1 with IEC Supplement — Procedures for the technical work [ISO/IEC, 2016b].

3.2 General

Committees dealing with new or existing standards are also encouraged to refer to or use the ISO Guide 82 [ISO/IEC, 2014a] for addressing sustainability in standards. For the development of safety standards committees should refer to ISO Guide 51 and ISO/IEC Guide 116 [ISO/IEC, 2014b]. ISO Guide 51 and 116 are general documents and should be considered for the development and adjustment for the use of flammable refrigerants especially with regard to the integration of risk assessment methods.

The participation in standardization meetings can be costly since the meetings involves international travel, and most delegates of committees or experts of working groups gets funded by their employers. So, although the participants officially represents member bodies in committees and only represents their own personal views in working groups, in reality there may also be a strong aspect of company politics in the participation. This is a deliberate feature of the structure, which ensures that standardisation is industry relevant. The down side is that the standards will be biased by the organisations funding the participation of experts for standards development.

3.3 Composition of committees, working procedures, membership and contribution

3.3.1 Composition of ISO and IEC standardisation bodies

The development process of standards is shown in Table An3-1, details can be found in ISO/IEC Directives, Part 1 Consolidated ISO Supplement — Procedures specific to ISO [ISO/IEC, 2016a] and ISO/IEC Directives, Part 1 with IEC Supplement — Procedures for the technical work [ISO/IEC, 2016b].

3.3.2 Involved entities

There are several entities involved within the standards development process. The most relevant entities are describe below:

- Technical management board (TMB) – the TMB is responsible for the overall management of the technical work. For instance TMB establishes technical committees (TCs) and maintains the rules for the standardisation processes. The members of the TMB are selected among the national standardization organizations also known as national bodies (NB).
- Technical Committee (TC) – the parent committee within the standards organisation that is assigned responsible for dealing with a particular subject matter. It may be related to an equipment category (e.g., "household appliances"), technology sector (e.g., "refrigeration systems") or a principal method (e.g., "risk assessment", "mitigation or prevention of flammable atmospheres"). A TC is responsible for strategic decisions relating to standards development within its subject. It is comprised of national bodies (NB) and at meetings, delegates represent their NB (as opposed to themselves or employers).
- Subcommittee (SC) – a committee that is set up under a TC in order to focus on a more specific category than its parent TC, for example, which demands a specific expertise and to minimise the workload for the TC. An SC is then responsible for strategic decisions relating to standards development within its allocated subject and is also comprised of NBs. Within the SCs, proposals for standards, resolutions, or other matters are put to the vote by NBs.
- Working group (WG) – a group of nationally-nominated experts and interested individuals that participate in their own capacity to develop the text of a new or revised standard or an amendment for an existing standard. A committee (TC/SC) normally creates a WG. In WG the main standardization work is realized. For this reason, WG meetings take place much more frequently than SC or TC meetings.
- Ad hoc group (AHG) – a small working group that is typically established in WGs for a limited period of time solely to resolve a discrete issue.
- Liaison organisation – an eligible entity that has mutual interest in the activities of a TC or SC, which essentially exchanges information that is relevant to their respective tasks and objectives. There are also types of liaisons (category A[3] and D[4]) which can participate in the working groups of the TC or SC.
- Liaison - between different TCs or SCs, typically proposed in a NP stage or established after a resolution process within the proposing TC or SC to ensure exchange of documents between technical committees[5].

---

[3] *Category A: at TC / SC level, non – profit, membership based technical oriented organizations that make an effective contribution to the work of a TC / SC, nomination of experts for WG work*

[4] *Category D: at WG level, multinational organizations such as manufacturer, commercial organizations, user groups or professional societies, actively in working groups*

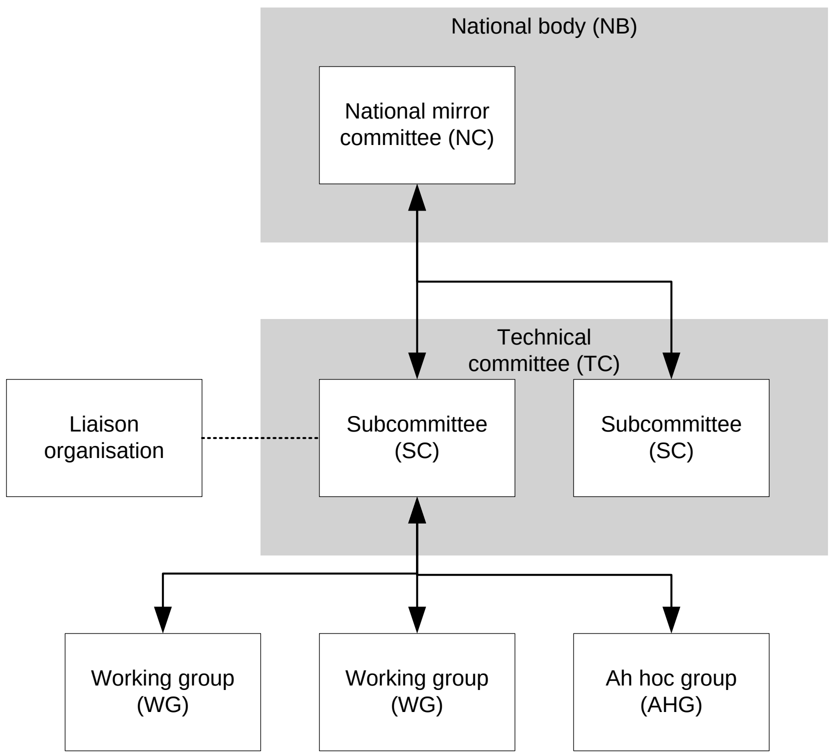
[5] *An example is given in chapter 6.7.2, where a connection between an application-related standardization committee (in this case ISO TC 104-Freight container – Thermal container) and a basic refrigeration*

- National Body (NB) – also known as the national standardisation organisation – the nominated standardisation organisation within a country that is a member of a given TC or SC. It may be an observing (“O-“) member or participating (“P-“) member. Only P-members are permitted to send experts to participate in WGs. Only P-members' positive votes are counted but both P- and O-members' negative votes are counted[6].
- National mirror committee (NC) – the committee within the NB that is responsible for communicating with the applicable TC or SC and in particular, submitting comments and votes and – for P-members – sending delegates for TC and SC meetings.

Detailed information on the definition of liaison organizations, whose categories and on the possibilities for non-profit organizations for participation in standardization work can be found in [ISO/2010].

Note that NB activities and involvement and tasks associated with NCs can vary widely. For example, participation of stakeholders within a countries’ particular NC may be entirely open to all individuals, whilst in others membership demands substantial fees and in others participation is by invitation only. Whilst participation in TCs and SCs is relatively open (providing the necessary resources and funding is available for time, travel, etc.) accessibility at national level varies widely. Similarly, nomination of a potential expert to a WG or AHG is also controlled by the NB or NC and as such may be inclusive or exclusive.

An overview of the interrelations between the various entities identified above is provided in Figure 3-1.



committee (ISO TC 86 – SC1 –Refrigerating systems and heat pumps — Safety and environmental requirements) was established. Other examples are liaison between IEC 61D, developing standard series IEC 60335-2-xx and ISO TC 86, covering ISO 5149.

[6] *Refer to the voting approval system - 2/3s of positive P-member votes and not more than 1/4 of all members negative votes.*

Figure 3-1: Entities involved with International Standards development

3.3.3 Working procedures, technical development and evaluation

If a National Body wishes to be member of a committee then there are two kinds of membership to choose between:

(1) Participating members (P-members): who have the obligation to vote and the right to nominate experts to working groups, and

(2) Observing members (O-members): who have the right to submit comments and have limited voting rights but cannot nominate experts to the working groups.

There is a defined set of stages involved with a standard development, revision or amendment; Figure 3-2 shows the successive stages through which a project proceeds, including identification of the inputs expect from the relevant entities.

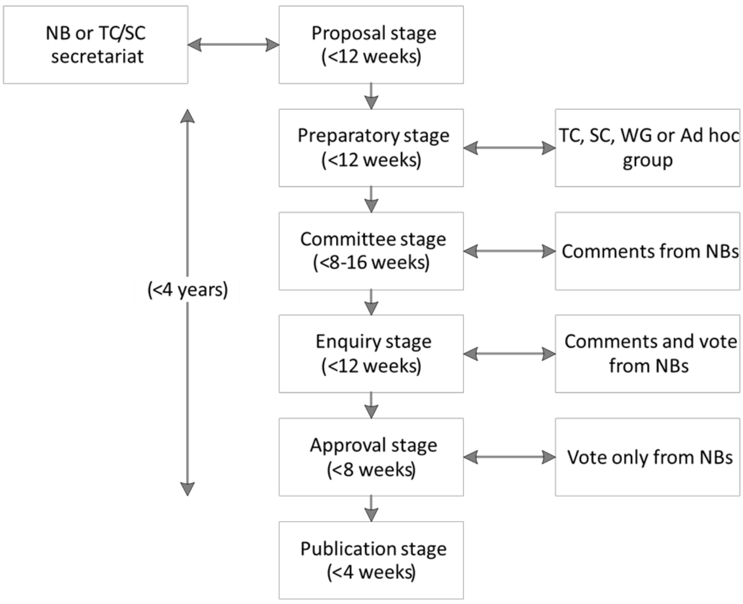


Figure 3-2: General standards development process

A project is any work intended to lead to the issue of a new, revised or amended International Standard, which has been accepted according to the applicable procedures. An indication of the times permitted for each voting and/or commenting stage is indicated.

However, the intervening steps where TCs, SCs or WGs are developing requirements have few constraints; whilst projects are expected to reach fruition within 2 – 4 years[7], TCs or SCs have the option to extend or renew the stages as required.

Critical to the development of material within WGs, is that any text shall be arrived with a view to reaching "consensus" of the participants. "Consensus" is defined within the ISO/IEC guidelines as:

> *"General agreement, characterized by the absence of sustained opposition to substantial issues by any important part of the concerned interests and by a process that involves seeking to take into account the views of all parties concerned and to*

[7] *Accelerated / default / enlarged standards development track — 24 / 36 / 48 months to publication*

reconcile any conflicting arguments." And "NOTE Consensus need not imply unanimity."

Conversely, when an entire draft is submitted for approval to the NBs, positive or negative votes are submitted.

3.3.4 Formal stages

Proposal stage

The start of a project is typically the proposal stage, where a new work item proposal (NP) is submitted for either a new standard or an amendment to an existing standard. The NP may be offered by a national body (NB), the secretariat of the technical committee (TC) or subcommittee (SC) (or even from another TC or SC), a category "A" liaison organisation or a category "B"[8] liaison entity (intergovernmental organisations such as IMO, UN). Ideally an NP should be submitted in the form of proposed text or working document (WD) along with a proposed project leader (typically a convenor for an ad hoc group or working group).

The NP is circulated to relevant committees, typically the TC or SC P-member country national bodies for a decision (by vote) and to O-member country NBs and liaison member committees for information. The NP is accepted if a simple majority of P-member NBs are in favour, plus sufficient commitment from NBs to participate in the development of the project, which includes nomination of experts.

Preparatory stage

The preparatory stage covers the preparation of a working draft (WD). In the event that the NP is accepted then a WG should normally be set up if not already existing – which can include experts from P-member NBs and category A and D liaison organisations – and target dates provided for the programme of work. The WG then develops the text of the WD, which may include several circulation of a committee draft (CD) for comments to the TC or SC O- and P-members–. The preparatory stage ends when a working draft is available and submitted for circulation to the NBs of the technical committee or subcommittee as a first committee draft (CD).

The committee may also decide to publish the final working draft as a Publically Available Specification (PAS) to respond particular market needs. A PAS is permitted provided that there is no conflict with existing International Standards by the committee concerned and following simple majority approval of the P-members. A PAS shall remain valid for an initial maximum period of 3 years.

Committee stage

The committee stage is the principal stage at which comments from national bodies are taken into consideration, with a view to reaching consensus on the technical content. Once available, a committee draft shall be circulated to all P-member and O-member countries of the TC or SC for consideration and comments over a period of 8 – 16 weeks (normally 8 weeks is chosen). National bodies shall fully brief their delegates on the national position before meetings. A response to the comments is then prepared by the secretariat, indicating possible actions arising from the comments and options for proceeding with the project, such as discussing at the next meeting, or circulating a revised CD for consideration, or to register the CD for the enquiry stage.

---

[8] *Category B: reserved for intergovernmental organizations, to be kept informed of work of a TC / SC.*

Consideration of successive drafts shall continue until consensus of the working group has been obtained or a decision to abandon or defer the project has been made. The secretariat of the TC or SC responsible for the committee draft shall ensure that the enquiry draft fully embodies decisions taken either at TC/SC/WG meetings or by correspondence. When consensus has been reached, its secretariat shall submit the finalized version of the draft in electronic form suitable for distribution to the national members for enquiry.

The committee stage ends when all technical issues have been resolved and a committee draft is accepted for circulation as an enquiry draft. If the technical issues cannot all be resolved within the allocated time, TC and SC may consider publishing a Technical Specification (TS) as an intermediate deliverable.

Enquiry stage

At enquiry stage, the enquiry draft – Draft International Standard (DIS) in ISO and Committee Draft for Vote (CDV) in IEC – shall be circulated to all national bodies for a 12-week vote. Votes submitted by national bodies shall be explicit: positive, negative, or abstention. A positive vote may be accompanied by editorial or technical comments, on the understanding that the secretary, in consultation with the chair of the technical committee or subcommittee and project leader, will decide how to deal with them.

If a national body finds an enquiry draft unacceptable, it shall vote negatively and state the technical reasons. It may indicate that the acceptance of specified technical modifications will change its negative vote to one of approval, but it shall not cast an affirmative vote which is conditional on the acceptance of modifications.

An enquiry draft is approved if:

a) a two-thirds majority of the votes cast by the P-members of the technical committee or subcommittee are in favour, and
b) not more than one-quarter of the total number of votes cast are negative.

When the approval criteria are met the following step is, in IEC to register the enquiry draft, as modified, as a final draft International Standard, or in ISO, to proceeds to publication.

In the case of an enquiry draft where no negative votes have been received, the process is to proceed directly to publication.

When the chair has taken the decision to proceed to the approval stage or publication stage, the secretariat of the TC/SC shall prepare, within a maximum of 16 weeks after the end of the voting period and with the assistance of its editing committee, a final text of the final draft International Standard.

The enquiry stage ends with the registration, of the text for circulation as a final draft International Standard (FDIS) or publication as an International Standard.

Approval stage

At the approval stage, the final draft International Standard (FDIS) shall be distributed within 12 weeks to all national bodies for a 6-week vote in IEC and an 8-week vote in ISO. Votes submitted by national bodies shall be explicit: positive, negative, or abstention. If a national body votes affirmatively, it shall not submit any comments, beside the fact that editorial comments are still acceptable. If a national body finds a final draft International Standard unacceptable, it shall vote negatively and state the technical reasons and cannot cast an affirmative vote that is conditional on the acceptance of modifications.

An FDIS is approved if

a) a two-thirds majority of the votes cast by the P-members of the technical committee or subcommittee are in favour, and
b) not more than one-quarter of the total number of votes cast are negative.

Abstentions are excluded when the votes are counted, as well as negative votes not accompanied by technical reasons. Technical reasons for negative votes are submitted to the TC/SC for consideration at the time of the next review of the International Standard. If the FDIS has been approved in accordance with the conditions, it shall proceed to the publication stage, otherwise the document shall be referred back to the TC or SC for reconsideration in the light of the technical reasons submitted in support of the negative votes. The committee may decide to resubmit a modified draft as a committee draft, enquiry draft or, FDIS (in ISO only), or publish a TS or cancel the project.

The approval stage ends with the circulation of the voting report stating that the FDIS has been approved for publication as an International Standard, with the publication of a TS or with the document being referred back to the committee.

3.3.5 Additional contribution to ISO/IEC standards development

For the committee meetings it is also possible for other organisations to be present, these are typically representatives from other technical committees (internal liaisons from the same TC) or from external organisations (liaisons of category A), neither have voting rights but liaisons of category A may nominate experts to working groups.

If explicitly invited, it is also possible for organizations that make a technical contribution to and participate actively in the work of a WG and to be present at committee meetings as observers (liaisons of category D). These organisations needs to be approved by the parent committee. In addition technical experts can be invited by the project leader or convenor to the working group meetings to support the standard development process.

3.4 References

ISO/IEC, 2014a — ISO/IEC Guide 82, Guidelines for addressing sustainability in standards, 2014

ISO/IEC, 2014b — ISO/IEC Guide 51, Safety aspects — Guidelines for their inclusion in standards, 2014

ISO/IEC, 2016a — ISO/IEC Directives, Part 1 Consolidated ISO Supplement — Procedures specific to ISO, Seventh edition 2016

ISO/IEC, 2016b — ISO/IEC Directives, Part 1 with IEC Supplement — Procedures for the technical work, Edition 12.0, 2016

ISO, 2010 — Guidance for ISO liaison organizations, Engaging stakeholders and building consensus, https://www.iso.org/files/live/sites/isoorg/files/archive/pdf/en/guidance_liaison-organizations.pdf

4 Risk assessments and other technical work applicable to standards development

4.1 Introduction

As described in Chapter 3, technical committees (TC) and particularly working groups (WG) carry out the majority of the deliberations associated with developing, drafting, assessing and refining technical requirements, in this case related to the safe application of refrigerants within R/AC&HP systems and equipment.

Much of the input used for the determination of the appropriate requirements is drawn from the wider literature on the topics under consideration and related subjects as well as the experience and knowledge of experts and other participants. Due to the nature of the deliberations often being highly specific, theoretical and practical work is often carried out primarily for the purpose of assisting deliberations within the TCs and WGs.

Technical work is important for determining likelihood of faults and failures, possible consequences of an unintended outcome and ways and means of mitigating these. Such considerations should be addressed and implemented in a manner appropriate for developing a safety standard. To assist with this, IEC and ISO publish guides to enable those involved in standards development to articulate, structure and apply weightings to findings from supporting information, so that some degree of consistency can be achieved throughout the safety standards across a wide range of sectors and industries.

This chapter addresses the following topics:

- Principles and approach described by ISO and IEC guidelines
- Overview of publically available studies related to alternatives refrigerants
- Summary of the topics considered with the various standards' TCs and WGs

In order to provide a structure to the technical discussion, Figure 4-1 provides an overview of the causes, effects and consequences associated with the hazards posed by refrigerants. Many of these are applicable to all refrigerants; CFCs, HCFCs, HFCs, HCs, ammonia and carbon dioxide. However, hazards which are particularly applicable to refrigerants with medium and low GWP that are absent with "conventional" refrigerants are flammability, higher toxicity and greater pressures. Investigation into the safety implications associated with the use of alternative refrigerants, particularly the flammable refrigerants, may cover a range of areas such as, but not exclusively:

- Fluid flammability characteristics
- Release/leakage characteristics
    - Leak size/rates, frequencies and system tightness
    - Release amounts
- Behaviour of leaked refrigerant
    - Dispersion of refrigerant within rooms (quiescent, with airflow, etc.)
    - Dispersion of refrigerant outside
    - Equipment characteristics and external conditions
- Potential sources of ignition
- Evaluation of consequences
    - Thermal intensity
    - Pressure wave/overpressure
    - Secondary fire
    - Hazardous decomposition products

- Risk mitigation systems/functions
- Risk assessment (qualitative/quantitative)
  - In use
  - Installation, service and maintenance
  - End-of-life
  - Transportation and storage

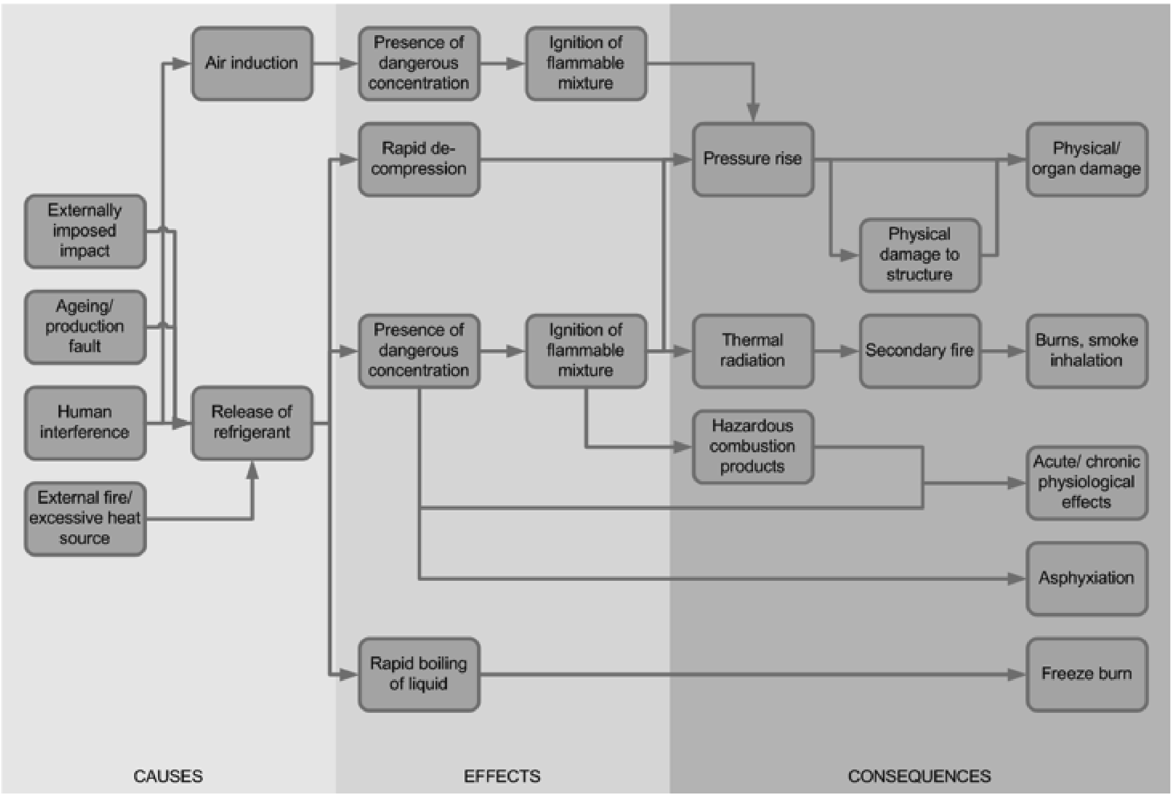


Figure 4-1: General causes, effects and consequences associated with refrigerants

4.2 ISO and IEC guidelines on addressing risks in safety standards

IEC and ISO publish two guides that are intended to assist with the handling of risks when applied to safety standards. They are generic and can be applicable to almost anything.

4.2.1 ISO/IEC Guide 51:2014, IEC Guide 116

In these guides, risk assessment is advised to be conducted to evaluate safety. The three-step method is adopted to determine the level of risk reduction. The order of priority of risk reduction which should be applied to safety standards is as follows.

i.) inherently safer design;
ii.) risk reduction measures;
iii.) information for users.

This order of priority is based on the concept that inherently safe design measures and built-in protective devices can usually be expected to eliminate the potential for user error or misuse.

Figure 4-2 shows a risk assessment-based approach. The risk evaluation is continued until the risk reduces to a tolerable level. Risk evaluation needs to be considered over a complete life cycle.

Risk assessment starts with the determination of the limits of the equipment such as use limits, time limits, space limits, and other limits. The next step is hazard identification. After hazard identification, risk estimation is carried out based on the concept that risk is a function of severity of harm and probability of occurrence of that harm. Tolerable level depends on benefit to the user, and conventions of the society concerned.

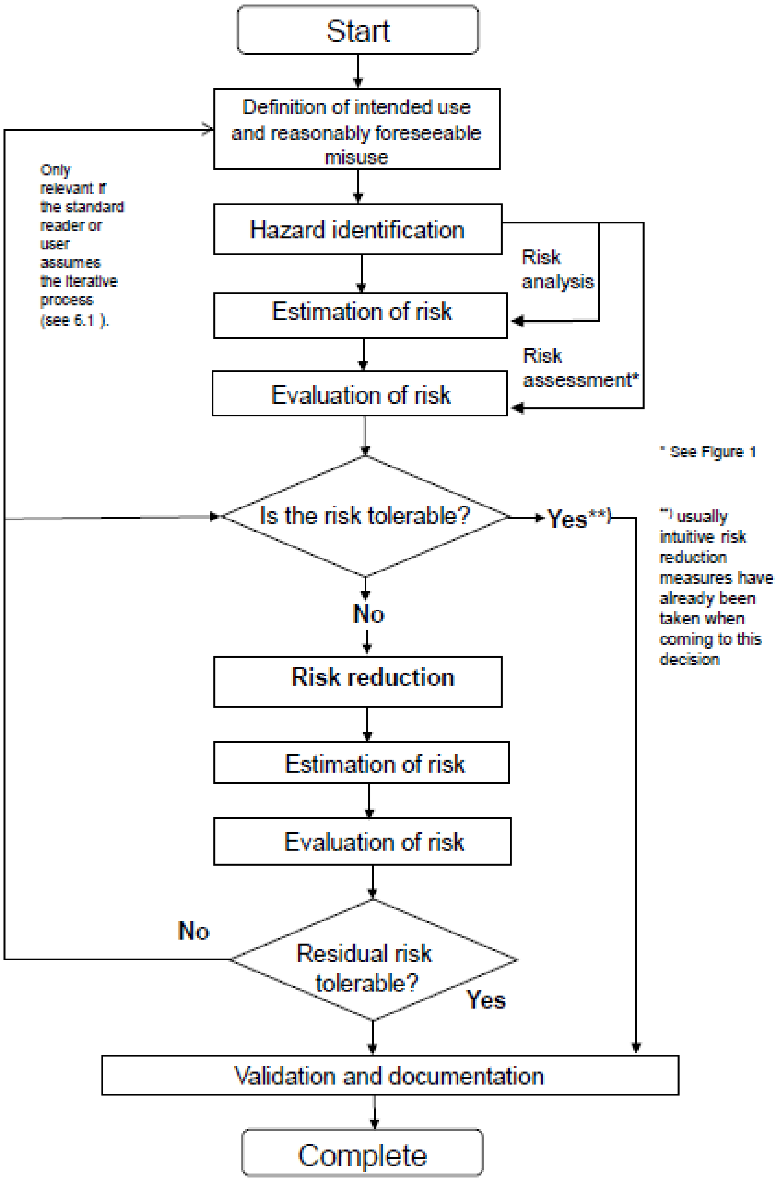


Figure 4-2: risk assessment-based approach (Source: ISO/IEC Guide 51)

For risk assessment, the concepts to be paid attention to are described as follows.

- All product suppliers need to consider safety aspects for the intended uses and the reasonably foreseeable misuses of the product.
- Training and information for use does not become a substitute for the application of inherently safe design measures, and complementary protective measures.

- The absence of an incident history, a small number of accidents or low severity of injury should not be taken automatically as a presumption of a low risk.
- The content of an instruction should give product users the means to avoid a harm presented by a product hazard that has not been reduced or eliminated.
- The simultaneous occurrence of two independent and unrelated faults need not normally be taken into account, but a double fault situation with two independent and unrelated faults has to be considered when the first fault situation is not automatically detected.
- The risk estimation accounts for situations where it is necessary to suspend safety functions (e.g. during maintenance).

4.2.2 IEC Guide 116

This IEC Guide reflects ISO/IEC Guide 51 and gives more detailed practical way of carrying out risk assessment and implementing risk reduction for risks commonly considered during all relevant phases of the life of low voltage equipment. This Guide has also the same basic principle as ISO/IEC Guide 51. As shown in Figure 4-2, the three-step method is adopted to determine the level of risk reduction in the same way as ISO/IEC Guide 51.

The minimum necessary risk reduction is the reduction in risk that has to be achieved to meet the tolerable risk for a specific situation. This guide emphasises that risk assessment should be a series of logical steps.

Risk assessment starts with the determination of the limits of the equipment. The limits of equipment to be considered are use limits, time limits, space limits, and other limits. Operating modes, experience and ability of the users, service interval, weather conditions, etc. should be also taken into account. The next step is hazard identification. To accomplish it, it is necessary to identify the operations to be performed by the equipment and the tasks to be performed by persons who interact with it. Annex C in this guide gives examples of hazards, hazardous situations and hazardous events to assist in this process. After hazard identification, risk estimation is carried out based on the concept that risk is a function of severity of harm and probability of occurrence of that harm. Figure 4-3 shows an image of risk estimation.

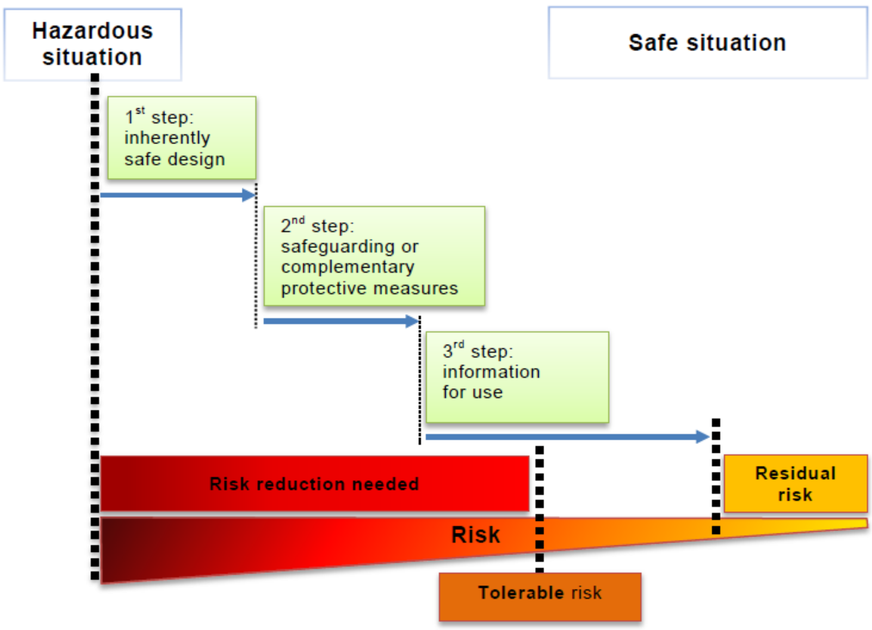


Figure 4-3: Illustration of risk estimation approach (Source: ISO/IEC Guide 116)

Hence, given a tolerable level of risk: the acceptable probability of occurrence increases as the severity of harm is reduced. There is an implicit relationship between probability and severity in order to achieve a tolerable risk level (see Figure 4-4). There are a several items to be noted. .

- If more than one person can be expected to be injured or killed, the probability of occurrence is F2.
- The simultaneous occurrence of two independent and unrelated faults need not normally be taken into account, but a double fault situation with two independent and unrelated faults has to be considered when the first fault situation is not automatically detected.
- The risk estimation accounts for situations where it is necessary to suspend safety functions (e.g. during maintenance).
- Training, experience and ability can't be used as a substitute for hazard elimination, risk reduction by design, safeguarding or complementary protective measures.

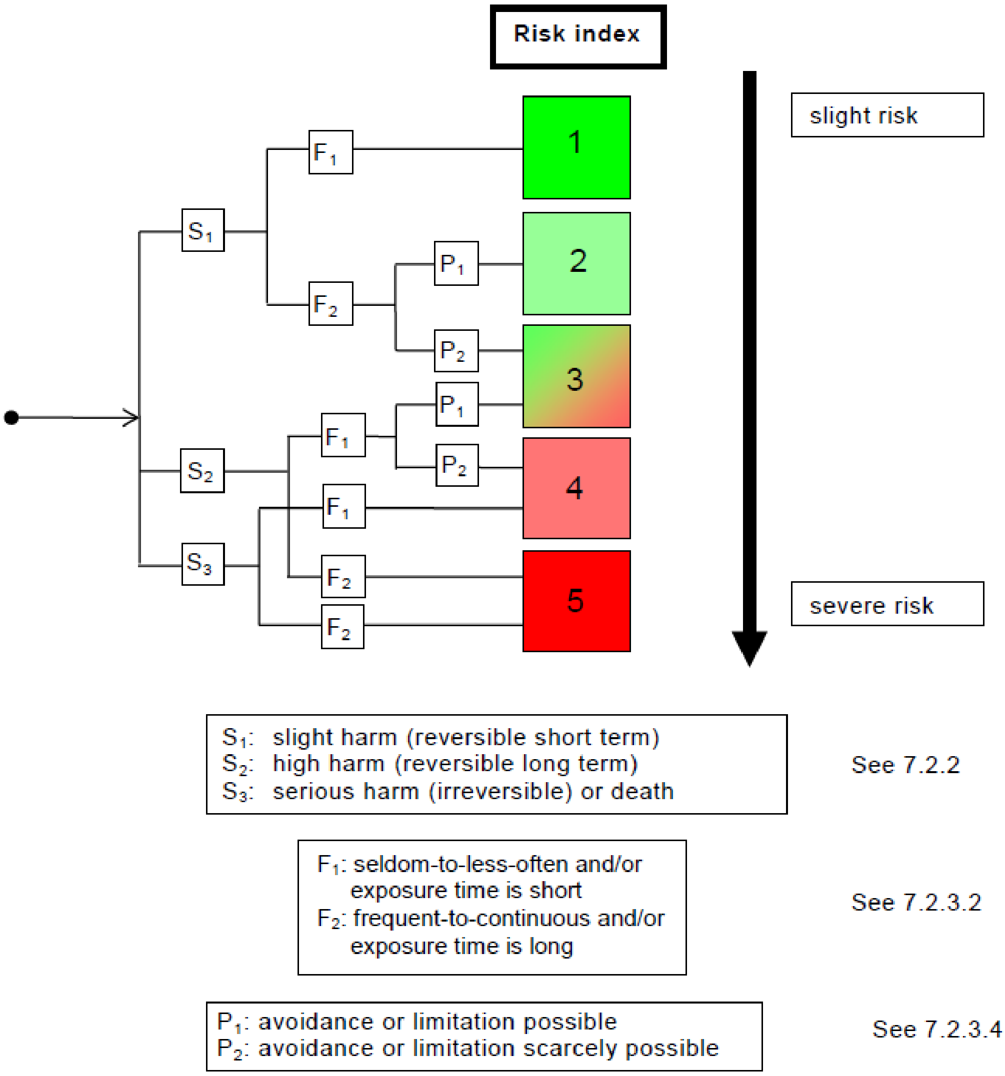


Figure 4-4: Approach to determine risk indicator (Source: ISO/IEC Guide 116)

In the end, risk evaluation is carried out to determine if risk reduction is required or whether tolerable risk has been achieved. Depending on the kind of product, human factors, reliability of risk reduction measures, ability to defeat or circumvent protective measures, ability to maintain risk reduction measures, and the current values of society, a decision has to be taken. If residual risks remain, the user is sufficiently informed about the residual risks in the different phases of the equipment life. As part of the process of risk evaluation, the risks associated with the equipment can be compared with those of similar equipment or comparable products.

4.3 Overview of published safety studies related to refrigerants

This section is intended to provide an overview of the published literature that addresses the technical issues associated with hazards and risks arising from the use and application of flammable refrigerants. The knowledge generated from work carried out in this area is applicable when developing safety standards. Some of the literature is directly applicable to standards development, whilst some may be useful for providing background information.

Studies are categorised broadly according to the topics listed in section 4.1, i.e., flammability characteristics of a refrigerant, leak characteristics, dispersion behaviour of the refrigerant following a leak, consequences in the event of ignition, mitigation measures and overall risk assessment tasks, which normally encompasses elements of the prior topics.

4.3.1 Fluid flammability characteristics

As inferred by the separated refrigerant flammability classifications under ISO 817 (i.e., 2L, 2 and 3 in ascending order of flammability), different refrigerants exhibit a broad range of flammability characteristics. Class 2L refrigerants have substantially different flammability characteristics from many common flammable substances (such as hydrocarbons), so there has been a considerable amount of research to closely measure their various properties so that the implications on likelihood of ignition and consequences of ignition can be better understood. Apart from investigation into lower flammability limits (LFLs), work has been carried out into determining minimum ignition energy (MIE), quenching distances and/or minimum experimental safe gap (MESG), laminar burning velocity, rate of pressure rise, etc. Similar work has also involved investigating alternative approaches for classifying refrigerants according to their flammability.

Conversely, flammability data for HCs is widely available throughout the literature, although not necessarily within the context of their use as refrigerants.

References (list of references is provided in the Annex to Chapter 4)
Chen 2007; Grosshandler 1998; Grove 1968; Holtappels 2014; Holtappels 2002; JSRAE 2013; JSRAE 2014; JSRAE 2015; JSRAE 2016; JSRAE 2017; Kondo 2008; Li 2016; Lisochkin, 2001; Richard 2003; Takizawa 2016; Wilson 2002.

4.3.2 Release/leakage characteristics

There are several elements related to refrigerant leak characteristics that have an impact on flammability safety assessments. Information relating to leak characterisation is largely independent of refrigerant classification. Possibly the most important is the frequency of leaks, and particularly, the frequency of leaks of a given hole size. Empirical data for this is extremely scarce so approximations and assumptions are normally used. Other information is the location of leaks (and the probability of their occurrence) and the mechanism for the leak development (e.g., corrosion, mechanical impact, etc.) so that the rate of hole development can be considered. Another important parameter is the phase and mass flow rate of the leakage, whether it is constant, decaying or increasing. Furthermore, characterising leak size and development according to materials, manufacturing schemes, regional aspects, etc., is also largely absent.

In contrast, there are several datasets and models available for leak frequency for "process industry" cases, within the literature (not referenced). Whilst these could be used – before or after adoption – to R/AC&HP systems, substantial uncertainties would remain. Similarly, models for determining mass flow of leaks can also be used (and often are within R/AC&HP risk assessment studies), but these are typically for constant flow conditions and are therefore broadly inapplicable.

Background information and assumptions associated with size and likelihood of leaks is often included within the general risk assessments.

References (list of references is provided in the Annex to Chapter 4)
AHRI 2015; Blackwell 2006; Colbourne 2012b; Colbourne 2004a; Colbourne 2013; Goetzler 2012; Goetzler, Guernsey 2016a; Goetzler 2013; Goetzler 2016b; Jia 2015; JSRAE 2013; JSRAE 2014; JSRAE 2015; JSRAE 2016; JSRAE 2017; Zhao 2002.

4.3.3 Behaviour of leaked characteristics

Within the wider literature, there has been extensive research into dispersion of neutrally buoyant (and buoyant) gases, both in the open air and within rooms (not referenced). Whilst most of the literature on outside releases involves amounts of gas far in excess of what would be typical for R/AC&HP systems, the majority of work for releases inside is on the scale of refrigerant application. There has been several decades of research concerning characterisation of jets and plumes of flammable gas releases, as well as filling of rooms which are sealed, are naturally ventilated, mechanically ventilated and which have internal airflows. Much of this work is broadly analogous to situations involving R/AC&HP equipment.

Similarly, considerable amounts of work has been published relating to the behaviour and distribution of leaked refrigerant. This includes both experimental and/or computational studies, including those that focus on improvements and optimisation of CFD approaches specifically for present circumstances. Amongst the various studies, most of the main flammable refrigerants are addressed.

Specifically for R/AC&HP applications, there are publications covering releases from different types of equipment (such as refrigerators, air conditioners, display cabinets, etc.) and also "neutral" cases where a diffuser is used to minimise momentum. Both empty and congested rooms have been addressed. More recent work has also considered the effect of the local release environment, such as characteristics of the enclosure containing refrigerant-containing parts.

The behaviour of leaked refrigerant is fairly well understood although there are many aspects that still demand study, such as better characterisation of the effect of enclosure or housing geometry, impact of airflows, two-phase releases and impact of non-constant leak rates.

References (list of references is provided in the Annex to Chapter 4)
Cai 2014; Clodic 1996b; Cheng 2015; Clodic 1997c; Clodic 1996a; Clodic 1997a; Colbourne 2003a; Colbourne 2003b; Colbourne 2014; Colbourne 2016b; Colbourne 2008a; Dorman 2013; Gigiel 2004; Hiroaki 2014; Iz 1996; Jabbour 2002; Jabbour 2004; Jia 2015; JSRAE 2013; JSRAE 2014; JSRAE 2015; JSRAE 2016; JSRAE 2017; Kataoka 2000; Kataoka; Laughman 2015; Laughman 2016; Li 2014a; Li 2014b; Nagaosa 2014; Nagaosa 2012; Papas 2016.

4.3.4 Potential sources of ignition

Generally for A3 refrigerants (hydrocarbons), since minimum ignition energy is low and auto-ignition temperature is well known through historical literature (not referenced), items that could act as potential sources of ignition are established. Several industrial handbooks can be referred to for compilations of items that can act as ignition sources. As such, the majority of literature that deals with what is or is not a potential source of ignition is seldom investigated within A3 refrigerant safety studies.

Conversely, due to A2L refrigerants having significantly different flammability characteristics – and even amongst the various A2L refrigerants – a number of studies have evaluated various sources to determine whether or not they could initiate an ignition event.

References (list of references is provided in the Annex to Chapter 4)
Goetzler 2012; Goetzler, 2016b.

4.3.5 Evaluation of consequences

There are a number of different consequences associated with ignition of a flammable refrigerant. Primary consequences include development of overpressure, emission of thermal radiation and generation of combustion products with significant toxicity. Secondary consequences include damage to persons and property, secondary fire and physiological injury from decomposition products.

For A3 refrigerants (hydrocarbons) the likelihood and degree of severity of consequences are well known from decades of work on fuel gases. Throughout the wider literature there are extensive studies examining development of overpressure for confined and partially confined deflagrations, thermal intensity and degree of damage and subsequent potential injury.

For A2 and particularly A2L refrigerants the situation is perhaps less clear, so recent studies have examined these various aspects in some detail. Whilst confined ignition events lead to overpressures comparable to A3 refrigerants, various studies have addressed the case of unconfined deflagrations. However, the issue of thermal intensity and development of secondary fires has barely been addressed to date.

Unlike non-fluorinated refrigerants, A2L refrigerants do generate decomposition products such as hydrogen fluoride upon ignition and this feature has also been the focus of various studies (it is noted that possible decomposition products are not considered in the safety classification.)

In addition to immediate or delayed ignition of a release into the atmosphere, additional scenarios exist for all flammable refrigerants.

One is ignition of a mixture within the compressor, due to internal sparking and the fact that the flammable range is extended under elevated pressures, temperatures and presence of oil. This situation has been addressed to a limited extent. Another consequence is that arising from a secondary fire. In almost all studies, the likelihood of a secondary fire (either caused by R/AC&HP equipment itself or by external sources) is far higher than that caused by ignition of a leak of refrigerant. Therefore the situation associated with consequence arising from the R/AC&HP equipment being engulfed by an external fire it of critical importance.

References (list of references is provided in the Annex to Chapter 4)
AHRTI-9007 2017; Colbourne 2013; Colbourne 2004a; Higashi 2014; Higashi 2016; Holtappels 2009; Holtappels 2017; Imamura 2016; Koenig 2016; Ritter 1998; Saburi 2014; Saburi 2016; Tadros 2008; Yajima 2011; Zgliczynski 1994; Zhang 2013; Zhang 2015.

4.3.6 Risk mitigation systems/functions

In order to reduce the level or risk – either in terms of minimising the likelihood of leakage, the size and duration of a flammable mixture and/or the severity of consequences, certain measures can be introduced into the design, construction and operation of the equipment. Typical examples include improved leak tightness, use of airflow (natural ventilation, mechanical ventilation or internal air circulation), features to limit the amount of released refrigerant and enclosure structures to provide overpressure relief.

References (list of references is provided in the Annex to Chapter 4)
Colbourne 2013b; Colbourne 2012a; Dorman 2013; JSRAE 2013; JSRAE 2014; JSRAE 2015; JSRAE 2016; JSRAE 2017; Tadros 2008; Walter 2014.

4.3.7 Risk assessment (qualitative/quantitative)

There are various International Standards providing methodologies for risk assessment techniques (such as general risk management, fault tree analysis, event tree analysis, hazard and operability studies, human reliability assessment, failure modes and effects analysis, etc.) Throughout the wider literature, risk assessment of flammable substances is handled extensively, including numerous handbooks and a vast array of technical articles covering specific elements of flammability risk assessment in fine detail.

Similarly, for QRAs specifically on the topic of flammable refrigerants there been numerous studies carried out over the past 20 years, with application to various types of R/AC&HP equipment.[9] These include: room air conditioners, display cabinets, freezer cabinets, refrigerated transport units, domestic refrigerators, beer coolers, reefer containers, mobile/car ac systems, milk tanks, domestic heat pumps, ducted air conditioning systems, multi-split/VRF air conditioning systems and chillers.

Risk assessments include class A2L, A2 and A3 refrigerants.

Most studies deal with new systems, although the case of flammable refrigerants in systems manufactured for non-flammable refrigerants are also addressed.

Methodologies differ widely, in terms of numerical approach, determination of leak characteristics, quantification of flammable times, volumes and mixture concentration (both computationally and experimentally) and representation of consequences. Similarly, the granularity is handled to various extents, for instance, the number of leak holes or leak mass flow rates, the range of local environmental conditions, system operating modes and failure conditions. Some risk assessment studies address the implementation and effectiveness of mitigation measures.

There are a host of assumptions that typically need to be made, due to absence of suitable data, and this can have a substantial impact on the outcome of the QRA. Furthermore, a large number of variables for which assumptions should be made (or data obtained) are often overlooked within studies which equally skews outputs.

Most risk assessments are limited to the R/AC&HP equipment “in-use”, since this ordinarily represents more than 99% of the lifetime of the equipment. Some studies have addressed the

[9] Many enterprises have carried out such risk assessments when developing and in preparation of new products using flammable refrigerants, but tend not to publish them.

infrastructural stages such as manufacturing, transportation, storage, etc.; however, these are typically addressed by manufacturers internally.

Despite installation, service, maintenance and decommissioning overall representing a small proportion of the lifetime of R/AC&HP equipment, it nevertheless can result in the highest contribution to flammability risk on account of these stages involving intentional transfer and release of flammable refrigerant. Several studies have tackled these stages, however, quantification of the flammability risk here is difficult and highly uncertain due to variations in technician behaviour, access to tools and equipment, environmental conditions and so on.

Another important aspect is the choice of “tolerable”, “acceptable” or “negligible” risk and how it is interpreted and compared against calculated values.

References (list of references is provided in the Annex to Chapter 4)
AHRI 2015; Blackwell 2006; Blom-Bruggeman 1996a; Blom-Bruggeman 1996b; Colbourne 2004a; Colbourne 2004b; Colbourne 2008; Colbourne 2011; Colbourne 2014; Colbourne 2013; Colbourne 2016a; Colbourne 2016c; Gerwen 1994; Gerwen; Gmünder 2002; Goetzler 1998; Goetzler 2016; Goetzler 2013; Imamura 2014; Jansen 1996; JSRAE 2013; JSRAE 2014; JSRAE 2015; JSRAE 2016; JSRAE 2017; König 2014; Lewandowski 2012a; Lewandowski, 2012b; Maclaine-cross 2004; Poolman. 2016; Ritter 1998; Takaichi 2014; Ueda 2014; Wolfer 1999a; Wolfer 1999b; Yajima 2014; Yao 2000; Zhang 2013; Zhang 2015.

4.4 Overview of recent work on safety of alternative refrigerants under ISO and IEC

This section contains a summary of subjects being considered and addressed within the various TCs and WGs that are revising and developing amendments for R/AC&HP safety standards. (Refer to Chapter 5 for details of the genesis of the various WGs.)

The main focus of the WGs dealing with A2Ls is to greatly extend the applicability of the refrigerants across a wider variety and size of R/AC&HP equipment. Part of this is to enable greater flexibility of ways by which A2L refrigerants can be applied with the larger charge sizes.

For A2L refrigerants, there has been considerable work generated and deliberated (mostly previously) within ISO TC86 SC1 WG1, ISO TC86 SC8 WG5, but most substantially within IEC SC61D WG9. There has been some limited A2L-specific discussion within IEC SC61C WG4. Table 4-1 provides a summary.

For A3 refrigerants the limited charge mass (as a function of room size) set by safety standards is the most significant obstruction to broader market penetration. Accordingly the focus of the work amongst the various WGs is to develop requirements, including mitigation strategies, to enable larger charge sizes (for a given room size, etc.) whilst not adversely compromising risk. The situation is less of a concern for A2 refrigerants.

For A2 and A3 refrigerants, there is relatively minor discussion within ISO TC86 SC1 WG1 and ISO TC86 SC8 WG5. Most of the substantive work has occurred within IEC SC61D WG16 and IEC SC61C WG4. Table 4-2 provides a summary.

Table 4-1: Summary of topics under discussion for A2Ls within WGs

Area	Addressed within current WGs
▪ **Fluid flammability characteristics**	Consideration of latest data within WG1. Particularities of A2Ls associated with lower likelihood of ignition integrated into many requirements under WG1 and WG9
▪ **Release/leakage characteristics**	
— **Leak size/rates, leak frequencies and system tightness**	Handled by WG9 and WG1 by assuming smaller leaks for "enhanced tightness systems" thus allowing larger charge sizes
— **Release amounts**	WG9 and WG1 permit larger charge sizes if valves are used to stop leakage into rooms. WG1 considering quantifiable method of reduced releasable charge according to test.
▪ **Behaviour of leaked refrigerant**	
— **Dispersion of refrigerant within rooms (quiescent, with airflow, etc.)**	Considered under WG1 and WG4 and an extensive part of WG9 proposal developments. Addressed: influence of various leak sizes, adjoining rooms, rooms with natural ventilation/openings, mechanical ventilation, unit circulation.
— **Dispersion of refrigerant outside**	No
— **Equipment characteristics and external conditions**	No
▪ **Potential sources of ignition**	Considered in WG9 in two respects. Assigning features of electrical switch components to avoid ignition. Assumed ignition sources within rooms to tolerate certain flammable volumes and persistence.
▪ **Evaluation of consequences**	In WG1 and WG9 assumed to be controlled through limited size and duration of flammable mixture.
— **Thermal intensity**	No
— **Pressure wave/ overpressure**	No
— **Secondary fire**	No
— **Hazardous decomposition products**	No
▪ **Risk assessment**	Considered broadly across all WGs.
— **In use**	Considered broadly across all WGs.
— **Installation, service and maintenance**	Addressed within WG9, but only by refining existing technician refrigerant handling guidelines.
— **End-of-life (transport and disposal / recycling)**	No
— **Transportation and storage**	No

Table 4-2: Summary of topics under discussion for A2 and A3s within WGs

Area	Addressed within current WGs
▪ Fluid flammability characteristics	No
▪ Release/leakage characteristics	
— Leak size/rates, leak frequencies and system tightness	Handled by WG16 by assuming smaller leaks for "improved tightness systems" thus potentially allowing larger charge sizes
— Release amounts	WG16 developing quantifiable method of reduced releasable charge according to test. WG1 further considering the approach.
▪ Behaviour of leaked refrigerant	
— Dispersion of refrigerant within rooms (quiescent, with airflow, etc.)	Considered extensively under WG16 and WG4 for proposal developments. Addressed: influence of various leak sizes, unventilated/quiescent conditions, unit air circulation.
— Dispersion of refrigerant outside	No
— Equipment characteristics and external conditions	WG4 and WG16 considered effects of housings/unit constructions.
▪ Potential sources of ignition	No
▪ Evaluation of consequences	In WG1, WG16 and WG4 assumed to be controlled through limited size and duration of flammable mixture.
— Thermal intensity	No
— Pressure wave/ overpressure	No
— Secondary fire	No
— Hazardous decomposition products	No
▪ Risk assessment	Considered broadly across all WGs.
— In use	Considered broadly across all WGs.
— Installation, service and maintenance	No (already handled with existing guidelines)
— End-of-life	No
— Transportation and storage	No

An important distinction may be made between the approach of the various R/AC&HP safety standards in terms of how measures for addressing the flammability hazard is conveyed. ISO 5149-1, IEC 60335-2-24, IEC 60335-2-40 and IEC 60335-2-89 – predominantly for static R/AC&HP systems – are broadly based on a "prescriptive" approach. Essentially, for a given situation (type of occupancy and location of the system) the flammability risk is broadly assumed to be a function of the quantity of flammable refrigerant (and it's flammability characteristics, in some cases). In this regard, there is little flexibility for system designers to offset additional refrigerant charge (as required) through implementation of risk reducing measures, specified or not. Although there are now opportunities for such flexibility within ISO 5149-1 and the proposals being developed by some of the WGs mentioned, the standard nevertheless dictates the form of mitigation measures, the extent of freedom and the limits for their application.

Conversely, two standards – ISO 13043 and ISO 20854 – that have been established relatively recently and under technical committees that do not historically deal with R/AC&HP applications, adopt a performance based approach. In these, the responsible body must carry out a comprehensive flammability quantitative risk assessment on the chosen design and identify whether a satisfactorily low risk is achieved. A detailed explanation of these two standards is provided in Annex 4.3.

Both these approaches have their merits and shortcomings. The prescriptive approach leads to technological constraints (such as those under discussion within this report) and subsequently limit innovation. On the other hand, it should be relatively straight-forwards for non-specialists to follow and apply and can therefore be used efficiently and across a broad range of enterprises and applications. A performance type approach (based on risk assessment) enables flexibility in terms of system design and function thereby minimising constraints on novel developments. The main disadvantage is that it typically demands a high level of expertise and is likely to be time- and resource-intensive. Thus, widespread use across a large number of differing products (e.g., within a single enterprise) could be prohibitive. Ideally, a safety standard should comprise both approaches to benefit enterprises under all circumstances.

4.4.1 Continuing work on fluorinated substances classed as A2L

Whilst the consequences of ignition of higher flammability substances such as hydrocarbons have been widely studied for many decades, work on fluorinated substances classed as A2L is in its infancy. As such, as new research is carried out, significant aspects concerning their behaviour are evolving. For instance, whilst small-scale experiments have previously shown that the severity of certain primary consequences of ignition is strongly dependent upon the relatively low laminar flame speed, some large/full scale experiments have yielded "unexpected" behaviour such as rapid pressure build-up and turbulent burning, which are indistinguishable over a range of laminar flame speeds. Additionally, testing carried out in conjunction with automotive industry and associated with the development period of ISO 13043 examined the effects of releases of HFO-1234yf in passenger compartments. These tests showed that decomposition of HFO-1234yf takes place after release at reaction threshold temperature below auto ignition temperatures and thus yields caustic decomposition products under unexpected conditions (e.g., Holtappels 2009; Holtappels, 2014). Accordingly it may be necessary to carry out deeper investigations into unanticipated consequences. Indeed there are several research projects planned (e.g., see Annex 4.2) that may address some of these topics.

4.5 Final remarks

Safety standards that handle refrigerants should be developed so as to minimise the likelihood of all the detrimental consequences to persons and property associated with their release. For flammable refrigerants this includes pressure rise (overpressure), thermal radiation, secondary fires and formation of hazardous decomposition products. Accordingly, safety standards need to address the various effects and causes of releases under a wide range of circumstances.

Guidelines published by ISO and IEC offer basic principle and suggestions as to how safety risks should be analysed and how approaches and requirements can be developed to mitigate those risks. Practical application of these guidelines demands detailed knowledge and understanding of the particular properties, physical mechanisms and applications of the substances and equipment for which the requirements are being developed.

It is evident from the compilation of published work related to the cause, effects, consequences and overall, the risk of applying flammable refrigerants that there is extensive and comprehensive collective knowledge. As the level of interest in flammable refrigerants has increased over time, more detailed and elaborate studies have been carried out, also considering more deeply the specifics and nuances of R/AC&HP equipment design, construction and operation that can affect flammability risk. This trend is likely to continue for at least the near- and mid-term future.

Whilst there is evidently a fairly substantial body of work, not all of it is directly or even indirectly applicable to development of technical requirements within safety standards. Moreover, whilst a significant portion of the body of work is relevant to the development of requirements, participants of the various TCs and WGs are seldom aware of, or even have access to the material. Alternatively, participants may be aware of the publications but often do not have the time to read and absorb the information to an extent that it can be used to for deliberations of and guide the drafting of standards' text. Another implication is that whilst the body of work covers a wide number of types of R/AC&HP equipment, the sheer breadth of varieties and variations in system designs, constructions, installation situations and operating conditions means that there will always be open questions as to the suitability and validity of proposed requirements. Unfortunately, this can be used as means – rightly or wrongly – to impede progress. Of course, many studies have and will further address as wide a range of important variables as possible so that conclusions can be drawn with a high level of confidence across a wide range of equipment and application characteristics.

Both the published literature and importantly, unpublished work developed specifically for resolving specific issues arising from deliberations within WGs, have helped in the development of various proposals for the relevant safety standards. A summary of the topics dealt with by the various TCs and WGs is given in Table 4-1 and Table 4-2. As the level of understanding and knowledge of the subject increases, it is likely that additional ways and means of extending the application of all flammable refrigerants and concurrently integrating risk mitigation measures will be featured within proposals for the safety standards.

5 Standards development and applicability to R/AC&HP sector

5.1 Introduction

Drafting of a new standard, revision of or amending an existing standard requires a systematic and well-defined series of steps, typically designed to enable input from interested stakeholders. The development process as prescribed within the ISO/IEC Directives Part 1 is summarised in Chapter 3. It also involves stakeholders from member countries, participating at national level and at committee and working group level. In this chapter the member countries for the various committees responsible for R/AC&HP standards are identified, as well as liaisons and working groups. A progress summary of the activities under various standards is provided, where it concerns developments applicable to alternative refrigerants. Lastly, a discussion is provided of possible involvement of stakeholders concerned with alternative refrigerants.

5.2 Participation in R/AC&HP standards development

At ISO and IEC level, there are at least five technical subcommittees that are responsible for the development of the previously identified safety standards. This chapter covers the five main committees. Table 5-1 lists all of the member countries (P-members and O-members) within each of the five technical subcommittees. In addition, the applicable national body is included.

Table 5-1/1: P-members and O-members of committees responsible for the R/AC&HP standards

ISO TC86 SC1	ISO TC 22 SC 34	IEC TC61 SC61C	IEC TC61 SC61D	ISO TC 104 SC 2
Participating members	**Participating members**	**Participating members**	**Participating members**	**Participating members**
France (AFNOR) United States (ANSI) India (BIS) United Kingdom (BSI) Germany (DIN) Denmark (DS) Egypt (EOS) Russian Federation (GOST R) Japan (JISC) Korea, Republic of (KATS) Belgium (NBN) Netherlands (NEN) Poland (PKN) Australia (SA) China (SAC) Canada (SCC) Finland (SFS) Spain (UNE) Italy (UNI)	Brazil (ABNT) France (AFNOR) United States (ANSI) Austria (ASI) India (BIS) United Kingdom (BSI) Germany (DIN) Egypt (EOS) Japan (JISC) Korea, Republic of (KATS) Belgium (NBN) Netherlands (NEN) China (SAC) Sweden (SIS) Norway (SN) Italy (UNI)	Netherlands (NEC) Japan (JISC) Australia (SA) China (SAC) Germany (DKE) Sweden (SEK) Ukraine (UkrNEC) Czech Republic UNMZ) South Africa (SABS) Malaysia (DSM) Mexico (CEM) New Zealand (SNZ) United States of America (ANSI) France (AFNOR) Austria (OVE) Italy (CEI) Korea, Republic of (KATS) Portugal (IPQ) Jordan (JSMO) Iraq (IQC) Serbia (ISS) Brazil (COBEI) Egypt (MEE) Turkey (TSE) India (BIS) Switzerland (CES) Belgium (CEB) Poland (PCS) Philippines, Rep. of the (BPS) Slovakia (SEV) Finland (SESKO) United Kingdom (BSI) Spain (UNE) Denmark (DS)	Belgium (CEB) France (AFNOR) Egypt (MEE) Australia (SA) Germany (DKE) Sweden (SEK) Japan (JISC) Italy (CEI) Korea, Republic of (KATS) Netherlands (NEC) China (SAC) Serbia (ISS) South Africa (SABS) Denmark (DS) Spain (UNE) Iraq (IQC) United Kingdom (BSI) Philippines, Rep. of the (BPS) Turkey (TSE) United States of America (ANSI) India (BIS) Austria (OVE)	France (AFNOR) United States of America (ANSI) India (BIS) United Kingdom (BSI) Germany (DIN) Denmark (DS) Russian Federation (GOST R) Japan (JISC) Korea, Republic of (KATS) Kenya(KEBS) Netherlands (NEN) Ireland (NSAI) Australia (SA) China (SAC) Canada (SCC) Spain (UNE) Italy (UNI) Czech Republic (UNMZ)

Table 5-1/2: P-members and O-members of committees responsible for the R/AC&HP standards

ISO TC86 SC1	ISO TC 22 SC 34	IEC TC61 SC61C	IEC TC61 SC61D	ISO TC 104 SC 2
Observing members	**Observing members**	**Observing members**	**Observing members**	**Observing members**
Austria (ASI) Romania (ASRO) Bulgaria (BDS) Portugal (IPQ) Serbia (ISS) Iceland (IST) Kenya (KEBS) Hungary (MSZT) New Zealand (NZSO) Pakistan (PSQCA) Israel (SII) Slovenia (SIST) Switzerland (SNV) Slovakia (SOSMT) Turkey (TSE) Czech Republic (UNMZ)	Romania (ASRO) Bulgaria (BDS) Korea, Democratic People's Republic of (CSK) Ukraine (DSTU) Russian Federation (GOST R) Croatia (HZN) Argentina (IRAM) Serbia (ISS) Mongolia (MASM) Hungary (MSZT) Ireland (NSAI) Poland (PKN) Finland (SFS) Switzerland (SNV) Slovakia (SOSMT) Turkey (TSE) Spain (UNE)	Bulgaria (BIS) Kuwait (KNCEF) Canada (CANC) Indonesia (BSN) Israel (SII) Ireland (NSAI) Belarus (BELST) Slovenia (SIST) Singapore (SPIB) Iran (NCI) Norway (NEK) Hungary (MSZT) Colombia (ICONTEC) Greece (NQIS) Thailand (TISI) Romania (ASRO) Russian Federation (FATRM)	Slovenia (SIST) Belarus (BELST) Switzerland (CES) Brazil (COBEI) Singapore (SPIB) Thailand (TISI) Slovakia (SEV) Ukraine (UkrNEC) Czech Republic UNMZ) Malaysia (DSM) Mexico (CEM) Norway (NEK) New Zealand (SNZ) Poland (PCS) Romania (ASRO) Russian Federation (FATRM) Indonesia (BSN) Israel (SII) Ireland (NSAI) Portugal (IPQ) Hungary (MSZT) Greece (NQIS) Finland (SESKO) Iran (NCI) Canada (CANC) Bulgaria (BIS) Kuwait (KNCEF)	Romania (ASRO) Bulgaria (BDS) Malaysia (DSM) Ukraine (DSTU) Croatia (HZN) Luxembourg (ILNAS) Portugal (IPQ) Argentina (IRAM) Hungary (MSZT) Belgium (NBN) Poland (PKN) South Africa (SABS) Finland (SFS) Slovakia (SOSMT) Singapore (SPIB)

In addition to the member countries, there are also several liaisons within R/AC&HP standards Technical Committees and Subcommittees, including:

- With IEC SC61C – IEC SC61D
- With IEC SC61D – IEC SC31J (Classification of hazardous areas and installation requirements), IEC SC61C
- With ISO TC86 – European Committee of Domestic Equipment Manufacturers (CECED), IEC SC61C, European Environmental Citizens Organisation for Standardisation (ECOS), European Committee of Air Handling and Refrigeration Equipment Manufacturers (Eurovent), International Institute of refrigeration (IIR), United Nations Economic Commission for Europe (UNECE), United Nations Environment programme (UNEP)
- With ISO TC 104 SC 2 – ISO TC86 SC1, International Air Transport Association (IATA), International Institute of Refrigeration (IIR), International Maritime Organisation (IMO), plus others.

Within the Working Groups responsible for revisions of the safety standards that affect requirements for alternative refrigerants, the following comprise the participation:

- IEC SC 61C WG4 – 30 members from 16 countries (3 are Article 5 parties
- IEC SC 61D WG9 – 32 members from 13 countries (2 are Article 5parties)
- IEC SC 61D WG16– 27 members from 12 countries (3 are Article 5 parties)
- ISO TC86 SC1 WG1 – 52 members from 12 countries (1 is Article 5 party) 4 members from non-industry NGO
- ISO TC 104 SC 2 WG1 – 26 members from 12 countries (1 is Article 5 party)

The establishment of the various WGs arose at different times and circumstances.

IEC SC 61C WG4 arose from a proposal of the British national committee in September 2014 to increase the charge limit for all flammable refrigerants in IEC 60335-2-89 from 150 g to 500 g, provided additional mitigation measures are applied.

IEC SC 61D WG9 was initiated in November 2011 following a proposal from the Japanese national committee to add new requirements to IEC 60335-2-40 for refrigerants which (at the time) would become classified as A2L[10] . The proposal covered a broad range of aspects including charge size limits (absolute and in relation to room size), handling sources of ignition, etc.

IEC SC 61D WG16 was set up in response to a proposal from the British national committee in April 2015 to include additional requirements to allow greater A2 and A3 refrigerant charge for a given room size, on the condition of additional mitigation measures.

ISO TC86 SC1 WG1 is an already established WG that was working on the revision of ISO 5149 since 1995. Following the publication of the revised ISO 5149 in 2014, the WG was tasked to continue developing and improving requirements related to refrigerant safety (amongst other safety-related aspects) for forthcoming amendments and revisions of the standard.

ISO TC 104 SC 2 WG1 began work in September 2015 in response to a proposal from Denmark/Germany on drafting a new standard on safe operation of reefers containers with flammable refrigerants by means of risk based assessment for design and operation.

5.3 Implications of current standards on technology choice

Historical use of refrigerants gravitated towards those which were easiest and cheapest and which could be applied with minimal complications, depending upon the application and local conditions. Apart from industrial and process applications, this meant widespread use of a small number of fairly benign substances, in terms of safety hazards to users and workers. Once substances had been developed that posed the least significant safety hazards, there was seldom a need to opt for higher toxicity, flammable or very high pressure refrigerants. Majority of established stakeholders and participants in most of the relevant TCs, SCs and WGs only had experience, knowledge and interests in class A1 refrigerants. Accordingly, R/AC&HP safety standards evolved to reflect this widespread practice. With the advent of the Montreal Protocol and shift towards zero ODP and increasingly towards lower GWP refrigerants, the need for revised safety standards to enable broader safe use of higher pressure, higher toxicity and particularly flammable refrigerants became more important. Since the beginning of this process, achieving progressive changes to safety standards has been largely sluggish and laborious, partly due to sustained traditional views and established commercial interests in existing or competing technologies and possibly due to insufficient knowledge[11]. Present technical requirements, particularly concerning flammable and higher flammability refrigerants within the majority of the international safety standards are reflected by this situation.

Given the wide variety of different types, arrangements, positioning, operating temperatures and end uses of R/AC&HP systems and equipment and how the different ways by which the various

[10] To clarify, at that time the current version of IEC 60335-2-40 (Edition 4.2), as with the current version (IEC 60335-2-40:2013+AMD1:2016, Edition 5.1) contained requirements for the application of flammable refrigerants, including those which are now classified as A2L, e.g., HFC-32.

[11] As with most sectors, certain stakeholders will always claim that there is insufficient evidence to justify permitting a change in policy or technology; there is always an opportunity to find an exception or variable that has not been satisfactorily accounted for. Where there are adverse principles or commercial interests at stake, the proportion of stakeholders that may perpetuate this position will usually be higher.

safety standards address the implementation of flammable refrigerants, it is difficult to clearly identify circumstances where a given refrigerant or refrigerant class is effectively prohibited. However, the characteristics of the current limitations and constraints to important technologies can be described.

Broadly, there are four "forms" of constraints that the various international safety standards pose to flammable refrigerants:

i.) Scope of the standard excludes the refrigerant(s) totally or above a certain quantity
ii.) Requirements prohibit charges above a certain (absolute) quantity (for a given type of system and/or location)
iii.) Requirements prohibit charges above a certain quantity in relation to a room size
iv.) Requirements are sufficiently onerous that equipment costs would be commercially prohibitive

Where the boundaries of these constraints lie for a particular type of R/AC&HP system differs widely according to the opinion and degree of experience of the individual consulted, as well as geographical conditions, degree of technological development or application expertise, etc. It should also be recognised that there may not be consensus on whether a certain constraint (e.g., prevention of a given flammable refrigerant being used in a particular system or situation) already represents a tolerable or acceptable "safe" boundary[12]. According to some opinions, certain constraints currently represent some sort of "natural" safe boundary, whilst other opinions hold that those boundaries are either too stringent or could at least be flexible. Often the positioning of such a conceptual boundary (e.g., in terms of charge size in relation to an occupancy) is custom and practice, rather than evidence based, meaning that certain stakeholders would find it difficult to accept any further deviation.

Nevertheless, considering the forms of constraints (as listed above), Table 5-2 provides an indication as to where limitations may exist according to each safety standard, R/AC&HP sub-sector (according to (RTOC, 2014)) and refrigerant safety classification.

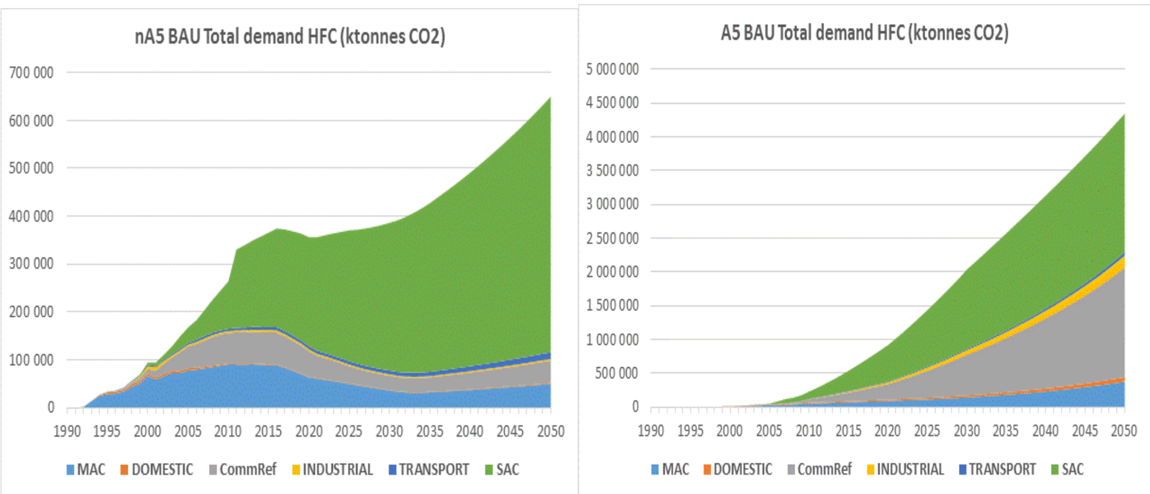


Fig. 5-1, 5-2: Non-Article 5 and Article 5 parties BAU HFC demand up to 2050; large demands are forecast for particularly the stationary AC (SAC) and commercial (CommRef) sector (TEAP TF XXVIII/4 report, 2016)

---

[12] For instance, the current absolute limit of 1.5 kg of A3 refrigerant (per circuit) in indoor public areas constrains the type and size of equipment to some fraction of equipment population currently applied in such situations (with non-flammable refrigerants). Increasing that limit to 150 kg of A3 may enable almost all types of currently equipment to be used, but it may not be "safe" (even with additional mitigation measures).

It is important to consider the impact of the most severe constraints indicated in Table 5-2 on the sub-sectors to which the applicable safety standards apply. For both non-Article 5 and Article 5 parties (see Figure 5-1 and 5-2 above), the sub-sectors that exhibit the greatest anticipated consumption of HFCs in terms of t CO_2-eq. are "SAC" and "Commref"[13].

These are exactly the sub-sectors where the most severe constraints exist to applying low GWP alternatives, particularly A2 and A3 refrigerants, which exhibit the greatest t CO_2-eq reduction potential.

Table 5-2: Indication of where different types of constraints may exist (see text for definition of constraints (i), (ii), (iii), (iv)0

Standard	**IEC 60335-2-24**			**IEC 60335-2-40**			**IEC 60335-2-89**			**ISO 13043**			**ISO 5149**		
	A2L	A2	A3	A2L	A2	A3	A2L	A2	A3	A2L	A2	A3	A2L	A2	A3
Domestic refrigeration	i	i	o	–	–	–	–	–	–	–	–	–	–	–	–
Commercial refrigeration	–	–	–	–	–	–	i,ii	i,ii	i,ii	–	–	–	o	ii,iii	ii,iii
Industrial systems	–	–	–	–	–	–	–	–	–	–	–	–	o	o	o
Transport refrigeration	–	–	–	–	–	–	–	–	–	–	–	–	o	o	ii,iii
Air-to-air AC & HP	–	–	–	ii,iii	ii,iii	ii,iii	–	–	–	–	–	–	o	ii,iii	ii,iii
Water heating HP	–	–	–	o	o	iv	–	–	–	–	–	–	o	ii,iii	ii,iii
Chillers	–	–	–	o	o	o	–	–	–	–	–	–	o	o	o
Vehicle AC	–	–	–	–	–	–	–	–	–	i	i	i	i	i	i

" – " means not applicable
"o" means broadly acceptable

5.4 Status of the most relevant R/AC&HP safety standards

Amongst the most relevant R/AC&HP safety standards, it is recognised that there are notable problems and inconsistencies as well as substantial limitations imposed by current requirements. In response to this, there are a number of development activities on-going that relate to alternative refrigerants. The processes are dynamic and subject to continual change, so providing specific details is inappropriate. However, as a summary of these various activities, details are provided in Table 5-3.

5.5 Possibilities for stakeholder involvement

Depending upon the approach of the national body, stakeholders – individuals, government representatives, enterprises, etc. – may participate within the standards development process:

- At national level, e.g., through submitting proposals, comments to circulated documents and proposed position for voting;
- At committee level, e.g., through participation at TCs and SCs;

[13] Graphs are for business as usual, BAU, scenarios, but the various MIT scenarios show the same ranking.

- At WG level, i.e., by actively participating in discussions and submitting supporting technical work.

Table 5-3: Details of responsible committees and member countries for the relevant R/AC&HP standards

Standard	Projects	Description/current stage (Apr 2017)	Expected publication
IEC 60335-2-24	Revision of IEC 60335-2-24	7th Edition of the standard is at FDIS stage. A number of minor changes that relate to the application of alternative refrigerants.	Within 2017
IEC 60335-2-89	WG 4: To define the maximum flammable refrigerant amount for appliances according to IEC 60335-2-89 and measures to maintain the equivalent safety level as for the present limit.	A revised DC being circulated for comments. The draft includes requirements to allow an increase in flammable refrigerant charge size.	2018 – 2020
IEC 60335-2-40	WG 9: Addition of coverage for A2L refrigerants	CDV accepted and will be submitted for another CDV or FDIS. It allows an increase in A2L charge size by a factor of 10 along with associated measures. It also includes alternative measures for addressing sources of ignition.	2017 – 2018
	WG 16: Address A2 and A3 refrigerants	DC on "releasable charge" issued. DC on charge formula for integral airflow and improved tightness in preparation	2019 – 2025
	SC61D: specific requirements for the use of carbon dioxide (R744) and similar refrigerants in potentially transcritical refrigeration systems	CDV accepted and will be submitted for FDIS	2017 – 2018
ISO 5149	WG 1: Safety and environmental requirements for refrigerating systems and heat pumps	Working on various aspects relating to new and revised requirements for alternative refrigerants for inclusion into ISO 5149. (No drafts have been circulated for consideration yet.)	Before 2030
ISO 13043	None	None	–
ISO CD 20854	WG 1: drafting a new standard of safe design and operation of reefers with flammable refrigerant	Document for entire standards circulated to NCs as a CD in April 2017	2018-2019

Currently, with the development of the various R/AC&HP safety standards, there are a relatively few entities involved in the development process at TC, SC and WG level. As such, these stakeholders exercise a dominant role within the TCs, SCs and WGs at most of the development stages. Whilst there are tens of thousands of equipment manufacturers, installation and service contractors and end users of R/AC&HP systems and equipment, current active participation in the standards development process is in the order of a few tens of stakeholder entities. Furthermore, there are even fewer entities that have a substantial participation (in terms of representatives), over and above other stakeholders. Whilst this may be viewed as resulting in disproportionate influence over the process, it also highlights the importance of active participation from other interested parties.

Arguably, the reason for the lack of widespread participation of stakeholders is due to three main reasons:

- High investment costs associated with committing dedicated staff to continually review and comment on documents, frequent national and international meetings and carry out background technical work for contributing to developing, drafting and supporting proposals and counter-proposals. Further, many national bodies demand high participation fees, while others limit the participants to a certain number within each NC and/or WG category or accepts participants by invitation only.
- The development time is usually drawn out over a period of several years so any benefits from a stakeholder's investment will take some years to manifest; that is, if the desired content is accepted. It is easier for most enterprises to accept what other stakeholders formulate within a standard and fit their technology into the constraints arising from what is published. This can be especially evident when enterprises are nationally or regionally based and the significance of working on International Standards appears rather distant.
- Lastly, there is widespread ignorance of the standards development process; often within enterprises there is an assumption that standards are developed by some discrete entity, rather than the process being potentially open to almost any stakeholders.

Nevertheless, there are several interventions open for potential stakeholders who wish to contribute to the development of requirements to extend the application of alternative refrigerants and associated technologies. These intervention include the following:

- If not already a member, get the relevant national body to become a P-member of the applicable IEC or ISO R/AC&HP TC or SC;
- Representatives from interested stakeholders (whether industry, government, academia, etc.) can become an active member of the national body;
- Those representatives can attend meetings of the relevant TCs or SCs;
- Experts from the stakeholders can become active members of relevant working groups and/or ad hoc groups;
- Stakeholders, or even groups of interested stakeholders can actively gather data and carry out the necessary research and development activities necessary to contribute to the technical requirements within the TCs, SCs and WGs.

Since one of the fundamental principles of development of the standard is "consensus" (for example, within the WG), the evolution of the process is susceptible to the degree of involvement of participants. In one instance, if the WG comprises almost entirely of individuals with a common interest, the work can proceed quickly without obstruction. Conversely, if the composition of the WG includes individuals with opposing views, the process can potentially be stalled almost indefinitely. In addition to the usual active participation, taking the role of chair of NCs, TCs, SCs and convenors of WGs and AHGs (in the event of a vacancy) can be advantageous, albeit with the additional commitments to expenditure and resources.

5.6 Final remarks and possible implications

The standards development process is well defined and similarly tasks of entities involved within the process are clear at international level. Despite this, the process is relatively complicated and for drafting a new standard, revision or any substantial changes to an existing standard, can be protracted.

In order to actively participate in the process requires membership of a national body and attendance at NC meetings, TC or SC meetings and WG meetings, usually over a period of several years. Whilst at international level the activities are fairly inclusive to all nominated participants, at national level there is a wide variation. For instance, in some countries, membership may be freely available to stakeholders whilst in others countries it may be inhibited by high membership fees or by invitation only. Amongst the four TCs and SCs responsible for R/AC&HP safety standards there are about 50 countries which are members and about half of these are P-members. Just less than 30% of the countries are Article 5.

To supplement attendance, participants usually need to review and comments on an extensive number of documents, develop alternate proposals, supporting data and generate technical information for consideration by the TCs, SCs and/or WGs. Overall, active involvement in the standards development process can be demanding on time, resources, travel and morale. It also implies a long-term commitment to executing the task.

It is also important to highlight that discussions within national bodies, TCs, SCs and WGs can often be contentious and polarised, for instance where it concerns requirements for conflicting technologies such as refrigerants. Accordingly, stakeholders may adopt various strategies to strengthen their preferences. An example is ensuring presence of a majority of participants in a meeting so that a consensus can be more easily achieved in a WG or a positive vote in a TC or SC.

Within each of the four WGs related to alternative refrigerants, there are about 25-30 members, coming from around 15 different countries. The participation of Article 5 countries is limited to between one and three members, depending upon the WG.

Revisions and particularly amendments to most of the R/AC&HP safety standards are occurring on a regular basis, albeit often on a minor scale (i.e., adjusting a few lines of text, for example) and also not necessarily being related to refrigerants. The most substantial work is being carried out by four WGs, as indicated in Table 5-3:

- IEC SC61C WG4 is developing requirements for increased refrigerant charge size for commercial refrigeration appliances and the work may be complete within one to three years.
- IEC SC61D WG9 is drafting new requirements for extended application of A2L refrigerants in air conditioners and heat pumps and the amendment is likely to be published within one year.
- IEC SC61D WG16 is drawing up proposals to allow larger charge sizes for A2 and A3 refrigerants (relative to room size) for air conditioners and heat pumps, with completion expected within two to six years.
- ISO TC86 SC1 WG1 is revising the horizontal standard ISO 5149 which will address refrigerant charge size limits, but publication is unlikely to occur within several years.
- ISO TC104 SC2 WG 1 is developing a product standard ISO 20854 to enable the application of flammable refrigerants in freight containers, based on a risk assessment approach.

There is no activity underway for the mobile air conditioning (MAC) standard.

Notably, whilst there are a variety of proposed texts under discussion within these WGs, it is not possible to state what the final requirements will prescribe, due to the likelihood of changes to the current material before it is finally published.

6 Assessment of the implication of International Standards for the implementation of MOP decisions

6.1 Introduction

The purpose of this chapter is to make "an assessment of the implications of the International Standards for the implementation of the decisions of the meeting of the parties to the Montreal Protocol on the accelerated phase-out of HCFCs and HFC control measures, and recommendations to the parties" (Decision XXVIII/4, paragraph 1(iii)). Implications are understood to be not only the achievability of reduction but also the issues related to the freedom for refrigerants choices in a broader sense.

Decision XIX/6 (on the accelerated HCFC phase-out) and Decision XXVIII/1 (on the HFC phase-down) are separate decisions, where Decision XIX/6 is related to an HCFC phase-out (measured in ODP tonnes) while Decision XXVIII/1 is related to a phase-down of Annex F substances (measured in CO_2-eq. tonnes). However, it should be noted that the type of conversion to lower GWP substances is similar for the processes considered under both decisions.

In this chapter the consequences of the Decision XIX/6 will be briefly discussed for non-Article 5 and Article 5 parties. Compliance with the reduction schedules as listed in Decision XXVIII/1 requires a choice when converting from high-GWP to lower GWP refrigerant, where time scales are different for Article 5 and non-Article 5 parties. The first reduction step for non-Article 5 parties is in 2019 (with a baseline based on historic consumption levels of HCFCs and HFCs), the first reduction step for many Article 5 parties will be in 2029 (with a baseline based on future HFC annual consumption levels plus a part of the baseline HCFC consumption). This ten years difference is directly related to ways and means for implementing alternative solutions, i.e., a freedom of choice. This chapter will specifically investigate whether constraints and limitations within the current International Standards can impact the way the abovementioned Montreal Protocol decisions are implemented. This based on earlier observations that the content of International Standards can potentially have implications, with a varying impact of the implications amongst countries, directly related to the way how the International Standards are inserted in a country's legal framework.

6.2 International Standards, National Standards and regulations and timelines

Where it concerns the type of refrigerant applied, technical developments follow certain criteria or trends. International (safety) Standards give guidance and recommendations. National standards, derived from International Standards, may form the basis for national regulations that sometimes introduce additional limitations to the amounts of refrigerants applied in equipment. Current national regulations that take into account National Standards may be derived from International Standards dated years or sometimes even decades ago. However, if a country or a group of countries wishes to accelerate the introduction of a regulation in their countries, they can do so, independently from the form of or the (revision) stage the International Standards process is in.

Standard revision processes are currently underway with the aim of making them more technologically flexible provided there is enough support from experts and assessments in the standards processes. This higher flexibility will point even more at the fact that there is no "one fits all" solution, even within a specific R/AC&HP sector or subsector. It is typically so that an International Standard which is being revised at present (2017) may be adopted and published as of 2019-2020, maybe slightly later (see Table 5-3). It is important to mention this timeline aspect (also when translation to national legislation will take time and even when timelines have delays and set-backs in practice), since it is directly related to the interlinkage of short term implementation in non-Article 5 parties and possible early actions in Article 5 parties within the framework of Decision XXVIII/1.

6.3 Linkage with national regulations

As indicated in Chapter 2, some countries have national regulations that address the application of refrigerants, including flammable refrigerants. In some countries, these regulations reflected the requirements of international or other R/AC&HP safety standards, for example, by prohibiting the use of flammable (and higher toxicity) refrigerants in and/or associated within certain types of buildings. Conversely, other countries have regulations that impose restrictions on flammable refrigerants, which had been brought into force irrespective of any safety standards. In either case, such regulations – since they are legal instruments – create substantially more tangible technical limitations to the implementation of certain lower GWP alternatives than the international safety standards themselves.[14]

Other countries exercise a different mechanism, that in some respects can have a similar impact as those with a "direct" regulation. In these cases, the country has national legislation (or local laws) that explicitly mandates the application of certain (usually national) safety standards that may apply to products and/or installations. Under other systems, compliance with such safety standards may be accepted as one (of several other) means of complying with certain regulations.

It should also be noted that many countries do not have any national rules that relate to or address the safe application of refrigerants. On the other hand, most of them do have regulations that address the safe use and handling of flammable substances at a conceptual level (e.g., hazardous area regulations, product liability regulations).

There is evidently a wide range of national mechanisms that do or do not impose restrictions on the application of flammable refrigerants; to try to analyse them all and draw conclusions in terms of the overall implications for the implementation of Montreal Protocol decisions would be inappropriate.

However, what can be said is that where regulatory technical limitations do exist nationally, the viability of overcoming and/or the amount of time necessary for eliminating these legal restrictions can vary from months to several years or even decades. To generalise on possible timescales would not be appropriate without detailed analysis. In addition, if the relevant departments within parties' legislative structures are aware of the implications (in terms of compliance to Decisions taken by the parties), then it may be hoped that removal of such technical limitations could be accelerated. Similarly, if a country or a group of countries wishes to accelerate the introduction or modification of a regulation, they can do it independently from the form of or the (revision) stage the International Standards process is in.

6.4 Decision XIX/6

Here, the conversion to zero ODP substances involves substances addressed in International Standards and can involve the use of flammable substances with a lower GWP resulting in lower climate impacts. National regulations, derived from older International Standards related to lower GWP substances played a significant role in the early 2000s, by not allowing flammable substances for "comfort cooling". Because the phase-out of HCFCs in manufacturing processes occurred before 2010-2015 and already before 2004 in several non-Article 5 parties, this led to an increase of the consumption of high GWP HFCs and HFC blends such as R-404A and R-410A,

[14] *Understood to be France, Spain, Italy, Thailand and Singapore.*

even when Decision XIX/6 mentioned in its paragraph (8): "*To encourage Parties to promote the selection of alternatives to HCFCs that minimize environmental impacts, in particular impacts on climate, as well as meeting other health, safety and economic considerations".*

For Article 5 countries the impact has been and is different. Namely, Decision XIX/6 states the following in its paragraph 9: "*To agree that the Executive Committee, when developing and applying funding criteria for projects and programmes, and taking into account paragraph 6, give priority to cost-effective projects and programmes which focus on, inter alia, substitutes and alternatives that minimize other impacts on the environment, including on the climate, taking into account global-warming potential, energy use and other relevant factors".* This implies that the GWP of the substitute selected for conversion should preferably be characterised by a low or lower GWP as well as at least the same (or lower) energy use when used in equipment.

During the period 2010-2012, the conversion of air conditioning manufacturing from HCFC-22 to non-ozone depleting substances was considered under the Multilateral Fund and conversion to HFC blends such as R-410A was decided to be not eligible for funding because the GWP of R-410A was considered as too high. This has the consequence that choices are limited to lower GWP substances where the national regulations in Article 5 parties may play a role in the freedom for refrigerant choices for each equipment type. In countries where current International Standards are applicable this may result to a switch over to a low GWP or medium GWP refrigerant in a first step and eventually to a low GWP refrigerant in a second step, resulting in a double conversion and funding as foreseen in the Decision XXVIII/1. So, even if Decision XIX/6 and Decision XXVIII/1 are separate decisions they may influence each other as the options for refrigerants are limited by the International Standards and these may change over time.

Article 5 parties with not yet converted R/AC&HP equipment manufacturing activities may be required to switch to HCFC alternatives to comply with Decision XIX/6. Currently, only HFC-32, HC-290 and possibly some of the new low and medium GWP A2L HFC/HFO blends are available options. Some Article 5 parties may find HFC-32 and the A2L HFC/HFO blends to be interim options since the resulting GWP based consumption levels may affect their future compliance with Decision XXVIII/1. HFC-32, the HFC/HFO blends and HC-290 are all flammable to a certain degree, where current standards limit their application in larger than e.g. 5 kW room AC and multi-split systems. Handling flammable refrigerants in Article 5 countries also requires significant quality improvement for manufacture, installation, service and end-of-life. Currently there are some gaps in addressing these aspects in the International Standards, particularly for the installation, service and end-of-life.

6.5 Decision XXVIII/1

Where it concerns Decision XXVIII/1 and the reduction schedules, one can and has to discriminate between non-Article 5 parties and Article 5 parties.

For non-Article 5 parties, Decision XXVIII/1 introduces consumption reductions (expressed in CO_2-eq.) from a baseline of 10% in 2019, 40% in 2024 and 70% in 2029, eventually leading to a remaining 15% of the baseline by 2035. The baseline is equal to the average of the 2011-2013 HFC consumption plus 15% of the non-Article 5 (1989) HCFC baseline consumption.

In this case, the first 10% reduction may be largely achieved by reduction of controlled substance consumption (HFC) as well as conversion in non-R/AC&HP sectors which implies that no drastic changes in refrigerant types to be applied . The next reduction of 30% by 2024 necessary leads to partial conversion of certain R/AC&HP subsectors to lower GWP refrigerants. International Standards and national regulations may play a role, however, this will still imply a degree of freedom for the refrigerants choice for each equipment type. It is expected that International safety

Standards that are current in 2019 will play an important role for developing national regulations that will be applicable in the 2024 timeframe, the time of the 40% reduction step. Attention will have to be paid to the prescribed reduction percentages as these should be added to the market growth (in %, expressed in CO_2-eq.) as of the freeze year, yielding a total reduction required in a control step year. On the other hand, one has to realise that actions including reuse, recover and destruction are likely to have a positive impact on achieving the reduction percentage targets.

For Article 5 parties, Decision XXVIII/1 prescribes its earliest reductions (expressed in CO_2-eq.) -- via a 2024 freeze-- of 10% in 2029, 30% in 2035 and 50% in 2040, eventually leading to a remaining 20% of the baseline. The baseline is equal to the average of the 2020-2022 HFC consumption plus 65% of the HCFC baseline (2009-2010). It is difficult to determine at this stage what the consequences will be of technical developments in different sectors (such as foam blowing, fire protection, technical aerosols and R/AC&HP) that will occur during the period 2019-2024, related to possible choices to be made for reductions after the freeze year, but before the first control step in the year 2029. National regulations applicable around 2029 could be a result of published International Standards around 2024 which enables the conducting of even more than one revision of the current International safety Standards. As stated before, the revisions of International Standards may lead to a higher degree of freedom for refrigerants choice for each equipment type if a number of limitations related to maximum refrigerant charge are changed, i.e., reduced or softened.

Also here, attention has to be paid to the reductions percentages as these should be added to the market growth that will have occurred "in a reduction year" compared to the freeze year. On the other hand, actions including reuse, recover and destruction are likely to again reduce the necessary efforts for achieving the reduction targets. This will also be the case in Article 5 parties where funding of good practices (reuse and recovery) has been considered since many years and where extra enabling activities will be funded again for high-GWP HFCs and their lower GWP alternatives, in particular also flammable refrigerants.

Table 6-1 below shows an overview of limitations in the International Standards to allow application of lower GWP substances in each R/AC&HP sector or subsector. For the majority of the sectors or subsectors there are no technical restrictions in the current International Standards that prevent an early change-over to lower GWP substances. Other limitations exist created by certain National Standards, codes and regulations based on older International Standards and limitations due to product cost, product liability, company sustainability and customer perception which are expected to have a significant impact.

Air conditioning includes applications where the current safety standards limits the use of some alternatives to only part of a typical product range, unless major changes are done to the system architecture. One example is domestic split A/C where R-290 can be used for the smaller capacities with only minor changes to system architecture, but where the charge needed for larger systems will exceed what is prescribed by safety standards. Another example is large A/C systems with direct expansion, where for A2L refrigerants the charge needed for larger capacity systems will exceed what is prescribed by current safety standards. This phenomenon is aggravated in high ambient conditions where a larger cooling capacity and consequently more refrigerant is needed to cool the same space.

These are typically applications where a risk assessment combined with additional mitigation means will allow the refrigerant charges needed, and as described in chapter 4 and 5, work is ongoing in the standardisation organisations to allow the refrigerant charges needed provided a series of mitigation means are implemented. The timing of these updates and especially the speed of acceptance of these in the national legislations will affect which technologies will be available to replace the ozone depleting substances or high GWP refrigerants.

Table 6-1/1 Overview of the assessment of sectors and subsectors

R/AC&HP sector	R/AC&HP Subsector	Current refrigerants	Future refrigerants with lower GWP	International Standard	Use of lower GWP refrigerants	Limitations in non IEC/ISO standards or regulations	Financial impacts	Number of units produced per year	Charge amount
Domestic appliances	Refrigerators	NCSs, HFC-134a	NCSs	IEC 60335-2-24	technically possible	UL 250 is more restrictive than IEC	Implementation of recent developed low GWP HFCs (HFOs) may be postponed due to cost issues.	170 million	0.02-0.25 kg
	Heat pump tumble dryers	HFC-134a	NCSs	IEC 60335-2-11	technically possible		Implementation of recent developed low GWP HFCs (HFOs) and R-744 may be postponed due to cost issues.	1.5 million	0.2-0.4 kg
Commercial refrigeration	Plug in	NCSs, R-404A	NCSs	ISO 5149 IEC 60335-2-89	technically possible		Implementation of low GWP HFCs (HFOs) and R-744 may be postponed due to cost.		0.1 – 5 kg
	Condensing units	NCSs, R-404A	NCSs	ISO 5149 IEC 60335-2-89	technically possible				1 – 30 kg
	Centralised	NCSs, R-404A	NCSs	ISO 5149	technically possible				10 – 1000 kg
Industrial refrigeration		NCSs, R-404A	NCSs	ISO 5149	technically possible				1 – 1000 kg

*NCSs means Non Controlled Substances which include, among others, HCs (hydrocarbons), CO_2 and ammonia as well as HFOs

Table 6-1/2 Overview of the assessment of sectors and subsectors

R/AC&HP sector	R/AC&HP subsector	Current refrigerants	Future refrigerants with lower GWP	International Standard	Use of lower GWP refrigerants	Limitations in non IEC/ISO standards or regulations	Financial impacts	Number of units produced per year	Charge amount
Air to air air conditioning and heat pumps	Small self-contained	NCSs, R-410A	NCSs, HFC-32, mixtures of lower GWP HFCs and NCSs, HC-290	IEC 60335-2-40	technically possible	Some National Standards and regulations as well as product liability regulations may limit the use of flammable substances		17 million	0.3-3 kg
	Split non-ducted	HCFC-22, R-410A	NCSs, HFC-32, mixtures of lower GWP HFCs with NCSs, HC-290		technically possible			80 million	0.5-5 kg
	Multi-split	HCFC-22, R-410A	NCSs, HFC-32, mixtures of lower GWP HFCs with NCSs		technically possible for small charges .			1 million	2-240 kg
	Split ducted	HCFC-22, R-410A	NCSs, HFC-32, mixtures of lower GWP HFCs with NCSs					10 million	1-250 kg
	Commercial ducted units	HCFC-22, R-410A	NCSs, HFC-32, mixtures of lower GWP HFCs with NCSs					1 million	5-200 kg

*NCSs means Non Controlled Substances which include, among others, also HC (hydrocarbons), CO_2 and ammonia as well as HFOs (even if HC-290 (propane) is a Non Controlled Substance it is mentioned here as it is proposed in several HPMPs)

Table 6-1/3 – Overview of the assessment of sectors and subsectors

R/AC&HP sector	R/AC&HP subsector	Current refrigerants	Future refrigerants with lower GWP	International Standard	Use of lower GWP refrigerants	Limitations in non IEC/ISO standards or regulations	Financial impacts	Number of units produced per year	Charge amount
Water heating heat pumps		NCSs, R-410A	NCSs, HFC-32, mixtures of lower GWP HFCs with NCSs	IEC 60335-2-40	technically possible	Some National Standards and regulations as well as product liability regulations may limit the use of flammable or highly toxic substances			
Chillers		NCSs, HCFC-123, HFC-134a, R-410A	NCSs, HFC-32, mixtures of lower GWP HFCs with NCSs	IEC 60335-2-40 → ISO 5149	technically possible	Some National Standards and regulations as well as product liability regulations may limit the use of flammable or highly toxic substances	There is a financial impact expected for the use of flammable refrigerants.		
Mobile air conditioners		HFC-134a	NCSs	ISO 13043	technically possible				0.6-0.8 kg
Transportation refrigeration	Thermal containers	HFC-134a, R-404A	NCSs	ISO 5149 ISO CD 20854 under preparation	technically possible			100,000	4-5 kg

*NCSs means Non Controlled Substances which include, among others, also HCs (hydrocarbons), CO_2 and ammonia as well as HFOs

6.6 Conclusions

The common process is that National Standards and regulations are following the International Standards. In some cases national regulations did not follow the speed with which the International Standard were revised. Therefore, a number of national regulations limit the freedom for refrigerant choice in certain equipment types more than most recent International Standards do. Extending the freedom to select refrigerants for a certain equipment to facilitate the use of lower GWP refrigerants may impact the way how to achieve the phase-down steps as given in Decision XXVIII/1.

Taking the 2018-2022 timeline for conversions under the HCFC accelerated phase out regime (Decision XIX/6) for Article 5 parties, choices are limited with regard to use of lower GWP substances since the national regulations in these countries play a role in the freedom for refrigerant choice for each equipment type. In the case of non-Article 5 parties and the 2019-2024 timeline for achieving the 40% HFC phase down under decision XXVIII/1, if International Standards, National Standards and – where applicable, national regulations – have been updated, it would result in a higher degree of freedom to select refrigerants and achieve easy compliance with the control schedule. In the case of Article 5 parties, and the first reduction of 10% in 2028, as established by decision XXVIII/1 HFC phase down schedule, the afore mentioned is even more valid.

Factors such as product cost, product liability, company sustainability and customer perception are as important as International Standards when refrigerant choices are made.

7 Concluding remarks and recommendations to parties

The current international safety standards impose varying degrees of restriction on the application of certain medium and low GWP alternatives, depending upon the type of refrigeration system and the location of refrigerant in the equipment. Whilst it is “technically feasible” to use almost all class A flammable refrigerants in all applications, the critical issue is whether or not a given alternative can be used in a cost-effective way using state-of-the-art system architectures.

Broadly, there are four levels of constraints that the various international safety standards pose to flammable refrigerants: (i) scope of the standard excludes the refrigerant(s) totally or above a certain quantity; (ii) the technical requirements prohibit charges above a certain (absolute) quantity (for a given type of system and/or location); (iii) the requirements prohibit charges above a certain quantity in relation to a room size; and (iv) the requirements are sufficiently onerous that equipment costs would be commercially prohibitive. The severity of each level of constraint varies according to refrigerant, type of application and location of refrigerant in the equipment.

Broadly, the most critical situations concerning restrictions are A2 and A2L refrigerants in domestic refrigeration, all flammable refrigerants in commercial refrigeration appliances, A2 and A3 refrigerants in commercial refrigeration systems, A2 and A3 refrigerants in small air conditioning and heat pump appliances and systems and all flammable refrigerants in large air conditioning appliances and all flammable refrigerants (except HFO-1234yf) in MAC systems.

7.1 International Standards for R/AC&HP equipment

Within the R/AC&HP sector, there are currently nine main safety standards that cover whole systems, appliances, and products. Five are product safety standards and four are group safety standards.

If a product safety standard is available for the specific product or equipment of interest, then it should be used in preference to a group safety standard. However, unless national legislation mandates a particular product safety standard, then the choice is voluntary.

Safety standards do not override national legislation, however, standards are commonly referred to from or copied into national legislation. Whilst the standards discussed are International Standards, these are seldom used directly. Most countries will adopt a standard nationally or regionally.

For national adoption, many countries will include national modifications or deviations, for instance there may be national legislation that may conflict with the text within the international standard.
Since many enterprises operate internationally, there is a preference to ensure that the requirements of a standard are as universal as possible applicable so that national variations are kept to the minimum.

Compliance with safety standards plays an important role when substantiating that the safety of a system is according to recognized good practice. This is important for companies for managing the legal risk associated with selling systems or services associated with systems.

Some of the standards discussed in this report do not cover all aspects of the lifecycle. Especially the competences of the service technicians are important for the safety throughout the life cycle. To address the full lifecycle, the use of safety standards needs to be supplemented with a risk assessment.

Standards are often too expensive, too complex and not available in the local language, and therefore cannot serve as a direct source of knowledge for technicians and contractors. Rather industry guidelines and similar material will be needed.

7.2 Risk assessments and other technical work applicable to standards development

Safety standards that handle flammable refrigerants should be developed so as to minimise the likelihood of all the detrimental consequences – such as pressure rise (overpressure), thermal radiation, secondary fires and formation of hazardous decomposition products – to persons and property associated with their release. Guidelines published by ISO and IEC advise on principles of risk analysis, management and mitigation for purposes of standards development. Practically, the implementation of these guidelines demands detailed knowledge and understanding and systematic consideration of the particular properties, physical mechanisms and applications of the substances and equipment for which the requirements are being developed.

Already published work on causes, effects, consequences and overall risk associated with applying flammable refrigerants infers that there is extensive and comprehensive collective knowledge on the subject. The general areas of interest are: flammability characteristics, release/leakage characteristics, dispersion behaviour of leaked refrigerant, potential sources of ignition, consequences of ignition and risk mitigation systems/functions, as well as the combination of these within overall risk assessment. As the level of interest in flammable refrigerants increases over time, more detailed and elaborate studies are being carried out. Accordingly, the specifics and nuances of R/AC&HP equipment design, construction and operation that can affect flammability risk are becoming addressed more deeply. This trend is likely to continue for at least the near- and mid-term future.

Whilst there is a fairly substantial body of work, not all of it is directly or even indirectly applicable to development of technical requirements within safety standards. Moreover, whilst a significant portion of the work is relevant to the development of requirements, participants of the various TCs and WGs are seldom aware of, or even have access to the material. Alternatively, participants may be aware of the publications but often do not have the time to read and absorb the information to an extent that it can be used for deliberations and thus guide the drafting of the text.

Another implication is that whilst the body of work covers a wide number of types of R/AC&HP equipment, the sheer breadth of varieties and variations in system designs, constructions, installation situations and operating conditions means that there will always be open questions as to the suitability and validity of proposed requirements. Unfortunately, this can be used as means – rightly or wrongly – to impede progress. Subjectivity and motivations of participants involved in standards development plays a significant role in achieving consensus of the requirements and this can limit the usefulness of technical studies. Many published studies have and will further address as wide a range of important variables as possible so that conclusions can be drawn with a high level of confidence across a wide range of equipment and application characteristics.

Both the published literature and importantly, unpublished work developed specifically for resolving specific issues arising from deliberations within WGs, have helped in the development of various proposals for the relevant safety standards. As the level of understanding and knowledge of the subject increases, it is likely that additional ways and means of extending the application of all flammable refrigerants and concurrently integrating risk mitigation measures will be featured within proposals for the safety standards.

There remain a number of substantive issues associated with the flammability characteristics and associated consequences, especially for A2L refrigerants, which have arisen due to their study being in relative infancy compared to, say, hydrocarbons, and limited large/full-scale experiments. Accordingly it may be necessary to carry out deeper investigations into unanticipated consequences. Indeed there are several research projects planned (e.g., see Annex 4.2) that may address some of these topics.

7.3 Standards development and applicability to the R/AC&HP sector

At ISO and IEC level, there are four technical subcommittees responsible for the applicable safety standards. IEC SC 61C is responsible for IEC 60335-2-24 (domestic refrigeration) and IEC 60335-2-89 (commercial refrigeration appliances). IEC SC 61D us responsible for IEC 60035-2-40 (air conditioners and heat pumps). ISO TC86 SC1 is responsible for ISO 5149 (the horizontal standard for all R/AC&HP systems). ISO TC 22 SC 34 is responsible for the MAC standard ISO 13043, but does not have any additional activities related to revising the standard as the scope addresses low GWP refrigerants already (HFC-134a, HFO-1234yf and CO_2). ISO TC 104 SC2 is developing the standard ISO 20854, a new safety standard for reefer container using flammable refrigerants, describing requirements for design and operation. Amongst the four SCs responsible for R/AC&HP safety standards there are about 50 member countries and about half of these are P-members. Slightly less than 30% of the countries are Article 5.

Generally, in order to actively participate in the process requires membership of a national body and attendance at NC meetings, TC or SC meetings and WG meetings, usually over a period of several years; this is definitely applicable to R/AC&HP safety standards development. Whilst at international level the activities are fairly inclusive to all nominated participants, at national level there is a wide variation in conventions of national bodies/NCs. For instance, in some countries, membership may be freely available to stakeholders whilst in others countries it may be inhibited by high membership fees or by invitation only, which can and does create a technical limitation to active participation of interested parties. On a broader scale, active involvement in the standards development process, especially within WGs, is demanding on time, resources, travel and morale. It also implies a long-term commitment to seeing through the work. It is also important to highlight that discussions within national bodies, TCs, SCs and WGs can often be contentious and polarised, for instance where it concerns requirements for conflicting technologies such as refrigerants. Accordingly, stakeholders may adopt various strategies to strengthen their preferences. An example is ensuring presence of a majority of participants in a meeting so that a consensus can be more easily achieved in a WG or a positive vote in a TC or SC.

The majority of the technical work associated with developing existing and establishing new requirements is carried out within the WGs. Under the IEC and ISO SCs, there are four WGs specifically addressing material involving alternative refrigerants. WG4 is developing an amendment to -89 to increase the charge limits for flammable refrigerants; it has 27 members from 14 countries, 3 of which are Article 5. WG9 is developing an amendment for extended applicability of A2L refrigerants; it has 31 members from 12 countries, 1 of which is Article 5. WG16 is developing an amendment for increasing allowable charge (relative to room size) for A2 and A3 refrigerants; it has 28 members from 12 countries, 2 of which are Article 5. WG1 is working on a revision, which is hoped to include improvements for all flammable refrigerants; it has 43 members from 11 countries, none of which are Article 5. There is no need for a revision of the mobile air conditioning standard, ISO 13043. The product standard ISO 20854 for reefer container is in CD stage (April 2017) and describe requirements for a risk assessment comparable to ISO 13043. Notably, whilst there are a variety of proposed texts under discussion within these WGs, it is not possible to state what the final requirements will prescribe, due to the likelihood of changes to the current material before it is finally published. Similarly, publication years of the amendments and revisions under development is highly uncertain due to the nature of the process, but depending upon the WG changes are anticipated for anywhere between 2018 and 2030.

Lastly, dependent upon the conventions of the national body/national committee, there are several possibilities for interested parties to actively partake in the relevant national committees and SCs ranging from commenting on proposals and voting positions, participating in SC meetings, contributing to WGs, carrying out background technical work, etc. Parties with interests in extending the applicability of such alternative refrigerants should be encouraged to become actively involved with the process.

7.4 Assessment of the implications of International Standards for the implementation of MOP Decisions

The common process is that National Standards and regulations are following the International Standards. In some cases national regulations did not follow the speed with which the International Standard were revised. Therefore, a number of national regulations limit the freedom for refrigerant choice in certain equipment types more than most recent International Standards do. Extending the freedom to select refrigerants for a certain equipment to facilitate the use of lower GWP refrigerants may impact the way how to achieve the phase- down steps as given in Decision XXVIII/1.

Taking the 2018-2022 timeline for conversions under the HCFC accelerated phase-out regime (Decision XIX/6) for Article 5 parties, choices are limited with regard to use of lower GWP substances since the national regulations in these countries play a role in the freedom for refrigerant choice for each equipment type. In the case of non-Article 5 parties and the 2019-2024 timeline for achieving the 40% HFC phase down under decision XXVIII/1, if International Standards, National Standards and – where applicable, national regulations – have been updated, it would result in a higher degree of freedom to select refrigerants and achieve easy compliance with the control schedule. In the case of Article 5 parties, and the first reduction of 10% in 2028, as established by Decision XXVIII/1 HFC phase down schedule, the afore mentioned is even more valid.

Factors such as product cost, product liability, company sustainability and customer perception are as important as International Standards when refrigerant choices are made.

7.5 Recommendations to parties

Both IEC and ISO are independent entities, in so far as they have no political or otherwise oversight such as by any governments, the UN system, etc. As such, where issues arise concerning the process or content of international safety standards, there is no scope for political intervention. As such any changes to the process or documents has to be done through following the directives, as mentioned in Chapter 3 and 5.

Within the context of the existing ISO/IEC directives, parties may wish to consider the following practical interventions:

- Funding and support for education and training of technicians handling and using flammable refrigerants
- Identifying what types of systems/equipment/applications are of national interest and determine whether technical limitations exist due to existing safety standards.

- Encouraging and supporting national experts' participation at national and international level. Provide funding as and where necessary and try to ensure such funding is guaranteed on a long-term basis (recognising that effective interventions normally take many years).
- Actively supporting technical and research activities, data gathering, etc. to help contribute to new and/or improved requirements that reflect the national interests.
- Enabling rapid transfer of International-Standards for flammable refrigerants into national regulations. This would ensure that revisions of International Standards underway will apply to Article 5 parties' National Standards and regulations (where applicable). In this way the flexibility in the refrigerant choice for these parties could be improved, and this may then contribute to lower CO_2-eq. based HFC consumption and to a lower (future) freeze level.
- Setting up mechanisms to avoid delays in introducing lower GWP substances e.g., quota credits for early implementation in one sector to balance slower implementation in another more difficult sector.
- Ways to disseminate competence on safety standards within their programs for the education of competent personnel for service and maintenance. Currently the cost of standards and guidelines is prohibitive for technicians and contractors in Article 5 parties.

Until the International Standards of interest have been revised and published in a form that is less obstructive to the adoption and application of certain alternative refrigerants, National Standards bodies can develop their own safety standards. As is done more often, a country can introduce national modifications to existing International Standards (when adopted nationally) so as to include requirements that enable the broader and more cost effective use of alternative refrigerants of interest. The approach of making national modifications is common practice amongst many countries.

8 List of acronyms and abbreviations

AHRI	American Heating and Refrigeration Institute
AIHA	American Industrial Hygiene Association
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
CEFIC	European Chemical Industry Council
CEN	European Committee for Standardisation
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
CO_2-eq.	Carbon Dioxide equivalents
COP	Coefficient of Performance
EPA	US Environmental Protection Agency
EU	European Union
FIC	Fluoroiodocarbon
FK	Fluoroketone
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HCFO	Hydrochlorofluoroolefin
HCO	Oxygenated hydrocarbon
HFC	Hydrofluorocarbon
HFE	Hydrofluoroether
HFO	Hydrofluoroolefin
HP	Heat Pump
HTOC	Halons Technical Options Committee
IIR	International Institute for Refrigeration
IMO	International Maritime Organisation
IPCC	Intergovernmental Panel on Climate Change
IEC	International Electrotechnical Commission
ISO	International Organisation for Standardisation
LCA	Life Cycle Analysis
LCCP	Life Cycle Climate Performance
MBH	Thousand BTUs per Hour
MTOC	Medical Technical Options Committee
NFPA	National Fire Protection Association
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
OEL	Occupational Exposure Limit
R/AC	Refrigeration and Air Conditioning
R/AC&HP	Refrigeration/Air Conditioning and Heat Pump
RTOC	Refrigeration, AC and Heat Pumps Technical Options Committee
SNAP	Significant New Alternatives Policy
TEAP	Technology and Economic Assessment Panel
TEWI	Total Equivalent Warming Impact
TLV	Threshold Limit Value
UL	Underwriters Laboratories Inc.
UNEP	United Nations Environment Programme
VOC	Volatile Organic Compound

Annex to Chapter 2

An2.1 The relation between standards and legislation in China

China is changing and urging the development and the implementation of standards giving more space to market. By now, though the situation is changing, China has a complex standardization system.

Legal force of standards

China government has issued a standardization law in 1989 and many regulations/rules with legal effect to support standard development. There are two kinds of standards in China. One category is mandatory standards which usually concern important issues such as safety, energy efficiency and environmental protection etc. Mandatory standards can be regarded as "technical laws" with legal effect and must be obeyed. The other one is called recommendation standards or voluntary standards. Those who concern can choose the standards in the recommendation standard list for their products. For the recommendation standards, an additional rule is that no product without standard is allowed to be sold in market. So, in fact, due to the industry tradition and the market requirement, manufacturers do not have many choices but usually make same decisions. Sometimes, when some mandatory standards, or some regulations or policies with mandatory force, quote recommendation standards or parts of them, they are automatically upgraded to the mandatory level in the coverage areas of these mandatory standards or policies.

Classification of standards

Standards can be developed in many channels in China and can be classified into four kinds according to the different channels, National Standards, industry standards, local standards and enterprise standards. The National Standards (GB) are managed by Standardization Administration of the People's Republic of China (SAC) supported by many standard technical committees (TCs) from different industries. TCs must submit applications to SAC for the developments or revisions of standards and are then responsible for the developments/revisions and the approval of the standards if the applications are approved. At last, SAC issues the developed/revised standards. The industry standards are developed and issued with similar procedure to National Standards, but the relevant industry management governments (usually the similar agencies to SAC) take the role of SAC. All issued industry standards must be registered in SAC. The local standards are developed and issued by local governments and only effective in local areas. Occasionally, enterprises might develop enterprise standards for their new products in case that there are no corresponding public standards.

Implementation of standards

Two kinds of government agencies are responsible for the monitoring of standard implementation. At the national level, they are General Administration for Quality Supervision, Inspection and Quarantine (AQSIQ) and State Administration for Industry and Commerce the People's Republic of China (SAIC). AQSIQ and similar local governments at different levels are responsible for the monitoring of product manufacturing. SAICs are responsible for the monitoring of products in market. They sample products in production lines and in market respectively and entrust test agencies to check if the relevant standards are well followed or not.

Internationalization of standards

China government always encourages and insist for the compliance with International Standards. It is asked for TCs to adopt International Standards as much as possible. In this viewpoint, there are three grades of China standards, identical adoption (IDT), modified adoption (MOD) and not equivalent adoption (NEQ). Basically, it is not allowed to lower the original grade of a standard when the standard is revised or updated.

Safety standards

There are two major standards that involve the safety of flammable refrigerants in China, one is GB 4706.32-2012 "Household and similar electrical appliances - safety- particular requirements for electrical heat pumps, air-conditioners and dehumidifiers" which is IDT (identical adoption) to IEC 60335-2-40: 2005. The other one is GB 9237 "Mechanical refrigerating systems used for cooling and heating – safety requirements" (to be issued in 2017) which is MOD (modified adoption) to ISO 5149:2014. There is another standard, GB 4835, which covers the installation of systems and handling practices for flammable refrigerants. Besides, there are also some recommended standards concerning safety issues in China, such as GB/T 7778 (Number designation and safety classification of refrigerants) which corresponds to ISO 817:2014 (MOD). Some new standards are still under development for the handling and operations of flammable refrigerants.
All standards are national mandatory standards and keep the charge limitation of flammable refrigerants in corresponding International Standards. China is one of a few countries to choose HC-290 as R22 alternative in split-type room air-conditioners. The strict charge limitation of the standards is regarded as a great technical limitation for the marketing of HC-290 products for larger capacities.

An2.2 The relation between standards and legislation in France

France is one of the countries where legislation have copied text from safety standards.

In the "Arrêté du 25 juin 1980 portant approbation des dispositions générales du règlement de sécurité contre les risques d'incendie et de panique dans les établissements recevant du public (ERP)"[15] is a safety regulation against the risks of fire and panic in establishments open to the public. Buildings covered by this regulation includes (Article GN 1): Facilities for the elderly and disabled; Rooms for conferences and meetings; Shops and shopping centres; Restaurants and pubs; Hotels; Establishments for education and training; Exhibition halls; Healthcare institutions; Religious Institutions; Stations.

For the purpose of this discussion the main conclusions are in Article CH 35 updated in 2003:

- §1 classifies refrigerants into L1, L2 and L3 according to EN378:2000 Annex E. EN378 stopped using this classification in the 2004 version, and the class L1 covers A1 refrigerants, L2 covers B1, A2L, B2L, A2 and B2 refrigerants, while L3 covers A3 and (in principle) B3 refrigerants.
- §2b states that L2 refrigerants (A2L, B2L, A2 and B2) are only allowed indoors in public buildings if it is in a machinery room, the system is indirect (i.e. uses a brine to transport heat), and the charge is less than 150 kg.
- §2c bans all use of L3 refrigerant (A3 and B3) indoors in public buildings.

[15] *"Arrêté du 25 juin 1980 portant approbation des dispositions générales du règlement de sécurité contre les risques d'incendie et de panique dans les établissements recevant du public (ERP)" (http://www.legifrance.gouv.fr/affichTexte.do;?cidTexte=LEGITEXT000020303557: Decree of 25 June 1980 approving the general provisions of the safety regulation against the risks of fire and panic in establishments open to the public (ERP))*

The article is aligned with the requirements of the safety standards applicable when the law was written, but since 2004 it has clearly been more restrictive than the European standard and today is considered a technical limitation for the use of flammable refrigerants in France.

An2.3 The relation between standards and legislation in Japan

There are two major laws to regulate air conditioning equipment and refrigeration equipment. One is High Pressure Gas Safety Act and the other is Electrical Appliance and Material Safety Act. The former widely regulates the handling of high-pressure gases and their containers as well as air conditioning equipment and refrigeration equipment. The equipment with less than certain levels of refrigerating (or cooling) capacity, such as room air conditioners, is exempted from this Act. This Act is not always harmonized with International Standards, but there are related technical standards where some parts are based on ISO 5149. Although they are not legally mandatory, local authorities recommend the conformity to them. The latter regulates manufacturing, import, and sales of electrical appliances designated in this Act. Room air conditioners fall under the scope of this Act. Manufacturers or importers of electrical appliances are obliged to produce or import electrical products that comply with technical standards stipulated in this Act. This Act has two kinds of technical standards. One is Japanese unique safety standards and the other is largely harmonized with IEC standards. Manufacturers can optionally choose one of the two standards, but there is lately a move by the government to encourage them to adopt the technical standards harmonized with IEC standards. This Act cites the Japanese Industry Standard (JIS) based on the corresponding IEC standard as technical standard. There are no building codes with a ban on the use of air conditioning and refrigeration equipment using flammable refrigerants.

Annex to Chapter 3

Table An3-1: Options for development of a standardization project (ISO/IEC)

Project stage	Normal procedure	Draft submitted with proposal	"Fast-track procedure" [a]	Technical Specification [b]	Technical Report [c]	Publicly Available Specification [d]
Proposal stage (see 2.3)	Acceptance of proposal	Acceptance of proposal	Acceptance of proposal [a]	Acceptance of proposal		Acceptance of proposal [g]
Preparatory stage (see 2.4)	Preparation of working draft	*Study by working group* [e]		Preparation of draft		Approval of draft PAS
Committee stage (see 2.5)	Development and acceptance of committee draft	*Development and acceptance of committee draft* [e]		Acceptance of draft	Acceptance of draft	
Enquiry stage (see 2.6)	Development and acceptance of enquiry draft	Development and acceptance of enquiry draft	Acceptance of enquiry draft			
Approval stage (see 2.7)	*Approval of FDIS* [f]	*Approval of FDIS* [f]	*Approval of FDIS* [f]			
Publication stage (see 2.8)	Publication of International Standard	Publication of International Standard	Publication of International Standard	Publication of Technical Specification	Publication of Technical Report	Publication of PAS

Stages in *italics*, enclosed by dotted circles may be omitted.

a See F.2.

b See 3.1.

c See 3.3.

d See 3.2.

e According to the result of the vote on the new work item proposal, both the preparatory stage and the committee stage may be omitted.

f May be omitted if the enquiry draft was approved without negative votes.

g See ISO and IEC Supplements for details on proposals for PAS.

Table An3-2: overview of standardization project work flow (ISO/IEC)

PARTY(IES) CONCERNED / DOCUMENTS	Proposer	TC or SC secre-tariat and chairs	TC or SC P-members	TC or SC O-members	Category A & B and internal liaisons	ISO Central Secr.	WG convener	WG experts	National bodies
Proposal stage									
New work item proposal	✱	●				❍			
NWIP ballot		✱ 1)	●	❍	❍	❍			
Completed ballot		●	✱			❍			
Result of voting	❍	✱ 1)	❍	❍	❍	■			
Preparatory stage									
Working draft(s) (WD)		❍				❍	✱	●	
Final working draft		●	❍			■	✱	❍	
Committee stage									
Committee draft(s) (CD)		✱	●	❍	❍	❍			
Comments/Vote		●	✱						
Compilation of comments + proposal		✱	●	❍	❍	❍	❍		
Final committee draft		✱ 1)	❍	❍	❍	■	❍		
Enquiry stage									
Draft International Standard		❍			❍	✱			●
Completed ballot					✱	●			✱
Result of voting + comments		● 1)	❍	❍	❍	✱			❍
Report of voting		✱	❍	❍	❍	●	❍		❍
Text for final draft International Standard		✱ 1)	❍	❍	❍	■	❍		
Approval stage									
Final draft International Standard + ballot		❍			❍	✱			●
Completed ballot					✱	●			✱
Result of voting		❍	❍	❍	❍	✱			❍
Final proof		●				✱			
Proof corrections		✱				●			
Publication stage									
International Standard		❍				✱			❍
Systematic review									
SR ballot		❍				✱			●
Ballot						●			✱
Completed ballot		●	●	❍	❍			❍	
Report of voting + proposal		✱	❍		❍	■			

✱	Sender of document	1)	In the case of an SC, a copy is also sent to the TC secretariat for information
●	Recipient for action	■	Recipient for registration action
❍	Recipient for information	☆	Optional action

Annex to Chapter 4

An4.1 List of studies referenced in Chapter 4

AHRI, 2015	AHRI, 2015. Risk Assessment of Refrigeration Systems Using A2L Flammable Refrigerants. AHRI Project 8009 Final Report
AHRTI-9007, 2017	AHRTI-9007, 2017. Benchmarking Risk by Real Life Leaks and Ignitions Testing. Testing by Underwriters Laboratories, USA.
Blackwell, 2006	Blackwell, N., Bendixen, L., and Birgfeld, E. 2006. Risk Analysis for Alternative Refrigerant in Motor Vehicle Air Conditioning. EPA, Washington DC.
Blom-Bruggeman, 1996a	Blom-Bruggeman, J. M, van Gerwen, R. J. M., Verwoerd, M. 1996a. Risk Assessment of typical cooling and heating systems using natural working fluids. Part: Risk assessment methodology. R96-348. Report of TNO, Apeldoorn. Netherlands.
Blom Bruggeman, 1996b	Blom-Bruggeman, J. M, van Gerwen, R. J. M., Verwoerd, M. 1996b. Risk Assessment of a Bulk Milk Tank using Hydrocarbon Refrigerant. Final Report of TNO, Apeldorn. Netherlands.
Cai, 2014	Cai D., He G., Tang W., et al. 2014. The simulation of the leaking distribution characteristics of R290 household air conditioner. Proc. 11th IIR GL2014, Hangzhou, China
Chen, 2007	Chen Q., Chen G. M., Zhang R., 2007. Experimental study on explosion limits of a new alternative refrigerant to HCFC-22. Proc. 22nd int. Congr. Refrig., Beijing
Cheng, 2015	Cheng, R. C., Shih, Y. C. 2015. Numerical Study on Evaluating the Safety of Refrigerant Leakage for a R290 Air-Conditioner. Journal of Beijing University of Aeronautics and Astronautics, June 2015.
Clodic, 1996a	Clodic D. 1996. Concentration gradients of isobutane or propane in rooms when leaks occur. Kelvin, n. 3-4; 56-78;
Clodic, 1996b	Clodic D., Cai W. 1996. Tests and simulations of diffusion of various hydrocarbons in rooms from air-conditioners and refrigerators. Proc. IIR Aarhus Meet.
Clodic, 1997a	Clodic D. 1997. Diffusion of flammables in rooms due to leaks from portable air-conditioners or refrigerators working with propane or isobutane. Proc. Int. Conf. Ozone Prot. Technol., Washington, DC
Clodic, 1997b	Clodic, D. 1997. Leak flow rates and measurements of concentration gradients of flammable refrigerants. AICARR Conf. “FREE ‘97”, Verona, Italy.
Clodic, 1997c	Clodic, D., Cai, W. 1997. Study of diffusion of propane and iso-butane in rooms respecting the standardised practical limit. Proc. ASHRAE Annual Meeting, Boston, USA.
Colbourne, 2003a	Colbourne, D., Suen, K. O., 2003a, Equipment design and installation features to disperse refrigerant releases in rooms. Part I: Experiments and analysis. Int. J. Refrig., No. 6, Vol. 26.
Colbourne, 2003b	Colbourne, D., Suen, K. O., 2003b, Equipment Design and Installation Features to Disperse Refrigerant Releases in Rooms. Part II: Determination of procedures. Int. J. Refrig., No. 6, Vol. 26.
Colbourne, 2004a	Colbourne, D., Suen, K. O., 2004a. Appraising the flammability hazards of hydrocarbon refrigerants using quantitative risk assessment model. Part I: modelling approach. Int. J. Refrig., pp.774–783, Vol 27.
Colbourne, 2004b	Colbourne, D., Suen, K. O., 2004b. Appraising the Flammability Hazards of Hydrocarbon Refrigerants using Quantitative Risk Assessment Model.

	Part II: Model evaluation and analysis. Int. J. Refrig., pp. 784 – 793, Vol. 27.
Colbourne, 2008a	Colbourne D., Suen K. O. 2008a. Risk analysis of flammable refrigerants. 1. Correlations for concentrations from leaks. Proc. 8th IIR GL2008, Copenhagen
Colbourne, 2008b	Colbourne D., Suen K. O. 2008. Risk analysis of flammable refrigerants. 2. Methodology for calculations of risk frequencies and flammable quantities. Proc. 8th IIR GL2008, Copenhagen, Denmark
Colbourne, 2011	Colbourne, D. 2011. Risk analysis of flammable refrigerant handling during service and maintenance activities. Proc. 23rd IIR Int Congr. Refrig., Praha
Colbourne, 2012a	Colbourne D., Hühren R., Vonsild A. 2012. Safety concept for hydrocarbon refrigerants in split air conditioner. Proc. 10th IIR GL2012, Delft, The Netherlands
Colbourne, 2012b	Colbourne D., Liu Z. X. 2012. R290 leakage mass flow rate from a refrigerating system. Proc. 10th IIR GL2012, Delft, The Netherlands
Colbourne, 2013a	Colbourne D., Espersen L. 2013. Quantitative risk assessment of R290 in ice cream cabinets. Int. J. Refrigeration, vol. 36; n. 4
Colbourne, 2013b	Colbourne D., Hühren R., Rajadhyaksha D. 2013. Refrigerant leakage control for R-290 in split type refrigeration and air conditioning systems. Proc. IIF-IIR. Compressors 2013, Častá - Papiernička.
Colbourne, 2014a	Colbourne D., Suen K. O. 2014a. Characterisation of a leak of flammable refrigerant within equipment enclosures. Proc. 11th IIR GL2014, Hangzhou, China
Colbourne, 2016a	Colbourne D., Solomon P., Wilson R., et al. 2016. Development of R290 transport refrigeration system. Proc. 12th IIR GL2016, Edinburgh, UK,
Colbourne, 2016b	Colbourne D., Suen K. O. 2016. R290 concentrations arising from leaks in commercial refrigeration cabinets. Proc. 12th IIR GL2016, Edinburgh, UK
Colbourne, 2016c	Colbourne D., Suen K. O., Huehren R. 2016. Risk assessment of R22 air conditioners using R290. Proc. 12th IIR GL2016, Edinburgh, UK
Dorman, 2013	Dorman, D., Branch, S. 2013. An Analytical Investigation of Class 2L Refrigerants. Proc. 2013 ASHRAE Annual Conference, USA
Gerwen, 1994	Gerwen, R. J. M., van, Jansen, C. M. A. 1994. Risk assessment of flammable refrigerants. Proc. IIR Conf. Natural Working Fluids, Hannover, Germany.
Gerwen, 1996	Gerwen, R. J. M., van, Verwoerd, M. 1996. Quantification and evaluation of safety risks related to the use of ammonia and hydrocarbons as refrigerants. Proc. IEA Heat Pump Programme Annex 22 Workshop “Compression systems with natural working fluids”, HPP-AN22-3.
Gigiel, 2004	Gigiel A. 2004. Safety testing of domestic refrigerators using flammable refrigerants. Int. J. Refrig., vol. 27; n. 6;
Gmunder, 2002	Gmünder, F. K., Wolfer, M., Seitz, E. 2002. Risk analysis of heating and refrigeration systems with natural working fluids. Elsevier Science, 0-0804-4120-3
Goetzler, 1998	Goetzler, W., Bendixen, L., Bartholomew, P. 1998. Risk Assessment of HFC-32 and HFC-32/134a (30/70 wt. %) in Split System Residential Heat Pumps. DOE/ AHRI/ ARTI DOE/CE/23810-92
Goetzler, 2012	Goetzler, W., Burgos, J., 2012. Study of Input Parameters for Risk Assessment of 2L Flammable Refrigerants in Residential Air Conditioning and Commercial Refrigeration Applications. ASHRAE Project 1580-TRP, USA.
Goetzler, 2013	Goetzler, W., Guernsey, M., Weber, C. 2013. Risk Assessment of Class 2L Refrigerants in Chiller Systems. Final Report June, 2013, AHRI Project No. 8005/Navigant Consulting Inc.

Goetzler, 2016a	Goetzler, W. Guernsey, M., Faltermeier, S., Droesch, M. 2016. AHRI Project No. 8016:
Goetzler, 2016b	Goetzler, W., Guernsey, M., Faltermeier, S., Droesch, M. 2016. Risk Assessment of Class 2L Refrigerants in Commercial Rooftop Units. AHRI Project No. 8016, Navigant Consulting Inc.
Grosshandler, 1998	Grosshandler W., Donnelly M., Womeldorf C. 1998. Lean flammability limit as a fundamental refrigerant property. Phase III. Final technical report. DOE-CE-23810-98; ARTI (Air-Conditioning and Refrigeration Technology Institute)
Grove, 1968	Grove, J. R. 1968. Measurement of quenching diameters and their relation to the flameproof grouping of gases and vapours. I. Chem. E., Symposium series no. 25, London.
Higashi, 2014	Higashi, T., Saitoh, S., et al. 2014. Diesel Combustion of Oil and Refrigerant Mixture During Pump Down of Air Conditioners. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.
Higashi, 2016	Higashi, T., Saitoh, S. , et al. 2016. Diesel Combustion of Oil and Refrigerant Mixture During Pump Down of Air Conditioners. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.
Hihara, 2014	Hihara, E. 2014. Research project on risk assessment of mildly flammable refrigerants in Japan. Proc. Int. Symp. on New Refrigerants and Env. Techn., JRAIA, Kobe.
Hihara, 2016	Hihara, E. 2016. Safety research and risk assessment of lower flammable refrigerants. Proc. Int. Symp. on New Refrigerants and Env. Techn., JRAIA, Kobe.
Hiroaki, 2014	Hiroaki, O., Tatsuhito, H. O., Chaobin D, Eiji, H. 2014. Leakage of Mildly Flammable Refrigerants into a Room. Proc. Int. Refrigeration and Air Conditioning Conf., Purdue, USA.
Holthappels, 2002	Holtappels, K. 2002. Report on experimentally determined self-ignition temperature and the ignition delay time. Deliverable No. 5 (DAM, TUD) of Programme "Energy, Environment and Sustainable Development" for Project SAFELINE: SAFe and Efficient hydrocarbon oxidation processes by KINetics and Explosion eXpertise. Federal Institute for Materials Research and Testing (BAM).
Holthappels, 2009	Holtappels, K., Pahl, R. 2009. Ignition behaviour of HFO1234yf. BAM test report, II-2318/2009 I. Bundesanstalt für Materialforschung und -prüfung (BAM), Germany.
Holthappels, 2014	Holtappels, K. 2014. Ignition Temperatures of R1234yf. Proc. 3rd Meeting WG on safety aspects of the use of R1234yf on MAC systems – Ispra. Bundesanstalt für Materialforschung und -prüfung (BAM).
Holthappels, 2017	Holtappels, K. 2017. BAM Experience with A2L Refrigerants. Proc. Meet. ISO/TC 104/SC 2/WG 1. Bundesanstalt für Materialforschung und -prüfung (BAM).
Imamura, 2014	Imamura, T., Sugawa, O. 2014. Experimental Evaluation of Physical Hazard of A2L Refrigerant Assuming Actual Handling Situations. Proc. of The International Symposium on New Refrigerants and Environment Technology, Japan
Imamura, 2016	Imamura, T. and Sugawa, O. 2016. Physical Hazard Evaluation of A2L Refrigerants Assuming Rapid Leak Accident from a VRF System. Proc. of The International Symposium on New Refrigerants and Environment Technology
Ishii, 2016a	Ishii, I. 2016. Safety guideline and standard against lower flammable refrigerants leakage of commercial air conditioners. Proc. Int. Symp. on New Refrigerants and Env. Techn., JRAIA, Kobe.

Ishii, 2016b	Ishii. Y. 2016. Safety guideline and standard against lower flammable refrigerants leakage of commercial refrigerators. Proc. Int. Symp. on New Refrigerants and Env. Techn., JRAIA, Kobe.
Iz, 1996	Iz H., Yilmaz T., Tanes Y. 1996. Experimental results of the safety tests on domestic refrigerators for refrigerant R600a. Proc. IIR Aarhus Meet.
Jabbour, 2002	Jabbour, T., Clodic, D. 2002. Analysis of the IEC 61D-amendment requirements for the use of flammable refrigerants. Public Report, Ecole de Mines, Paris, France.
Jabbour, 2004	Jabbour et al, 2004,
Jansen, 1996	Jansen, C. M. A., van Gerwen, R. J. M. 1996. Risk assessment of the use of flammable refrigerants. (In transport refrigeration.) R95-189. Final Report of TNO, Apeldoorn, Netherlands.
Jia, 2015	Jia, L. Z., Jin, W. F., Zhang, Y. 2015. Analysis of Indoor Environment Safety with R32 Leaking From a Running Air Conditioner. Procedia Engineering, vol. 121, pp. 1605–1612
JSRAE, 2013	JSRAE. 2013. Risk Assessment of Mildly Flammable Refrigerants 2012 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.
JSRAE, 2014	JSRAE. 2014. Risk Assessment of Mildly Flammable Refrigerants 2013 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.
JSRAE, 2015	JSRAE. 2015. Risk Assessment of Mildly Flammable Refrigerants 2014 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.
JSRAE, 2016	JSRAE. 2016. Risk Assessment of Mildly Flammable Refrigerants 2015 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.
JSRAE, 2017	JSRAE. 2017. Risk Assessment of Mildly Flammable Refrigerants 2016 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.
Kataoka, 2000	Kataoka, O. ,Yoshizawa, M., et al. 2000. Allowable Charge Calculation Method for Flammable Refrigerants. Proc. Int. Refrigeration and Air conditioning Conf., Purdue, USA
Kataoka, 2013	Kataoka, O. 2013. Safety Considerations When Working With 2L Flammability Class Refrigerants. Proc. Institute of Refrigeration, London, UK
Kondo, 2008	Kondo, S., Takizawa, K., Takahashi, A., Tokuhashi, K., Sekiya, A. 2008. A study on flammability limits of fuel mixtures. Journal of Hazardous Materials 155, 440–448
Konig, 2014	König H., Bararu M. 2014. Risk assessment for reefer containers with flammable refrigerants. Proc. 11th IIR GL2014, Hangzhou, China
Laughman, 2015	Laughman, C.R. , Grover, P., Nabi, S. 2015. A Study of Refrigerant Dispersion In Occupied Spaces Under Parametric Variation, ASHRAE Annual Conference, Atlanta.
Laughman, 2016	Laughman, C.R., Nabi, S., Grover, P. 2016. Simulation of refrigerant dispersion in single and multiple connected rooms. ASHRAE Transactions, TR2016-018
Lewandowski, 2012a	Lewandowski, T. A. 2012. Risk Assessment of Residential Heat Pump Systems Using 2L Flammable Refrigerants. AHRI Project 8004 Final Report.
Lewandowski, 2012b	Lewandowski, T., Reid, K. R. 2012. Risk assessment for residential heat pump systems using 2L flammable refrigerants. Proc. ASHRAE/NIST Refrigerants Conf., Gaithersburg, USA.

Li, 2016	Li Y., Tong M., 2016. An experimental investigation of the flammability limits of natural refrigerants. Proc. 5th IIR-Gustav Lorentzen Conf, Guangzhou, 2006
Li, 2014a	Li, T. X., 2014. Indoor leakage test for safety of R-290 split type room air conditioner. Int. J. Refrig., Vol 40, 380–389.
Li, 2014b	Li, Y. N., Tao, J. J., Han, Y. C., Han, X., Qin, J. 2014. Numerical and Experimental Study on the Diffusion Property of Difluoromethane (HFC-32) in Leakage. Procedia Engineering, vol. 71, pp. 34 – 43
Lisochkin, 2001	Lisochkin, Y. A., Poznyak, V. I. 2001. Explosion Hazard of Mixtures of Freons R31 and R32 with Air at Different Pressures. J . Combustion, Explosion, and Shock Waves, Vol. 37, No. 4, pp. 448–450
Maclaine-cross, 2004	Maclaine-cross, I. L. 2004. Usage and risk of hydrocarbon refrigerants in motor cars for Australia and the United States. Int. J. refrig. Vol. 27, pp. 339–345
Nagaosa, 2012	Nagaosa, R., et al. 2012. A risk assessment for leakages of flammable refrigerants into a closed space. Int. Refrig. and Air Conditioning Conf., Purdue, USA
Nagaosa, 2014	Nagaosa, R. S. 2014. A new numerical formulation of gas leakage and spread into a residential space in terms of hazard analysis. Journal of Hazardous Materials vol. 271, 266–274
Naito, 2016	Naito, Y. 2016. Safety guideline and standard against lower flammable refrigerants leakage of ACs for facilities. Proc. Int. Symp. on New Refrigerants and Env. Techn., JRAIA, Kobe.
Papas, 2016	Papas, P., Zhang, S. L., Jiang, H., Verma, P., Rydkin, P., Lord, R., Burns, L. 2016. Computational fluid dynamics modeling of flammable refrigerant leaks inside machine rooms: Evaluation of ventilation mitigation requirements. Science and Technology for the Built Environment, 22:4, 463-471
Poolman, 2016	Poolman C., Papas P., Rusignuolo G. et al. 2016. Low GWP refrigerants in transport refrigeration: risk and benefit assessment of flammable and mildly flammable alternatives. Proc. 12th IIR GL2016, Édimbourg, UK.
Rajadhyaksha, 2015	Rajadhyaksha, D., Wadia, B. J., Acharekar, A. A., Colbourne, D. 2015. The first 100 000 HC-290 split air conditioners in India. Int. J. Refrig., vol. 60, pp. 289–296
Richard, 2003	Richard R. G. 2003. Flammability hazard classification of refrigerants. Proc. 21st int. Congr. Refrig., Washington, DC
Ritter, 1998	Ritter T. J., Colbourne D. 1998. Quantitative risk assessment: hydrocarbon refrigerants. Proc. 3rd IIR GL1998, Oslo, Norway
Saburi, 2014	Saburi, T. and Wada, Y. 2014. Hazard Assessment of the Combustion of Mildly Flammable Refrigerants. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.
Saburi, 2016	Saburi, T. and Wada, Y. 2016. Hazard Evaluation Study on The Mildly Flammable Refrigerants. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.
Tadros, 2008	Tadros, Tadros A., Maclaine-Cross I., Leonardi E. 2008. Safe plant rooms for large hydrocarbon chillers. In: Natural refrigerants: sustainable ozone- and climate-friendly alternatives to HCFCs. GTZ Proklima
Taira, 2014	Taira, S., Watanabe, T. 2014. Outline of Risk Assessment in Mini Split (Store Package) Air-Conditioner. Proc. Int. Symp. on New Refrigerants and Env. Techn., JRAIA, Kobe.
Takaichi, 2014	Takaichi, K., et al. 2014. Overview of the Risk Assessment for Mini-Split Air Conditioner. Proc. of The International Symposium on New Refrigerants and Environment Technology, Japan

Takizawa, 2014	Takizawa, K. 2014. Fundamental and Practical Flammability Properties of 2L Refrigerants. Proc. Int. Symp. on New Refrigerants and Env. Techn., JRAIA, Kobe.
Takizawa, 2016	Takizawa, K., et al., 2016. Flammability Characteristics of Lower Flammability (2L) Refrigerants, Proc. Int. Symp. on New Refrigerants and Env. Techn., Japan.
Ueda, 2014	Ueda, K., et al. 2014. Chiller Risk Assessment and Guideline by Mildly Flammable Refrigerants. Proc. of The International Symposium on New Refrigerants and Environment Technology, Japan
Walter, 2014	Walter, W., et al. 2014. Evaluations for 2L Refrigerant Flammability and Ventilation Mitigation Requirements in Machine Rooms. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.
Wang, 2013	Wang, Z., Zhao, Y., Jie, W., Dong, L., Zhong, Z. F. 2013. Leakage Research of Split-type Air-conditioner using R290 as Refrigerant. Journal of Refrigeration, 2013-06
Wilson, 2002	Wilson, D. P., Richard, R. G. 2002. Determination of Refrigerant Lower Flammability Limits in Compliance with Proposed Addendum p to Standard 34. ASHRAE Transactions 2002, Vol. 108, Part 2, pp. 739-756.
Wolfer, 1999a	Wolfer, M. 1999. Flammable working fluids in Switzerland: risk assessment of natural working fluids. Proc. Workshop Proc. IEC Heat Pump Programme "Natural working fluids - a challenge for the future", Report no. HPC-WR-21, Paris, France
Wolfer, 1999b	Wolfer, M., Seiler, H. 1999. Ammoniak und Kohlenwasserstoffe als kaltemittel: riskoanalyse, produktehaftpflicht und strafrecht. Bundesamtes fur Energie, Switzerland.
Yajima, 2011	Yajima, R.et al. 2011. Experimental Safety Evaluation on Flammability of R32 Refrigerant. Proc. ICR 2011
Yajima, 2014	Yajima, R., et al. 2014. Overview of the Risk Assessment and Safety Guideline for VRF System using A2L Refrigerants. Proc. of The International Symposium on New Refrigerants and Environment Technology, Japan.
Yamashita, 2016	Yamashita, K. 2016. Standards of refrigerant leak detector and alarm for air conditioning and refrigeration equipment. Proc. Int. Symp. on New Refrigerants and Env. Techn., JRAIA, Kobe.
Yao, 2000	Yao K.2000. Risk assessments for a room air conditioner with propane. Proc. int. Symp. HCFC altern. Refrig. environ. Technol., Kobe
Zgliczynski, 1994	Zgliczynski, M., Sansalvadore P. 1994. Contribution to safety aspect discussion on isobutane compressors for domestic refrigeration. Proc. IIF-IIR Conf. New Applications of Natural Working Fluids in Refrigeration and Air Conditioning, Hanover, Germany
Zhang, 2015	Zhang, W., Yang, Z., Li, J., Ren, C. X., Lv, D. 2015. Study of the explosion characteristics and combustion products of air conditioner using flammable refrigerants. Journal of Fire Sciences, vol. 33 issue: 5, pp 405-424
Zhang, 2013	Zhang, W., Yang, Z., Li, J., Ren, C-X., Lv, D., Wang, J., Zhang, X., Wu, W., 2013. Research on the flammability hazards of an air conditioner using refrigerant R-290. Int. J. Refrig., Vol. 36, Issue 5, 1483-1494.
Zhao, 2002	Zhao, Y., Shigang, Z., Guansan, T., Bin, L., Yitai, M. 2002. Study of refrigerant leakage in refrigeration system. J. Fire Sciences, Vol. 20, pp. 237 – 245

An4.2 Summary of studies referenced in Chapter 4

Flammability characteristics

Takizawa, K., et al., 2016. Flammability Characteristics of Lower Flammability (2L) Refrigerants, Proc. Int. Symp. on New Refrigerants and Env. Techn., Japan.	Summary of flammability properties including quenching distances for various 2L refrigerants is described. It is also shown that static electric discharge from human body and electric discharge from household appliances don’t ignite 2L refrigerants
Chen Q., Chen G. M., Zhang R., 2007. Experimental study on explosion limits of a new alternative refrigerant to HCFC-22. Proc. 22nd int. Congr. Refrig., Beijing	An experimental apparatus with high accuracy was established to test the explosion limits of flammable refrigerants. The explosion limits of flammable pure and binary refrigerants of the HFC-161/125/32 systems were tested. On the basis of the experimental data, the critical flammability line of mixtures HFC-161/125/32 was analysed. Refrigerant mixtures composed of flammable refrigerants and retardative agents have been developed to inhibit the flammability of the refrigerants.
Richard R. G. 2003. Flammability hazard classification of refrigerants. Proc. 21st int. Congr. Refrig., Washington, DC	evaluates and compares the various schemes currently being used or being proposed for classifying refrigerant flammability hazard.
Grosshandler W., Donnelly M., Womeldorf C. 1998. Lean flammability limit as a fundamental refrigerant property. Phase III. Final technical report. DOE-CE-23810-98; ARTI (Air-Conditioning and Refrigeration Technology Institute)	Describes the current counter-flow burner facility and operating procedures, presents the experimental results with the analysis that yields flammability limits, and recommends further activities that could lead to a science-based methodology for assessing the risk of fire from refrigeration machine working fluids.
Lisochkin, Y. A., Poznyak, V. I. 2001. Explosion Hazard of Mixtures of Freons R31 and R32 with Air at Different Pressures. J . Combustion, Explosion, and Shock Waves, Vol. 37, No. 4, pp. 448–450	The concentration limits of explosion hazard and the maximum values of explosion pressure and pressure growth rates in explosion are determined. A strong effect of the initial pressure of the mixture with air on the upper concentration limit of explosibility is found. An explanation of this phenomenon is proposed.
Kondo, S., Takizawa, K., Takahashi, A., Tokuhashi, K., Sekiya, A. 2008. A study on flammability limits of fuel mixtures. Journal of Hazardous Materials 155, 440–448	Flammability limit measurements were made for various binary and ternary mixtures prepared from nine different compounds. The compounds treated are methane, propane, ethylene, propylene, methyl ether, methyl formate, 1,1-difluoroethane, ammonia, and carbon monoxide.
Wilson, D. P., Richard, R. G. 2002. Determination of Refrigerant Lower Flammability Limits in Compliance with Proposed Addendum p to Standard 34. ASHRAE Transactions 2002, Vol. 108, Part 2, pp. 739-756.	Provides a description and brief history of refrigerant flammability safety classification systems, a summary of a literature survey of flammability test data for single-compound refrigerants and refrigerant blends, and also presents new flammability test results on the lower flammability limits (LFLs) of refrigerants and refrigerant blends containing flammable components that are currently ASHRAE designated and classified.
Grove, J. R. 1968. Measurement of quenching diameters and their relation to the flameproof grouping of gases and vapours. I. Chem. E., Symposium series no. 25, London.	Reports on measurements of various flammable substances, including HCs and compares quenching diameters, minimum ignition current and maximum experimental safe gap.

Li Y., Tong M., 2016. An experimental investigation of the flammability limits of natural refrigerants. Proc. 5th IIR-Gustav Lorentzen Conf, Guangzhou, 2006	experimental investigation of the flammability limits of propane, isobutane and methylamine was carried out. It was shown that, if the consistency of the refrigerants in air increased approximately to the flammability limits, a high-energy ignition source was also needed to induce explosion.
Holtappels, K. 2014. Ignition Temperatures of R1234yf. Proc. 3rd Meeting WG on safety aspects of the use of R1234yf on MAC systems – Ispra. Bundesanstalt für Materialforschung und -prüfung (BAM).	Reports on measurements on R1234yf involving self-ignition phenomena, influences on ignition temperatures, analysis of published ignition temperatures and consequences on risk assessment if minimum ignition temperature is used.
Holtappels, K. 2002. Report on experimentally determined self-ignition temperature and the ignition delay time. Deliverable No. 5 (DAM, TUD) of Programme "Energy, Environment and Sustainable Development" for Project SAFELINE: SAFe and Efficient hydrocarbon oxidation processes by KINetics and Explosion eXpertise. Federal Institute for Materials Research and Testing (BAM).	Reports the results of SAFEKINEX task on Experimental Determination of the Ignition Delay Time (Self Ignition and Cool Flame Temperature). It focuses on oxidation phenomena (e.g. self-ignition, cool flame) of gaseous hydrocarbon-air mixtures. Chemical and physical influences of the test apparatus parameters, the determination procedure applied, the initial temperature, the initial pressure and others are not completely understood yet. Deals with the influence of initial pressure, initial temperature and vessel volume on oxidation phenomena and related characterising indices. Two different test set-ups have been used: a quartz glass vessel based on the standard equipment for determining the auto-ignition temperature and a stainless steel vessel designed to investigate the effect of higher pressures.

Release/leakage characteristics

Goetzler, W., Burgos, J., 2012. Study of Input Parameters for Risk Assessment of 2L Flammable Refrigerants in Residential Air Conditioning and Commercial Refrigeration Applications. ASHRAE Project 1580-TRP, USA.	Characterised leak rate profile
Goetzler, W. Guernsey, M., Faltermeier, S., Droesch, M. 2016. AHRI Project No. 8016: Risk Assessment of Class 2L Refrigerants in Commercial Rooftop Units. Air-Conditioning and Refrigeration Technology Institute, USA.	Leak frequencies for rooftop units
Colbourne D., Liu Z. X. 2012. R290 leakage mass flow rate from a refrigerating system. Proc. 10th IIR GL2012, Delft, The Netherlands	a model for estimating the transient leak rate of HC-290 following an instantaneous occurrence of a leak hole, based on a system at standstill (off-mode operation). The model is compared against a series of measurements taken for simulated releases from an air conditioner.

Behaviour of leaked refrigerant

Kataoka, O. ,Yoshizawa, M., et al. 2000. Allowable Charge Calculation Method for Flammable Refrigerants. Proc. Int. Refrigeration and Air conditioning Conf., Purdue, USA	Rationale of calculation method of allowable charge of flammable refrigerants which is adopted in IEC standards is described. The basis of the formula is to ensure that the concentration of leaked refrigerant that settles at floor level (under assumed conditions implicit in the formula) does not exceed the LFL. In order to get a simple and universal formula, many assumptions were adopted and other aspects related to the environment and construction of the equipment such as airflow and likelihood of a particular leak hole size were not accounted for.
Laughman, C.R. , Grover, P., Nabi, S. 2015. A Study of Refrigerant Dispersion In Occupied Spaces Under Parametric Variation, ASHRAE Annual Conference, Atlanta.	Study of refrigerant dispersion in a single occupied space with door undercut height or the exhaust ventilation flow rate as parameter.
Laughman, C.R., Nabi, S., Grover, P. 2016. Simulation of refrigerant dispersion in single and multiple connected rooms. ASHRAE Transactions, TR2016-018	Assesses performance of well-mixed models via a comparison to computational fluid dynamics simulations and studying the behaviour of refrigerant dispersion in multiple connected spaces. Results indicate that the well-mixed models are not able to capture variation in the geometric parameters very accurately, and should be used cautiously, while the studies of the dynamics in multiple spaces highlights the importance of the location of ventilation sources and sinks.
Nagaosa, R., et al. 2012. A risk assessment for leakages of flammable refrigerants into a closed space. Int. Refrig. and Air Conditioning Conf., Purdue, USA	Predictions of concentration of flammable refrigerants leaked into a poorly ventilated space using CFD analysis are described. An indicator for screening of ignition risk based on prediction of refrigerant concentration is proposed.
Nagaosa, R. S. 2014. A new numerical formulation of gas leakage and spread into a residential space in terms of hazard analysis. Journal of Hazardous Materials vol. 271, 266–274	A new numerical approach of the spread of leaked gases is proposed. A CFD technique without a turbulent model is employed. Numerical solutions without uncertainties produced by turbulent model are shown. A series of case studies of gas spread is demonstrated with flammable refrigerants.
Jabbour, T., Clodic, D. 2002. Analysis of the IEC 61D-amendment requirements for the use of flammable refrigerants. Public Report, Ecole de Mines, Paris, France.	R-32 can be ignited and cause secondary ignitions, meaning that Class A2L refrigerants must be considered flammable. A large whole room test was conducted using R-32. The refrigerant was released over 4 minutes and in sufficient quantity to exceed the LFL as the refrigerant migrated and diffused into the room. Ignition and secondary fires were possible on furniture in the room, when the refrigerant was release at the floor level. When refrigerant was release at a level above 1.8 m. the refrigerant did not ignite. Also measured R-290 and R-600a (isobutane) concentrations leaked from both split-type and portable air conditioners. It was found that for leaks occurring at higher elevations in the room, the concentrations are much lower than the formula implies. In some cases for leaks occurring from equipment installed at lower elevations in the room the concentrations exceeded the LFL.
Papas, P., Zhang, S. L., Jiang, H., Verma, P., Rydkin, P., Lord, R., Burns, L. 2016. Computational fluid dynamics modeling of flammable refrigerant leaks inside machine rooms: Evaluation of ventilation mitigation requirements. Science and Technology for the Built Environment, 22:4, 463-471	Gives technical basis for establishing ventilation rates for refrigeration systems with unlimited charge levels placed in a mechanical equipment room

Colbourne, D., Suen, K. O., 2003a, Equipment design and installation features to disperse refrigerant releases in rooms. Part I: Experiments and analysis. Int. J. Refrig., No. 6, Vol. 26.	Investigated dispersion of carbon dioxide to simulate refrigerant (R-290) leakage specifically taking into account the effect of airflow and subsequently the flammability risk of air conditioners with R-290 over a range of conditions
Colbourne, D., Suen, K. O., 2003b, Equipment Design and Installation Features to Disperse Refrigerant Releases in Rooms. Part II: Determination of procedures. Int. J. Refrig., No. 6, Vol. 26.	Developed correlations to estimate maximum mean room floor concentrations as a function of airflow rate, release height, air discharge height, unit air discharge opening area and release mass.
Clodic, D. 1997. Leak flow rates and measurements of concentration gradients of flammable refrigerants. AICARR Conf. “FREE ‘97”, Verona, Italy.	Measures gas concentration arising from simulated leaks from base of domestic appliances.
Li, T. X., 2014. Indoor leakage test for safety of R-290 split type room air conditioner. Int. J. Refrig., Vol 40, 380–389.	Tested developed concentrations of leaked HC-290 considering the influence of leak point location and height, air flow for both standby and running models. It is found that the concentration within the room cannot reach the LFL (under this study’s conditions). The concentration only approaches or exceeds the LFL is in an extremely localised region directly underneath the leak position
Colbourne D., Suen K. O. 2016. R290 concentrations arising from leaks in commercial refrigeration cabinets. Proc. 12th IIR GL2016, Édimbourg, UK	parameters have been investigated by carrying out simulated leaks of HC-290. These include charge size, leak mass flow rate, leak orientation, height of refrigerant-containing parts, cabinet doors, condensing unit enclosures, airflow and room congestion. HC-290 concentrations are measured at various locations such as the room floor, within and at the rear of the cabinet, and within the condensing unit enclosure and the adjacent cabinets.
Cai D., He G., Tang W., et al. 2014. The simulation of the leaking distribution characteristics of R290 household air conditioner. Proc. 11th IIR GL2014, Hangzhou, China	CFD technology to simulate proliferation of HC-290 and its concentration distribution after the leakage occurs in 3 rooms of different sizes and assume all of the leaking times in these 3 rooms are 240 seconds. Simulation indicates that the concentration of the space centred at the middle of leaking port with the a radius of 0.2 m from the leaking port down to the floor is relatively high, and exist potential risk of blasting, but in 10 seconds after the leakage, the highest HC-290 concentration falls under the lower limit of propane’s flammability limits. Results also show the side wall beneath leaking port, the floor and the corner tends to gather more HC-290, and larger room is more favourable for proliferation dilution of HC-290.
Colbourne D., Suen K. O. 2014a. Characterisation of a leak of flammable refrigerant within equipment enclosures. Proc. 11th IIR GL2014, Hangzhou, China	numerical model developed to describe the behaviour of the HC refrigerant concentrations from releases into different types of enclosures, associated with common AC&R equipment such as refrigerated cabinets and indoor air handling units, and under different operating conditions.
Colbourne D., Suen K. O. 2008a. Risk analysis of flammable refrigerants. 1. Correlations for concentrations from leaks. Proc. 8th IIR GL2008, Copenhagen	correlations for estimating the spatial and temporal variations of refrigerant concentrations under various conditions and leak scenarios,

Clodic D. 1996. Concentration gradients of isobutane or propane in rooms when leaks occur. Kelvin, n. 3-4; 56-78;	Tests show that the practical limit of 8 g/m3 for propane and isobutane does not prevent concentrations near the floor being higher than the lower flammability limit for durations between 30 minutes and 1 hour 30 minutes. In all cases, when leaks occur below 30 cm, the concentration horizontal gradient is significantly more uniform than the vertical gradient. With natural convection, durations in the range of 2 hours are necessary to return to a uniform concentration of propane in the test room and more than 5 hours with isobutane
Clodic D. 1997. Diffusion of flammables in rooms due to leaks from portable air-conditioners or refrigerators working with propane or isobutane. Proc. Int. Conf. Ozone Prot. Technol., Washington, DC	When obstacles on the ground divide the room in smaller areas, because of the "pooling effect" concentrations can reach very high values. Calculations of dilution of gases heavier than air should not take the total volume of a room as the referred volume.
Iz H., Yilmaz T., Tanes Y. 1996. Experimental results of the safety tests on domestic refrigerators for refrigerant R600a. Proc. IIR Aarhus Meet.	tested for several leak scenarios in the same experimental set-up that consists of a gas detector with two sensors calibrated for isobutane, a refrigerant bottle, an electronic scale on which the bottle is located and the capillary tubing for injecting the refrigerant into the insulating foam or the food compartment depending on the type of cooling system. During the tests, R600a concentration has been measured inside and outside the appliances in the vicinity of potential electrical spark sources
Clodic D., Cai W. 1996. Tests and simulations of diffusion of various hydrocarbons in rooms from air-conditioners and refrigerators. Proc. IIR Aarhus Meet.	Tests and simulations that were performed on various leak rates of propane or isobutane show that concentration is not always homogeneous. These gases heavier than air concentrate preferably down the ground especially when convection is natural. A test method and its results are presented in the paper as well as the first simulation results obtained with Fluent
Gigiel A. 2004. Safety testing of domestic refrigerators using flammable refrigerants. Int. J. Refrig., vol. 27; n. 6;	tests were all carried out as specified in the Standard. Some of the test specifications were straightforward but some tests ambiguous and gave different results depending on the method used. The method of testing the protection of the refrigeration circuit does not simulate the type of damage that could be caused by defrosting with a knife. The simulation of a leak in a protected cooling circuit is not specifically defined. The concentration of refrigerant in the compartment with the protected circuit depended on the method used to prevent foam from entering the capillary tube (either 140 or 17,500 ppm). The position and direction of a simulated leak in the compressor compartment is not specified in the Standard but had a significant effect on the concentration distribution (643-240,000 ppm). The sudden release of an accumulation of refrigerant caused peaks in the concentration that could not be measured by the response time of the measuring instrument specified (28,500-8000 ppm in 1.5 s).
Hiroaki, O., Tatsuhito, H. O., Chaobin D, Eiji, H. 2014. Leakage of Mildly Flammable Refrigerants into a Room. Proc. Int. Refrigeration and Air Conditioning Conf., Purdue, USA.	Diffusion phenomena were numerically analysed when a refrigerant leaked slowly from a room air conditioner (RAC) and package air conditioner (PAC) and rapidly from a chiller into a large space. Based on the calculation results, the refrigerant concentration distributions, the volumes and positions of the flammable regions, and their changes in time were examined.
Li, Y. N., Tao, J. J., Han, Y. C., Han, X., Qin, J. 2014. Numerical and Experimental Study on the Diffusion Property of Difluoromethane (HFC-32) in Leakage. Procedia Engineering, vol. 71, pp. 34 – 43	Based on computational fluid dynamics theory and the CFD software FLUENT, the process of leakage of difluoromethane was simulated to study the law of HFC-32 diffusion. And then in a same proportion of entity room experiments were carried out to corroborate the results. From both simulation and experimental results above, it is seen that when the leakage point is lower (cabinet air conditioners scene), the difluoromethane cannot easily diffuse to higher places.

Jia, L. Z., Jin, W. F., Zhang, Y. 2015. Analysis of Indoor Environment Safety with R32 Leaking From a Running Air Conditioner. Procedia Engineering, vol. 121, pp. 1605–1612	Analyses the leak variation and indoor R32 concentration distribution when it leaks from the running indoor unit using experimental methods. The results show that the leak rate of R32 decreases with the air conditioner operating. And the leak process of refrigerant under operating conditions can be classified into two stages, fast leak stage and slow leak stage. The concentration of test points increases at first, then decreases and gradually stabilizes. Near the leak hole, it is the highest and varies dramatically. And it is high in the supply air mine stream, but it is only about 15% of the LFL. The concentration of the corner that the supply air cannot reached is the lowest.
Clodic, D., Cai, W. 1997. Study of diffusion of propane and iso-butane in rooms respecting the standardised practical limit. Proc. ASHRAE Annual Meeting, Boston, USA.	Measures gas concentration arising from simulated leaks from base of domestic appliances.
Zhao, Y., Shigang, Z., Guansan, T., Bin, L., Yitai, M. 2002. Study of refrigerant leakage in refrigeration system. J. Fire Sciences, Vol. 20, pp. 237 – 245	Proposed a numerical method to approximate the size of the flammable region arising from a jet release of flammable refrigerant from a leak hole.
Wang, Z., Zhao, Y., Jie, W., Dong, L., Zhong, Z. F. 2013. Leakage Research of Split-type Air-conditioner using R290 as Refrigerant. Journal of Refrigeration, 2013-06	To determine the combustible region of leaked HC-290 from indoor unit of air-conditioner this study, a test room was established in this study. The distribution of HC-290 concentration was studied after it leaked in the room with different room area; installation height of indoor unit, location of the leakage and different leakage rate. The results showed that combustible region is limited only in the region very close to the indoor unit, and combustible region only exists during the leakage process, which will quickly disappear once the leakage stops
Cheng, R. C., Shih, Y. C. 2015. Numerical Study on Evaluating the Safety of Refrigerant Leakage for a R290 Air-Conditioner. Journal of Beijing University of Aeronautics and Astronautics, June 2015.	Used the numerical simulation to evaluate the safety of refrigerant leakage for a HC-290 air-conditioner. The CFD package software, ANSYS FLUENT, was employed to simulate the diffusion process of the leaking refrigerant within an indoor. During the CFD simulation, two leakage positions were considered: one was set at the pipe connector joining the inside and outside units, and the other was set at the return tubes of evaporator inside the indoor unit. In addition, the on and off of the compressor and the exhaust fan were also considered as the operating conditions. Comparing the numerical results with those of the experiment in literature, it can be found that both results had similar trend on the concentration distribution of HC-290. The numerical results also show that it is beneficial to lower the indoor HC-290 concentration when the exhaust fan was turned on.
Dorman, D., Branch, S. 2013. An Analytical Investigation of Class 2L Refrigerants. Proc. 2013 ASHRAE Annual Conference, USA	Gives technical basis for establishing mitigations via location of ignition sources, refrigerant detection and ventilation methods for refrigeration systems with limited charge levels placed in or directly serving the occupied space.

Evaluation of consequences

Yajima, R.et al. 2011. Experimental Safety Evaluation on Flammability of R32 Refrigerant. Proc. ICR 2011	Combustion behaviour of R32 accumulated in a test room is described. It is shown that flame propagation rate of R32 is 8 times of its burning velocity and the maximum pressure just reaches to one fifth of the pressure where a glass window is broken.

Imamura, T. and Sugawa, O. 2016. Physical Hazard Evaluation of A2L Refrigerants Assuming Rapid Leak Accident from a VRF System. Proc. of The International Symposium on New Refrigerants and Environment Technology	Combustion behaviour of R32 and 1234ze in a full-scale room (2m×2m×2.4m) is described. It is shown that the flame propagation rate of R32 was 1.0m/s and its peak overpressure was 4-5kPa, but the transition to the turbulent combustion doesn't happen.
Saburi, T. and Wada, Y. 2016. Hazard Evaluation Study on The Mildly Flammable Refrigerants. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.	Measurements of the scale effect of K_G values (deflagration index) of R32, 1234yf, and 1234ze are described. It is shown that K_G values for A2L refrigerants have little scale effect unlike A3 refrigerants.
Higashi, T., Saitoh, S. , et al. 2016. Diesel Combustion of Oil and Refrigerant Mixture During Pump Down of Air Conditioners. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.	Behaviour of diesel combustion of R1234yf, R32, and R410A in a small-scale engine are described. It is shown that there is difference in combustion behaviour between POE oil and PAG oil.
Saburi, T. and Wada, Y. 2014. Hazard Assessment of the Combustion of Mildly Flammable Refrigerants. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.	Measurements of K_G (deflagration index) of R32, 1234yf, and 1234ze are described. It is shown that the three refrigerants have smaller K_G values than that of ammonia.
Higashi, T., Saitoh, S., et al. 2014. Diesel Combustion of Oil and Refrigerant Mixture During Pump Down of Air Conditioners. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.	Behaviour of diesel combustion of 1234yf and R32 are described. It is shown that 1234yf and R32 have almost the same combustion behaviour as R410A and R22.
AHRTI-9007, 2017. Benchmarking Risk by Real Life Leaks and Ignitions Testing. Testing by Underwriters Laboratories, USA.	R-32 was used in a large room test, but at elevated LFL levels consistent with proposed IEC 60335-2-40 provisions (charge level based on LFL/2). Testing was complete in 2016. The results are not yet published. Initial results indicate that Class 2L refrigerants will ignite and cause secondary ignition. LFL/2 proposed in IEC 60335-2-40 is too high; charge level of LFL/4 in ASHRAE 15 is acceptable; The work by Jabbour and Clodic is confirmed; Class A2L refrigerants must be considered flammable and mitigation is needed to avoid ignition and / or post ignition damage.
Zhang, W., Yang, Z., Li, J., Ren, C. X., Lv, D. 2015. Study of the explosion characteristics and combustion products of air conditioner using flammable refrigerants. Journal of Fire Sciences, vol. 33 issue: 5, pp 405-424	Explosion pressures of R32 and HC-290 at different concentrations were studied using 20 L ball explosive test apparatus. The indoor unit combustion, total heat release, carbon monoxide, and carbon dioxide production were studied in the event of the indoor unit being ignited by an external fire. It is found that the maximum explosion pressures of R32 and HC-290 are basically the same. Besides, heat and smoke mainly come from the combustion of indoor unit plastic shell and compressor lubricants.

Zgliczynski, M., Sansalvadore P. 1994. Contribution to safety aspect discussion on isobutane compressors for domestic refrigeration. Proc. IIF-IIR Conf. New Applications of Natural Working Fluids in Refrigeration and Air Conditioning, Hanover, Germany	Measured developed overpressure within compressors arising from internal ignition of various concentrations of hydrocarbons.
Tadros A., Maclaine-Cross I., Leonardi E. 2008. Safe plant rooms for large hydrocarbon chillers. In: Natural refrigerants: sustainable ozone- and climate-friendly alternatives to HCFCs. GTZ Proklima	Shows plantrooms for chillers with large hydrocarbon charges can be designed and used safely through proper refrigerant handling, leak minimization, mixture dilution, ignition prevention and overpressure venting. This minimizes the consequences of any release or ignition. Major new recommendations were given, such as: a fire and vapour proof wall to separate the chiller or chillers and boilers from other plantroom components, and, if the minimum design ambient temperature is less than 5 K above the refrigerant boiling point, the compartment floor should form a basin to hold twice the volume of refrigerant liquid.
Holtappels, K. 2017. BAM Experience with A2L Refrigerants. Proc. Meet. ISO/TC 104/SC 2/WG 1. Bundesanstalt für Materialforschung und -prüfung (BAM).	Reports on measurements for explosion characteristics of R1234yf, combustion of R1234yf and formation of toxic reaction products and R1234yf release scenarios.
Holtappels, K., Pahl, R. 2009. Ignition behaviour of HFO1234yf. BAM test report, II-2318/2009 I. Bundesanstalt für Materialforschung und -prüfung (BAM), Germany.	Study examined the reaction behaviour of 2,3,3,3-Tetrafluoroprop-1-ene (HFO-1234yf) when exposed to ignition sources like sparks or hot surfaces. The focus of the examinations was not only to the determination of the flammability in different realistic scenarios and the formation of HF due to the hazards caused by the toxicity of HF. Therefore lab scale tests as well as tests with a car were carried out and are described.

Risk mitigation systems/functions

Walter, W., et al. 2014. Evaluations for 2L Refrigerant Flammability and Ventilation Mitigation Requirements in Machine Rooms. Proc. of The Int. Symp. on New Refrigerants and Environment Technology, Japan.	A range of refrigerant leak rates and different alarm ventilation rates are evaluated to understand dilution requirements in machine rooms. It is shown that alarm ventilation rate of 30 x air exchanges per hour to mitigate catastrophic leak rate (40 kg/min) is needed.
Colbourne D., Hühren R., Rajadhyaksha D. 2013. Refrigerant leakage control for R-290 in split type refrigeration and air conditioning systems. Proc. IIF-IIR. Compressors 2013, Častá - Papiernička.	Control strategies can be applied to restrict the amount of refrigerant that can leak into the occupied space can be applied, which may prevent up to 80% of the charge being released
Colbourne D., Hühren R., Vonsild A. 2012. Safety concept for hydrocarbon refrigerants in split air conditioner. Proc. 10th IIR GL2012, Delft, The Netherlands	Discusses options for certain safety concepts for medium capacity refrigerating systems, such as those for split-type air conditioning systems using HC-290 or R1270, whereby the range of systems sizes may be extended without diminishing the level of safety. These safety concepts combine release mitigation options (such as pump-down cycles, ventilation, etc) to ensure leaked refrigerant could not exceed the flammable limits, coupled with a sensing method (such as gas detection, system operating parameters, etc) to enable the leak to be identified.

Risk assessment

JSRAE. 2013. Risk Assessment of Mildly Flammable Refrigerants 2012 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.	Extensive collection of articles addressing many topics associated with application of mainly A2L flammable refrigerants in AC systems and applications.
JSRAE. 2014. Risk Assessment of Mildly Flammable Refrigerants 2013 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.	Update of extensive collection of articles addressing many topics associated with application of mainly A2L flammable refrigerants in AC systems and applications.
JSRAE. 2015. Risk Assessment of Mildly Flammable Refrigerants 2014 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.	Update of extensive collection of articles addressing many topics associated with application of mainly A2L flammable refrigerants in AC systems and applications.
JSRAE. 2016. Risk Assessment of Mildly Flammable Refrigerants 2015 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.	Update of extensive collection of articles addressing many topics associated with application of mainly A2L flammable refrigerants in AC systems and applications.
JSRAE. 2017. Risk Assessment of Mildly Flammable Refrigerants 2016 Progress Report. Japan Society of Refrigeration and Air Conditioning Engineers.	Update of extensive collection of articles addressing many topics associated with application of mainly A2L flammable refrigerants in AC systems and applications.
Imamura, T., Sugawa, O. 2014. Experimental Evaluation of Physical Hazard of A2L Refrigerant Assuming Actual Handling Situations. Proc. of The International Symposium on New Refrigerants and Environment Technology, Japan	It is shown that unlike piezo lighters, oil lighters can be an ignition source for R32, 1234yf, and 1234ze. It is shown that A2L refrigerants leaking into the space where the ignition source already exists cause no significant damages.
Takaichi, K., et al. 2014. Overview of the Risk Assessment for Mini-Split Air Conditioner. Proc. of The International Symposium on New Refrigerants and Environment Technology, Japan	Risk assessment of R32 (or 1234yf) mini-split air conditioners ranging from residential to light commercial including floor standing units is described. It is also shown that the indoor fan of a floor standing unit is effective measures in diluting leaked refrigerant.
Yajima, R., et al. 2014. Overview of the Risk Assessment and Safety Guideline for VRF System using A2L Refrigerants. Proc. of The International Symposium on New Refrigerants and Environment Technology, Japan.	Risk assessment of R32 VRF systems installed in a poorly-ventilated room (Karaoke room), semi-ground, and machinery room, which may pose severe risk is also considered, and safety requirements to mitigate its risk are described.
Ueda, K., et al. 2014. Chiller Risk Assessment and Guideline by Mildly Flammable Refrigerants. Proc. of The International Symposium on New Refrigerants and Environment Technology, Japan	It is shown that frequency of the occurrence of fire accident become smaller than once in one hundred year in machine rooms with appropriate ventilation rate(4 x air exchanges per hour).

AHRI, 2015. Risk Assessment of Refrigeration Systems Using A2L Flammable Refrigerants. AHRI Project 8009 Final Report	Provides a scientifically significant analysis of R32, R1234yf and R1234ze including Fault tree analysis, risk assessment, CFD analysis and test data. The study concludes the following in part: "In summary, this risk assessment evaluated the potential ignition risks associated with the use of R-32, R- 1234yf and R-1234ze(E) in commercial refrigeration systems. Based on CFD modelling, experimental testing, and FTA, the risk assessment indicates that the overall average risks associated with the use of these ASHRAE 2L refrigerants are significantly lower than the risks of common hazard events associated with other causes and also well below risks commonly accepted by the public in general." Thus the report provides a relative assessment of the gasses against "risks commonly accepted by the public in general", leaving the final conclusion of risk in the specific product design and application to the provider of the product and standards development body to ensure the safe application of the gas.
Goetzler, W., Bendixen, L., Bartholomew, P. 1998. Risk Assessment of HFC-32 and HFC-32/134a (30/70 wt. %) in Split System Residential Heat Pumps. DOE/ AHRI/ ARTI DOE/CE/23810-92	common ignition sources that are present in residential and commercial building can ignite Class A2L Includes testing and fault tree analysis of a variety of residential split system applications. Risk of fire is relatively high between 1 x 10-2 and 1 x 10-4 or about the same risk as a significant home fire in the US (1 x 10-3)
Lewandowski, T. A. 2012. Risk Assessment of Residential Heat Pump Systems Using 2L Flammable Refrigerants. AHRI Project 8004 Final Report.	Extensive analytical work for a wide variety of applications of residential heat pumps (main floor, garage, attic, basement) showing that risks are on the order of 10-5 or higher. Refrigerants R32 and R1234ze were studied
Lewandowski, T., Reid, K. R. 2012. Risk assessment for residential heat pump systems using 2L flammable refrigerants. Proc. ASHRAE/NIST Refrigerants Conf., Gaithersburg, USA.	Risk assessment of R-32, R-1234yf, and R-1234ze(E) in residential split heat pump systems was conducted. The work included CFD modelling, experimental measurements, and fault tree analysis (FTA) to quantify ignition risks. The assessment indicated that large releases of R-32, R-1234yf and R-1234ze(E) from units installed in basements, garages or attics would not reach flammable concentrations in areas where a sufficient ignition source might be present. Large releases of all three refrigerants from a unit located in a utility closet can generate flammable concentrations in the closet, although the time the refrigerant concentration was flammable was brief. Flammable concentrations did not occur with smaller leaks of R-1234ze(E) and R-1234yf in utility closets. The FTA estimated risks of refrigerant ignition due to an accidental leak.
Poolman C., Papas P., Rusignuolo G. et al. 2016. Low GWP refrigerants in transport refrigeration: risk and benefit assessment of flammable and mildly flammable alternatives. Proc. 12th IIR GL2016, Édimbourg, UK.	Assessed the flammability risks associated with the use of these refrigerants in transport refrigeration, and perform a risk–benefit analysis.
Goetzler, W., Guernsey, M., Faltermeier, S., Droesch, M. 2016. Risk Assessment of Class 2L Refrigerants in Commercial Rooftop Units. AHRI Project No. 8016, Navigant Consulting Inc.	Extensive analytical work for a variety of applications of light commercial rooftop refrigeration systems , used in commercial kitchens and offices, mounted on the roof and on the ground, showing that risks are on the order of 10-8 or higher. Refrigerants R-32 and R-1234yf were studied. Installation and various operating conditions were included in the study.

Goetzler, W., Guernsey, M., Weber, C. 2013. Risk Assessment of Class 2L Refrigerants in Chiller Systems. Final Report June, 2013, AHRI Project No. 8005/Navigant Consulting Inc.	Extensive analytical work for a variety of air cooled and water cooled chillers. Air cooled chillers were located outdoors. Water cooled chillers were located in a code compliant mechanical equipment room. The study included installation, operation and service. The study revealed that installation and service are the highest risk events with risks of 10-6 or higher.
Gmünder, F. K., Wolfer, M., Seitz, E. 2002. Risk analysis of heating and refrigeration systems with natural working fluids. Elsevier Science, 0-0804-4120-3	Reports on risk assessments for heat pump in a single-family house using ammonia, propane and R134a and compares with a central heating system with natural gas and a central cooling system in a supermarket with 20 to 40 kg refrigerants using ammonia, propene and R404A and decentralised cooling and freezer units in a supermarket with ammonia, propane and R404A.
Zhang, W., Yang, Z., Li, J., Ren, C-X., Lv, D., Wang, J., Zhang, X., Wu, W., 2013. Research on the flammability hazards of an air conditioner using refrigerant R-290. Int. J. Refrig., Vol. 36, Issue 5, 1483-1494.	Addresses the associated flammability concerns through a number of risk-related sub-studies. These include evaluating the distribution of HC-290 following a leak in room, overpressure arising from ignition of a flammable mixture, severity of a secondary fire and total heat release rate in the event of an external fire imposed upon an HC-290 system. It is found that the possibility of refrigerant existing within the flammable range is limited only to the region very close to the indoor unit. Besides, low overpressures in the event of ignition and limited additional heat flux in the event of external fire were registered.
Kataoka, O. 2013. Safety Considerations When Working With 2L Flammability Class Refrigerants. Proc. Institute of Refrigeration, London, UK	Rationale of IEC 60335-2-40 under revision for A2L refrigerant use is shown.
Colbourne, D., Suen, K. O., 2004a. Appraising the flammability hazards of hydrocarbon refrigerants using quantitative risk assessment model. Part I: modelling approach. Int. J. Refrig., pp.774–783, Vol 27.	Describes a quantitative risk assessment (QRA) model to evaluate the potential for ignition when hydrocarbons are employed in stationary refrigeration and air-conditioning equipment. QRA enables examination of the effects that design, installation of equipment and external conditions on the frequency of ignition of the refrigerant and its consequences. Presents the modelling approach for ignition frequencies, sub-models for refrigerant leakage and development of flammable concentration, and the associated consequences, being overpressures and thermal radiation.
Colbourne, D., Suen, K. O., 2004b. Appraising the Flammability Hazards of Hydrocarbon Refrigerants using Quantitative Risk Assessment Model. Part II: Model evaluation and analysis. Int. J. Refrig., pp. 784 – 793, Vol. 27.	Details empirical data that can be used in a quantitative risk assessment model presented in the earlier part of this study. Data for leakage, hardware failure and sources of ignition are used to demonstrate the application of the model, and the sensitivity of key variables. It examines the effects that design, installation of equipment and external conditions have on the frequency of ignition and the associated consequences. Efficacy of risk-reducing measures, such as refrigerant mass, room size, installation height, and ventilation rates is also examined. Results for selected types of equipment are also presented.
Blom-Bruggeman, J. M, van Gerwen, R. J. M., Verwoerd, M. 1996a. Risk Assessment of typical cooling and heating systems using natural working fluids. Part: Risk assessment methodology. R96-348. Report of TNO, Apeldoorn. Netherlands.	Details risk assessment methodology, data and application models for carrying out a risk assessment for hydrocarbons in various types of equipment.

Blom-Bruggeman, J. M, van Gerwen, R. J. M., Verwoerd, M. 1996b. Risk Assessment of a Bulk Milk Tank using Hydrocarbon Refrigerant. Final Report of TNO, Apeldorn. Netherlands.	Details risk assessment methodology, data and application models for carrying out a risk assessment for hydrocarbons in milk cooling tanks and provides HazOp study and overall results when applied to various scenarios.
Rajadhyaksha, D., Wadia, B. J., Acharekar, A. A., Colbourne, D. 2015. The first 100 000 HC-290 split air conditioners in India. Int. J. Refrig., vol. 60, pp. 289–296	Reports on development of HC-290 AC products and associated infrastructure and includes details of QRA of the products.
Colbourne, D., Suen, K. O. 2015. Comparative evaluation of risk of a split air conditioner and refrigerator using hydrocarbon refrigerants. Int. J. Refrig., vol. 59, pp. 295–303	A study demonstrated that the flammability risk associated with split air conditioners is around 100 times lower than with HC-600a domestic refrigerators
Colbourne D., Suen K. O., Huehren R. 2016. Risk assessment of R22 air conditioners using R290. Proc. 12th IIR GL2016, Édimbourg, UK	Addresses the flammability risk associated with applying HC-290 in converted R22 air conditioners and compares the risk against equivalent air conditioners that are specifically designed and built for HC-290. Different levels of conversion are considered in terms of the extent of modification that a technician may apply to the R22 air conditioner, ranging from no changes ("drop-in") to comprehensive alterations in order to bring the equipment as close as possible in line with standardised design requirements.
Colbourne D., Solomon P., Wilson R., et al. 2016. Development of R290 transport refrigeration system. Proc. 12th IIR GL2016, Édimbourg, UK,	to mitigate the flammability risk of using HC-290, several aspects were addressed. In terms of the equipment redesign, other than charge size reduction, the main changes were to remove potential sources of ignition or apply pre-ventilation to remove any build-up of potentially flammable mixtures. Additionally, a leak identification feature was integrated into the system controls whereby a suspected substantial leak would result in a shut-down of the system and a warning signal to ensure no additional refrigerant can leak into the refrigerated space.
König H., Bararu M. 2014. Risk assessment for reefer containers with flammable refrigerants. Proc. 11th IIR GL2014, Hangzhou, China	the use of flammable refrigerants requires a detailed risk assessment to understand the different safety concerns for operation. The results of an operational mode risk assessment and a safety concept using flammable refrigerants are presented
Colbourne D., Espersen L. 2013. Quantitative risk assessment of R290 in ice cream cabinets. Int. J. Refrigeration, vol. 36; n. 4	Flammability risk of hydrocarbon (HC) refrigerants within horizontal type ice cream cabinets (ICC). Quantitative risk assessment (QRA) is used to estimate the likelihood of ignition of leaked refrigerant and severity of the consequences. Variables were evaluated including effect of room size, positioning of ICC, compressor compartment fan airflow and ignition source distribution. To strengthen the QRA, tests were carried out for refrigerant leakage and effects of ignition to validate dispersion and consequence models. Ignition frequency is between 1 × 10-8 and 2 × 10-13 per year. The maximum overpressure and thermal intensity within the room is 3 kPa and 200 s (kW m#2)4/3, respectively and 6.5 kPa and 20 s (kW m-2)4/3 from within the compressor compartment.
Colbourne D., Suen K. O. 2008. Risk analysis of flammable refrigerants. 2. Methodology for calculations of risk frequencies and flammable quantities. Proc. 8th IIR GL2008, Copenhagen, Denmark	improved zonal dispersion model to estimate the size and duration of the flammable region resulting from a release. The output of the model, along with source of ignition characteristics, can then be used to estimate the ignition probability for a given set of circumstances.

Yao K., 2000. Risk assessments for a room air conditioner with propane. Proc. int. Symp. HCFC altern. Refrig. environ. Technol., Kobe	risk assessments and the evaluation of efficiency for a room air conditioner with propane, because of safety concerns. Although there is not much risk when air conditioners are being used, the results of the assessments throughout the life cycle show the necessity of doing further investigations.
Ritter T. J., Colbourne D. 1998. Quantitative risk assessment: hydrocarbon refrigerants. Proc. 3rd IIR GL1998, Oslo, Norway	Details are also presented on the approach of using background risks as a basis for comparison of calculated frequencies of fires and fatalities in respect to the use of flammable refrigerants, and contrasted to the actual performance of a hydrocarbon charged freezer in a fire situation, a number of independent risk assessments for a variety of different applications are described.
Colbourne, D. 2011. Risk analysis of flammable refrigerant handling during service and maintenance activities. Proc. 23rd IIR Int Congr. Refrig., Praha	procedures are broken down into discrete tasks: preparation of the working area, confirmation of correct tools, initial system checks, accessing the system, removing refrigerant, breaking into the system, carrying out repair, sealing the system, charging the system, strength pressure checking, closing the system, leak tightness checking and final system checks. Event tree analysis (ETA) is used to identify the combinations of sequence of events that may lead to a release of refrigerant and an active source of ignition that could result in ignition and eventually the probability of ignition and severity of consequences.
Blackwell, N., Bendixen, L., and Birgfeld, E. 2006. Risk Analysis for Alternative Refrigerant in Motor Vehicle Air Conditioning. EPA, Washington DC.	Analyses the potential risk to human health associated with two new mobile air conditioning (MAC) systems based on the refrigerants HFC-152a (or CO_2). Computational fluid dynamics (CFD) modelling simulated a reasonable worst-case scenario leak into the passenger compartment and the potential for passenger exposures. Fault tree analysis was conducted to estimate and broadly quantify the potential for passenger exposure and technician exposure in a range of scenarios.
Maclaine-cross, I. L. 2004. Usage and risk of hydrocarbon refrigerants in motor cars for Australia and the United States. Int. J. refrig. Vol. 27, pp. 339–345	Review use of HCs in MAC systems and likelihood of accidents across the population.
Gerwen, R. J. M., van, Jansen, C. M. A. 1994. Risk assessment of flammable refrigerants. Proc. IIR Conf. Natural Working Fluids, Hannover, Germany.	Covers general aspects related to accidents and risks, quantitative risk assessment techniques, safety standards and regulations. Preliminary results of a detailed risk assessment for a transport unit using a flammable refrigerant is given.
Gerwen, R. J. M., van, Verwoerd, M. 1996. Quantification and evaluation of safety risks related to the use of ammonia and hydrocarbons as refrigerants. Proc. IEA Heat Pump Programme Annex 22 Workshop “Compression systems with natural working fluids”, HPP-AN22-3.	TNO has been working with quantitative risk' analysis for a number of years, and have applied the advanced models in many case studies.
Jansen, C. M. A., van Gerwen, R. J. M. 1996. Risk assessment of the use of flammable refrigerants. (In transport refrigeration.) R95-189. Final Report of TNO, Apeldoorn, Netherlands.	Details risk assessment methodology, data and application models for carrying out a risk assessment for hydrocarbons in transport refrigeration systems and provides HazOp study and overall results when applied to various scenarios.

Wolfer, M., Seiler, H. 1999. Ammoniak und Kohlenwasserstoffe als kaltemittel: riskoanalyse, produktehaftpflicht und strafrecht. Bundesamtes fur Energie, Switzerland.	The risks of ammonia or propane/propene as a working fluid are estimated by quantifying the damage and the related probabilities by means of representative release scenarios. Three systems are considered: Heat pump in a residential building, Central cooling unit in a supermarket, Group of individual freezer units in a supermarket.
Wolfer, M. 1999. Flammable working fluids in Switzerland: risk assessment of natural working fluids. Proc. Workshop Proc. IEC Heat Pump Programme "Natural working fluids - a challenge for the future", Report no. HPC-WR-21, Paris, France	If the commonly used working fluids (CFCs, HCFCs, HFCs) are going to be replaced by natural fluids such as ammonia (toxic) or propane (highly flammable) the question arises as to whether the environmental benefits will outweigh the additional risks. The presentation takes a look at the risks of natural working fluids in comparison with HFCs. It was followed by a discussion of the legal aspects.

An4.3 Studies in progress

ASHRAE 1806-RP: Computer based simulations to quantify severity of events (temps, delta P, contamination, etc). This includes A2L and A3 refrigerants. Publication expected December 2017.
ASHRAE 1807-TRP: Guidelines for flammable refrigerant handling, transportation, storage, service and disposal. Propose requirements to be included in relevant safety standards. This includes A2L, A2 and A3 refrigerants.

ASHRAE 1808-WS: Identify robustness of field-made joints and determine which are suitable with flammable refrigerants.

ASHRAE 1507-RP: Database of flammability characteristics of refrigerant pairs.

ASHRAE 1773-WS: Baseline ignition potential of A2L refrigerants from common electrical devices in building. On hold

ASHRAE 1791-WS: Study effects of humidity on burning velocity to aid in proper classification of refrigerants.

ASHRAE 1794-RTAR: Identification of odorants that could be added to refrigerants for leak detection.

ASHRAE 1802-RTAR: Review and possibly modify criteria for boundary between Class 2 and Class A2L refrigerants.

AHRI 9007: Study of A2L refrigerants for PTAC applications. Part 1 experiments focus on understanding ignition events when refrigerant is discharged into an enclosed space with ignition sources external to appliance. Part 2 experiments focus on events from ignition sources within the appliance (fusite pin, etc).

AHRI 9008: Investigation of hot surface ignition. This works includes determining temperatures that result in ignition for components such as nichrome heaters.

AHRI 9009: Leak detection technology.

AHAM TG Alternative Refrigerants: Study of A2L refrigerant for RAC, PAC, Dehumidifier applications. Part 1 experiments focus on understanding ignition events when refrigerant is discharged into an enclosed space with ignition sources external to appliance. Part 2 experiments focus on events from ignition sources within the appliance (fusite pin, etc). This study mirrors AHRI 9007 at lower charge amounts.

Oak Ridge National Laboratory Alternative Refrigerant: Use CFD simulations to better understand refrigerant distribution/concentrations in the event of a leak.

An4.4 Examples of safety standards based on risk assessment approach

There are two standards which adopt a risk-assessment type approach, as opposed to those which typically use physical criteria limits. Both of these standards are for transport cooling applications.

ISO 13043: Road vehicles — Refrigerant systems used in MAC systems — Safety requirements

The purpose of the ISO 13043 standard, in force since 2011, is to minimise possible risk to persons, occupants, vehicles, traffic participants, property as well as the environment caused by failures of the mobile air conditioning (MAC) system and the refrigerant used therein.

The standard addresses R-1234yf and R-744 only and aims at maintaining a comparable level of safety as that valid for MAC systems using R‑134a.

The consequence of the refrigerant safety strategy is that each vehicle manufacturer has to carry out a risk assessment for R‑1234yf based refrigerant systems that will be used in new vehicles.

The risk assessment should consider the following scenarios*:*

- Exposure to R-1234yf concentrations above the health limits due to a leak in the passenger compartment (during vehicle normal operation and when a collision occurs);
- Exposure to R-1234yf concentration above health limits during vehicle service (workshop);
- Ignition event associated with a leak in the passenger compartment*;
- Ignition event associated with a leak in the engine compartment*;
- Ignition event due to R-1234yf release during vehicle service*;
- Liquid or fragment projection resulting from high pressure system burst;
- Exposure to decomposition products (e.g. HF, hydrogen fluoride) above the health limits (AEGL2) resulting from refrigerant thermal decomposition in the event of a refrigerant release caused by MAC system failure or a vehicle fire produced by vehicle failure.

* These items have to be considered as the most relevant because they address risks related to the presence of a flammable refrigerant gas in non-specifically trained users' operations.

ISO CD 20854: Thermal containers — Safety standard for refrigerating systems using flammable refrigerants – Requirements for design and operation

The development of this new safety standard started 2015 and is currently at CD stage; publication date for the standard is hoped to be before 2019. The standard belongs to the committee ISO TC104 "freight container" with an established liaison to several intermodal committees and ISO TC86 (refrigeration). The initiating background for the development was the foreseeable global regulations on HFCs and subsequent phase down of R134a and R404A in intermodal transport refrigeration. The WG comprises all reefer refrigeration system manufacturers, the main reefer container box manufacturers, major shipping lines, classification societies, equipment owners and others.

The scope is limited to container refrigeration system and the carriage of cargo or used as non-operating reefer or empty container for repositioning, whilst in intermodal transit. Land based continuous operation – meaning not in transit[16] – is excluded. The safety target is to maintain a comparable level of safety for normal operation as that of container refrigeration systems using non-flammable refrigerants, such as R134a and R404A.

Requirements cover normal operation of reefer container refrigeration systems in well ventilated areas or in open air, other atypical operation locations, foreseeable misuse and relevant requirements are covered as well. The inside of the container is defined as non-occupied space but is classified as a flammable zone (i.e., according to IEC 60079-10-1) in which Ex-type electrical equipment is mandatory. For the definition of operational requirements, such as ventilation rates in vessel cargo holds in case of leaks in normal operation and accidental type situations, IEC 60079-10-1 is used. For the purpose of the risk assessment reported refrigerant releases, leak mass flow, leak frequencies and examples of charge release times for different leak types are described. Relevant hazardous events are evaluated according to IEC 60079-10-1 taking fugitive refrigerant releases in normal operation for design requirements and ventilation conditions in to account. Accidental type situations with larger releases and requirements for prevention are part of the standard, including the description continuous improvement processes.

Testing requirements are defined, such as for charge releases tests and functioning of the safety equipment in such events, for shock, impact and vibration. Further testing of the implemented safety systems within an approval procedure is mandated to be done by a nominated classification society for the maritime industry for type approval.

Responsibilities are described for the manufacturer as well as the responsible operator. Both parties shall investigate the risks associated with the use of flammable refrigerants. As part of defining the design requirements the manufacturer of the refrigerating system should consult with the container box manufacturer and service personnel on the design concepts. The manufacturer should also provide the results of the risk assessment to the responsible operators of different operating sites for evaluation.

The operational mode risk assessment considers the following operational modes:

- Transport: ship transport including handling at harbour and terminals; road transport including interim parking or storage anywhere; all rail transport; tunnel passages; loading and unloading;
- Storage: industrial areas; public space; cold space or cold rooms;
- Service and repair: maintenance at professional workshops, functionality testing and quality of repair;
- Reasonable foreseeable misuse, such as improper repair and maintenance, use of improper tools or parts;
- Packing and unpacking: factory or professional packing / unpacking, Nonprofessional packing / unpacking by untrained persons;

[16] Not imported and customs declared.

- External events: accidents, crash, fire, vibration, corrosion, mechanical damage, unauthorized intervention;
- Inspections: customs, veterinarian, port health, such as terminal workers, cargo quality inspection;
- End-of-life and disposal of equipment.

The operational mode risk assessment should be carried out using methods such as HAZOP (Hazard and operability analysis), FMEA (Failure mode and effects analysis), or FTA (Fault tree analysis) or combination of methods. Note that there are published International Standards that comprehensively cover these methods.

Accordingly, the overall risk assessment shall include the following elements:

- Operational Mode Risk Assessment: determination of the likelihood of occurrence of an flammable atmosphere and the amount of refrigerant involved;
- Risk analysis: recognised methods e.g., HAZOP, FMEA, FTA identification or equivalent;
- Determination of the probability of the presence of sources of ignition;
- Assessment of the possible effects of an explosion by testing;
- Evaluation of the risks;
- Identification of measures for the reduction of risks.

The risk assessment should be supported by test and simulations.

The acceptance criteria of the risk should be in accordance with industry standards and a probability risk matrix is presented.

For the evaluation of requirements for the system design different safety concepts are described, such as separation of system parts by valves, leak detection inside the container and ventilation mechanisms. Finally the standard describes requirements for service and maintenance using flammable refrigerants. Reference to existing standard and best practice guidelines is made with adjustment of requirements for repairs in well ventilated areas, taking the implementation of continuous improvement processes and human behaviour into account. This section includes education and training requirements for technicians.