Ecodesign & Labelling Review Household Refrigeration

Preparatory/review study
Commission Regulation (EC) No. 643/2009 and
Commission (Delegated) Regulation (EU) 1060/2010

Interim report

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Acronyms

a	year (annum)
AC/DC	Alternating/Direct Current
CECED	European Committee of Domestic Equipment Manufacturers
Cenelec	European Committee for Electro-technical Standardization
CIRCA	Communication and Information Resource Centre
DoC	Document of Conformity
DoE	US Department of Energy
EC	European Commission
EN	European Norm
TWh	Tera Watt hour 10^{12} Wh
ICSMS	Information and Communication System on Market Surveillance
IEC	International Electro-technical Committee
ISO	International Standardisation Organisation
kW	kilo Watt, 10^{3} W
RAPEX	EU Rapid Alert System
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (Regulation)
RoHS	Restriction of Hazardous Substances (directive)
TC	Technical Committee (in ISO, CEN, etc.)
TWh	Tera Watt hour 10^{12} Wh
WEEE	Waste of electrical and electronic equipment (directive)
WG	Working Group (of a TC)
yr	year

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Executive summary

This is the interim-report of the preparatory review study of the existing Ecodesign and Energy Label regulations for household refrigeration appliances. The study started in January 2015 and final reporting is foreseen by the end of November of the same year. The interim-report is intended for stakeholder feedback in and after the stakeholder meeting 1 July 2015.

The study is undertaken in response of the review clauses (Art. 7) of both existing regulations, which asks for an update in view of technological progress, addressing the necessity or reduction of correction factors as well as the necessity of verification tolerances. As regards wine storage appliances, the study should verify the need for ecodesign requirements.

The current report deals, after introductory chapters 1 and 2, with Task 1 to 4 of the MEErP methodology:

- Scope, standards and legislation (Task 1, Chapters 3, 4 and 5);
- Market analysis (Task 2, Chapter 6);
- User analysis and end-of-life (Task 3, Chapter 7);
- Technical analysis (Task 4.1, Chapter 8).

Different from what the scope may suggest, this is not a simple update study of values and factors within an existing framework.

The new IEC:62552:2015 global standard, issued in February with major contributions of the EU industry, offers the opportunity to set a completely new and improved framework for energy efficiency and ecodesign regulations. But the options are many and the implications can be complex. That is why input from all stakeholders is vital.

Industry association CECED has offered several preliminary analyses for discussion, including initial proposals, which are ready for download from the project website www.ecodesign-fridges.eu.

Apart from the new standard and its possible implications, another complex issue is the non-energy resources efficiency discussed in Chapter 7. The study team signals opportunities for fighting food waste, but finds for this product group no or even negative impact for prolonging product life, improving reparability or recycling.

Comments on all issues in this report are welcomed, but with points that require some extra attention the requests are made explicit.

Tasks 4.2, 5, 6 and 7, as well as the amendments of the tasks in the current report, following stakeholder input, will be addressed in the period July until, and including, October 2015.

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1 Introduction

1.1 Background

Article 7 of Commission Regulation (EC) No. 643/2009 with regard to the revision of ecodesign requirements for household refrigeration appliances[1] stipulates that

"The Commission shall review this Regulation in the light of technological progress no later than five years after its entry into force and present the result of this review to the Ecodesign Consultation Forum. The review shall in particular assess the verification tolerances of Annex V and the possibilities for removing or reducing the values of the correction factors of Annex IV.

Furthermore *'The Commission shall assess the need to adopt specific ecodesign requirements for wine storage appliances..'.* This is due two years after entry into force.

Article 7 of Commission Delegated Regulation (EU) No. 1060/2010 with regard to the revision of energy labelling of household refrigeration[2] also requires, within four years after entry into force, to *'assess the verification tolerances in Annex VII'* and *'the possibilities to remove of reduce the correction factors in Annex VIII'*. Wine storage appliances are already included in the scope of the delegated regulation and thus not specifically mentioned as part of its revision.

In order to meet the requirements of Article 7 of both regulations, the Commission contracted a consortium of experts to perform an 'Omnibus' review study, which amongst others explored the issues mentioned in Article(s) 7 for household refrigeration appliances. The Omnibus study was concluded in March 2014.[3]

In the Consultation Forum of the 5th of May 2014 the Commission reported on the outcome of the Omnibus review[4], i.e. largely within the review deadlines, and proposed a way forward which was welcomed by the participants.

Household refrigeration appliances were identified as a *'high or medium priority'* product group *'as the energy saving potential is significant (at least 5 TWh/year in 2030), and an assessment of correction factors, number of product categories and the effect of a revised international test standard is required. In addition, there is a possibility for resource efficiency requirements. The revision should also include an assessment of possible ecodesign requirements for wine storage appliances.'*

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[1] COMMISSION REGULATION (EC) No 643/2009 of 22 July 2009 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for household refrigeration appliances, OJ.L 191, p.53, 23.7.2009. 12 August 2014 is 5 years after entry into force

[2] COMMISSION DELEGATED REGULATION (EU) No 1060/2010 of 28 September 2010 supplementing Directive 2010/30/EC of the European Parliament and of the Council with regard to energy labelling of household refrigeration appliances, OJ.L 314, p.17, 30.11.2010.

[3] VHK, VITO, VM, Wuppertal Institute, Omnibus Review Study on Cold Appliances, Washing Machines, Dishwashers, Washer-Driers, Lighting, Set-top Boxes and Pumps, Final Report to the European Commission, 12 March 2014.

[4] EC, Working Document on the Omnibus Review Process of existing measures (Agenda Point no. 7), EC/DG ENER/C3, 4 April 2014.

1.2 Assignment

As a result of the above, the Commission engaged the authors in a specific contract to perform a more in-depth investigation to prepare for the revision of the ecodesign and labelling regulations on household refrigeration.

Specifically, the request for services entailed to

- Assess the technological progress in the sector, in terms of possible efficiency-improvements, new technologies and new measurement standards, and investigate the possible consequences for a review of the regulations following the MEErP, in consultation with the Commission services.
- Assess the verification tolerances of Annex V of the Regulation and Annex VII of the Delegated Regulation.
- Assess the possibilities for removing or reducing the values of the correction factors of Annex IV of the Regulation and Annex VIII of the Delegated Regulation.
- Assess the need to adopt specific ecodesign requirements for wine storage appliances, based on the key elements covered by a preparatory study following the MEErP.
- Prepare a Technology Roadmap for household refrigeration appliances, i.e. describe best available and not yet available technologies and trends in usage and markets for a time scope up to the year 2030 and beyond.

The MEErP will be applied as follows:

- Task 0 (quickscan) is not needed because it is already covered by the Omnibus study
- Task 1 should focus on discussion of the scope and standards (1.1 and 1.2). The main controversial issues are the correction factors (for climate, built-in, no-frost) and possibly the definition of categories. For an overview of existing legislation (Task 1.3) existing source material shall be used.
- Task 2 will use market data that are available (Eurostat, GfK in public domain, CECED database), which means only data for EU as a whole and possibly some split-up by main Member States. (Task 2.1 and 2.2). For product life, pricing, etc. an update will be sought but otherwise use data as in the overall Ecodesign Impact Accounting (VHK, June 2014).
- Task 3 will adhere only to the strict approach (Task 3.1.1.). The functional system and indirect use (Task 3.2) relate to food preservation and --waste as the main function and will also be mentioned in the Roadmap report, but not in the strict prep. study. In Task 4 not a disproportionate amount of time on finding new Bills of Materials (BOMs) will be spent for all the fridge categories, because it is not a controversial issue and no large changes took place in recent years. The study team will check with industry if there are updates, e.g. for possible new categories, and –if not—use existing material.

- For MEErP tasks 5, 6 and 7 there are also parts that are less relevant for fridges. This is to be discussed with the Commission policy officer.

Work started in January 2015. A stakeholder meeting, preceded by this interim report four weeks earlier, is set for 1 July 2015. A draft final report and a separated final report on the technology roadmap are planned by the end of October 2015.

The Technology Roadmap is a separate and relatively new element of the assignment. It is intended to give the Commission the basis in terms of a technology overview to develop a strategy on future effective support under the EU research framework programme, Horizon 2020, to foster the development and production of energy efficient, novel or emerging technologies within the European Union.

The Roadmap should show previous technological innovations, current product technologies including best available technology (BAT) and concentrate mainly on an outlook of technologies yet to enter the market (BNAT) as well as general technological trends in the examined product sector, using the findings from the MEErP as a basis. It should include a basic estimation of the potential of future technologies, including but not limited to energy efficiency improvements, as well as an indication of potential hindrances to a successful market entry such as research gaps or missing production facilities.

Further details of the assignment were discussed in the kick-off meeting between contractor and Commission Services.

As regards the Technology Roadmap, the US DoE methodology (guidance: TRA-Guide and example fridges) will be used as a model for the Technology Roadmap. It uses the same TRL (Technology Readiness Level) definitions and shows a practical way forward. Not only cooling technology should be included, but also –as indicated in the Integrated Roadmap of the EC (see Annex on Energy Efficiency under heading Nº 4[5])—the intelligent use of the appliances (e.g. food management, reduction of food waste) with particular attention devoted to the interaction and active participation by the user/customer. The Smart Appliances project of VITO , currently ongoing, could feed into the study. Its focus is on energy peak shaving by utilities, using appliances which are adequately equipped for the task. the technologies should be fridge-specific and not only horizontal; freezers and fridges are special in this respect because of their storage capacity (i.e. they can go without current for a while).

Regarding the implementation of the MEErP, in view of the tight timeline and the fact that already an Omnibus study was done, the study will adhere itself only to the parts that are relevant for a strict product approach (see Chapter 7.1.1) and that the emphasis will be on the development of new metrics.

The study interfaces with several other Commission activities:

- Labelling review: Commission proposal expected in mid-2015. The objective for this study will be to propose a definition of 7 label classes, with the top class (and preferably also the 2nd highest class if possible) 'empty' (no models). How these classes will be called is not subject of the study.

[5] EC, SET-Plan: The Integrated Roadmap, ANNEX I: Research and innovation actions, Part I - Energy Efficiency, Dec. 2014.

- ‘Verification tolerances’ (admissible deviations from declaration): A reduction of the 10% tolerance for the energy consumption should be investigated (Task 7).

The Ecofys consultancy monitors the development of related EN standards following mandates by the Commission. That work will also feed into this study[6]

EC DG ENV is doing research (assisted by Ricardo-AEA) on durability of refrigerators.[7] The study is ongoing and –apart from an inventory of endurance testing of components in test standards— does not (yet) give any results that could be incorporated in this interim report.

[6] Ecofys (coordinator), Monitoring the development of standards for household appliances, Ecofys in collaboration VHK and SEVEn, 18.10.2013-18.4.2015 project for the European Commission.
[7] Project website http://www.productdurability.eu/

2 Consultation and data-retrieval

2.1 Activities

The study began in January 2015. The kick-off meeting between contractor and Commission services took place 12 January 2015.

On the 27th of January the study team met with the industry, i.e. the CECED Working Group Cold, to introduce the project and request collaboration in data retrieval, addressing the specific and detailed issues for which input is required. CECED represents the EU white-goods industry, which covers approximately three-quarters of the EU household refrigeration market.

The project website www.ecofridges.eu, intended to register and inform interested stakeholders of context, planning, documents and meetings, was launched 3 February 2015. The text for the website, presented at the kick-off meeting, was approved by the Commission services. The latter also informed stakeholders during Consultation Forums on the existence of the project website.

In February the study team approached the UK technical experts that could provide input on the 2011 Intertek report that proposed changes to especially the correction factors in the current legislation.

By the end of April, CECED delivered the requested data in the form of two reports, which are placed on the project website, and several databases. An initial internal scan was performed by the study team, including the reviewers. These documents were the basis of a follow-up meeting with CECED on the 6th of May, where also the UK technical experts were present.

Over the period January to May 2015 the study team engaged in desk research relating to the various parts of the assignment. Key sources include

- IEA-4E Benchmarking study (update 2014)[8],
- Clasp online database on global Standards and Labels,
- Clasp 2013 omnibus study,
- Commission Standards Monitoring project, report on refrigerators,
- US DoE, TRA-Guide and Fridges report (Technology Roadmap),
- Integrated Roadmap of the EC (esp. Annex on Energy Efficiency heading Nº 4),
- Smart Appliances ecodesign study by VITO,
- Commission study on durability of refrigerators (Ricardo-AEA for EC DG ENV),
- IEC 62552 and related standards,
- ReGent reports on new standards 2013,
- manufacturer data on wine storage appliances,
- Intertek report on correction factors.

Apart from the above, the study builds on the 2014 Omnibus study as well as the previous preparatory and impact assessment studies.

[8] IEA-4E, Mapping and Benchmarking Domestic Refrigerated Appliances, Updated version May 2014.

2.2 Consultation

The study's desk-research will take into account the suggestions and criticism from stakeholders and experts voiced in recent years, especially in the context of the 2014 Omnibus study. In addition position papers and publications by TopTen, CLASP, IEA-4E, Intertek were studied.. Furthermore, the broad composition of the study team, with experts from 5 Member States (NL, FR, DE, DK, BE), should provide input on the most critical issues.

Specific written feedback was received from industry, i.e. CECED, especially regarding the metric to be used rather than specific targets. The CECED reports are published on the project website.

The study has been underway only 5 months and it is expected that much more feedback will be provided by stakeholders before and after the stakeholders meeting on the 1st of July.

2.3 Positions

Topics mentioned by stakeholders (to be expanded in final report:

- Revisit correction factors for climate (remove), built-in (re-assess), no-frost (adapt)
- Align new IEC 62552 standard
- Not linear curve but exponential (curved) reference (SAE formula in par. 5.3)
- Not only efficiency, but total energy consumption important
- Cooling capacity may be relevant (according to latest StiWA test)
- Address non-energy resources efficiency

3 Scope (Task 1.1)

3.1 Article 1 (Scope)

According to Art. 1.1 of Ecodesign Regulations (EC) 643/2009 and (EU) 1060/2010 the scope relates to '*electric mains-operated household refrigeration appliances with a storage volume up to 1500 litres'* . Art. 1 of Energy Label Delegated Regulations (EU) 1060/2010 is similar, but refers to a storage volume '*between 10 and 1500 litres*'. The reason for this distinction lies in the Annex II, point 1 of the Ecodesign regulation, which prescribes, from 1 July 2013, an auto-off feature for fridges with storage volume <10 litres when they are empty[9].

The definition of the scope thus depends on a quantitative parameter (*storage volume 0 or 10 to 1500 litres*), the energy source (*electric mains*) and a generic 'intended use' (*household refrigeration*).

In Article 1.2 the definition of the scope also includes appliances *'sold for non-household use'* and *'for the refrigeration of items other than foodstuffs'* and *'including built-in appliances'*. This was to avoid some possible loopholes, but especially with the Commission planning to regulate commercial and professional refrigeration appliances the Article 2 should be reviewed and possibly also the 1500 litre limit for the storage volume (1000 litre would be more common) should be revisited. The addition *'including built-in appliances'* only appears in the 2010 Energy Label Delegated Regulation and not in the 2009 Ecodesign Regulation.

Article 1.2 also specifies –somewhat in contrast with the exemption (b) in Article 3— that electric mains-operated appliances *'that can be battery operated'* are included in the scope. Article 3 (b) stipulates that the regulation shall not apply to '*battery-operated refrigeration appliances that can be connected to the mains through an AC/DC converter, purchased separately*'. The deciding words here are probably 'purchased separately' because technically the AC/DC converter will usually come into play if an electric mains-(AC) operated appliance can also be battery (DC) operated.

Article 1.3(a) gives an explicit exemption for appliances that are '*primarily*' powered by other energy sources (but might also be electric mains-operated), thus ensuring LPG, kerosene and bio-diesel fuelled appliances are not included. However, natural gas is not mentioned. The typical camping/mobile-home multi-fuel refrigerators that can run on AC or DC electricity or on butane are not mentioned either.

Article 1.3 (c) excludes '*custom-made appliances, made on a one-off basis and not equivalent to other refrigerating appliances'*, which is not a stipulation that can be found in regulations of other large domestic appliances such as washing machines, dishwashers, etc.. It would make sense to harmonise the definition with the scope of planned Ecodesign measures for professional and commercial appliances.

This applies to the remaining two exemptions in Article 1.3 (d) and (e). The first (in sub d) exempts *'refrigeration appliances for tertiary sector application where the removal of refrigerated foodstuffs is electronically sensed and that information can be automatically transmitted through a network connection to a remote control system*

[9] And states that 'The mere presence of a hard off switch shall not be considered sufficient to fulfil this requirement'.

for accounting'. If Article 1.2 would not mention the possibility of *'non-household use*', this exemption would not be necessary.

Likewise, Article 1.3 (e) exempts *'appliances where the primary function is not the storage of foodstuffs through refrigeration, such as stand-alone ice-makers or chilled drinks dispensers'*, a provision that would also not be necessary if non-household use is exempted.[10]

Recommendation (for stakeholder comment): Article 1 can be simplified if the intended use is restricted to 'household refrigeration'. It can be made more robust if the definitions of the scope of regulations for the household, professional and commercial refrigeration appliances are aligned.

3.2 Article 2

Likewise, it seems that Article 2 (Definitions) can also be simplified and improved. There are a number of definitions that actually appear only in Article 2 and nowhere else in the main text of the regulations. Hence, the definitions of *'refrigerator', 'compression-type..', 'absorption-type..', 'refrigerator-freezer', 'frozen food storage cabinet', 'food freezer', 'multi-use appliance'* as well as probably also *'wine storage appliance'* and *'built-in appliance'*(in the Energy Label regulation) can all be transferred to Annex I.

What remains, and could probably be improved in clarity, is the definition of *and 'household refrigerating appliance'*, including the definition of *'foodstuffs'* , as well as *'equivalent refrigerating appliance'* [11](referenced in Article 4) and the more generic definitions in the energy label regulation of *'end-user'* and *'point-of-sale'*.

The *'household refrigerating appliance'* is currently defined as: *'An insulated cabinet, with one or more compartments, intended for refrigerating or freezing foodstuffs, or for the storage of refrigerated or frozen foodstuffs for non-professional purposes, cooled by one or more energy-consuming processes including appliances sold as building kits to be assembled by the end-user'*.

The inclusion of building kits is probably relating to remote condenser units and walk-in rooms for non-household use, which would be redundant with the introduction of ecodesign requirements for professional and commercial refrigeration appliances.

The new IEC 62552-1:2014 standard uses the definition: *'an insulated cabinet with one or more **compartments** that are controlled at specific temperatures and are of suitable size and equipped for household use, cooled by natural convection or a forced convection system whereby the cooling is obtained by one or more energy-consuming means'.*

The IEC definition does not mention foodstuffs, but merely describes the technical/ functional characteristics and not 'intended use'. In that sense, it is legally more robust and verifiable for market surveillance.

[10] And which, by the way, is contradicting the definition in Article 2.1 of 'foodstuffs' which does include e.g. beverages.

[11] Definition mainly relevant for conformity assessment and market surveillance: *it means a model placed on the market with the same gross and storage volumes, same technical, efficiency and performance characteristics, and same compartment types as another refrigerating appliance model placed on the market under a different commercial code number by the same manufacturer.*

To complete the IEC-definition of refrigerating appliance, the standard gives the definition of *'compartment'*, which in turn necessitates the definition of *'sub-compartment'*:

- *Compartment* is an enclosed space within a **refrigerating appliance**, which is directly accessible through one or more external doors, which may itself be divided into **sub-compartments**
- Sub-compartment is a permanent enclosed space within a **compartment** which has a different operating temperature range from the **compartment** within which it is located.

Recommendation (for stakeholder comment): to replace the current definitions in Article 2 with the IEC definitions of (household) refrigerating appliance, compartment and sub-compartment as indicated above.

3.3 Annex I

If the recommendation is followed to transfer all definitions from Article 2 that are not used in the main text of the regulation to Annex I then this Annex will contain over 30 definitions.

Annex I is vital because it determines, or rather prepares for the determination in the other Annexes, the details of the actual scope.

It distinguishes three types of *energy-using processes* (from the definition of household refrigerating appliance), i.e. *compression-type*, *absorption-type* and *other.* The two latter types are then excluded in Annex II from the specific ecodesign requirements for categories 4 to 9 'as set out in Annex IV'. Also they are subject, for the remaining categories, to different minimum Ecodesign requirements.

It defines one type of installation, i.e. *built-in*, which implicitly defines all other appliances as not being built-in. This definition is used in Annex IV (Calculation of the EEI) to give a volume correction factor for built-in appliances (in IV, Table 6). Note that CECED, in its most recent proposal sets, also with respect of the new IEC standard, a more strict definition.[12]

It defines specific features, i.e. *frost-free system* and *frost-free compartment* as well as *fast freeze*. The frost-free definitions are used for a FF correction factor in Annex IV, Table 6. The fast-freeze definition is used in the generic ecodesign requirements of Annex II[13], which stipulates –in summary-- that after activation of the fast-freeze facility the appliance shall return to its 'previous normal storage temperature' after no more than 72 hours, with an exception for electromechanically controlled refrigerator-freezers with only one thermostat and one compressor.

Annex I addresses the (pre-dominant) position of the external door by defining *top-opening/chest type* versus *upright type*, including also a specific definition for a *chest*

[12] Built-in appliance: Any appliance that is designed, tested and marketed exclusively (1) tob e installed totally encased (top, bottom, sides and back) by cabinetry or panels that are attached during installation, (2) tob e securely fastende to the sides, top or floor of the cabinetry and (3) to either be equipped with an integral factory-finsihed face or accept a custom front panel.

[13] Requirement from 1 July 2013 (Annex II, Point 1)

freezer that may have also two compartments with different door openings and where the top-opening compartment exceeds 75% of the total gross volume. This definition is important to define, in Annex IV Categories 8 and 9, two different freezer types (chest and upright).

The rest of the definitions in Annex I relates to different types of (combinations of) compartments, mainly by storage temperature:

Definitions of compartments are

- **fresh food storage** for 'unfrozen foodstuffs';
- **cellar** for 'particular foodstuffs or beverages at a temperature warmer than that of a fresh food storage compartment';
- **chill** for 'highly perishable foodstuffs';
- **frozen-food storage** means a 'low-temperature compartment specifically for frozen foodstuffs and classified according to temperature as follows', using the star(*) designation: 0* <0°C but not intended for highly perishable foodstuffs; * ≤ 6°C; ** ≤ 12°C; *** ≤ 18°C;**** or 'food freezer' ≤ 18°C but with a defined food freezing capacity;
- **ice making** for 'freezing and storage of ice';
- **multi-use** for compartments where the end-user can set the storage temperature[14];
- **wine storage** for short-term (to bring to drinking temperature) or long term (maturation) storage of wine with continuous storage temperature (±0.5 K) in the range from 5 to 20 °C, with humidity control in the range 50-80% and constructed for vibration reduction.
- **other compartment** is a compartment 'other than a wine storage compartment, intended for the storage of particular foodstuffs at a temperature warmer than 14°C.'

Annex I definitions of combinations of compartments, including the ones transferred from Article 2, are:

- **refrigerator:..** with at least one compartment *'suitable for the storage of fresh food and/or beverages, including wine'*;
- **refrigerator-freezer**: .. with at least one fresh-food and one *** frozen food compartment;
- **frozen-food storage cabinet:** *..with one or more compartments suitable for the <u>storage</u> of frozen foodstuffs;*
- **frozen-freezer:** *..with one or more compartments suitable for <u>freezing</u> foodstuffs with temperatures ranging from ambient down to -18*°C, and which is also suitable for *** storage, possibly with a **section[15]*;*

[14] Full definition: 'multi-use compartment' means a compartment intended for use at two or more temperatures of the compartment types and capable of being set by the end-user to continuously maintain the operating temperature range applicable to each compartment type according to the manufacturer's instructions; however, where a feature can shift temperatures in a compartment to a different operating temperature range for a period of limited duration only (such as a fast-freeze facility) the compartment is not a 'multi-use compartment' as defined by this Regulation.

[15] A 'two-star section' also defined in Annex I, i.e. part of a food-freezer, a food-freezer compartment or a three-star frozen-food storage cabinet which does not have its own individual access door or lid and in shich the temperature is not warmer than -12 °C.

- **wine storage appliances:** *..has no compartment other than.. wine storage compartments;*
- **multi-use appliances:** *..has no compartment other than.. multi-use compartments;*
- **cellar:** .. has no compartment other than.. cellar compartments;
- **refrigerator-chiller:** *at least a fresh-food and a chill compartment, but no frozen food compartment;*

Note that the a definition of '*wine storage compartment'* is included, which **is** regulated in the current Ecodesign Regulation when the refrigerating appliance also has other compartments. Only in the case that the appliance has '*no compartment other than one or more wine storage compartments*' (cit. Art. 2, sub 7) it is a *'wine storage appliance'* and thus excluded from the Ecodesign requirements in Annex II. The wine storage appliances are not excluded from the 'Measurements' in Annex III[16] and the verification of the humidity performance is explicitly part of Annex V.

Considerations (for stakeholder comments):

1. Some definitions in Annex I contain ambiguous and inconsistent terminology. If definitions are maintained (see next point), it is recommended to propose the definitions from the new IEC 62552: 2014 (see Annex A of this report).
2. Compartments could be defined by their design/nominal/extreme temperature, like in Annex IV Tables 4 and 5. This would simplify the legislation and improve transparency.
3. The same applies to the definition of appliances, i.e. combinations of compartments. They are not really descriptions of categories, but they seem to contain the elements of these inputs. In that sense, Table 2 (with the numbering from Table 1) in Annex IV is clearer.
4. The new IEC 62552:2014 has added the 'pantry' compartment(14-20°C, nominal 17 °C) and also the various performance issues have to be aligned (e.g. freezing capacity).
5. As regards the current exemption of wine storage appliances from the Ecodesign regulation it is probably too early in this interim report to reach a final conclusion. This exemption was introduced because these appliances, in majority with glass doors, would have had to answer to the same stringent requirements as the 'normal' (solid door) appliances. However wine storage appliances could just as well have to answer to different minimum requirements. All tests and measurements for wine storage appliances have to be done already today, and thus there would be no extra administrative burden from such a measure.

The tables from the current regulation, discussed above, are given hereafter.

[16] Note that Annex III 'Measurements' are not product Information requirements. This Ecodesign regulation for household refrigeration appliances does not have explicit information requirements, as far as the study team could establish.

Table 1

Household refrigerating appliances categories

Category	Designation
1	Refrigerator with one or more fresh-food storage compartments
2	Refrigerator-cellar, cellar and wine storage appliances
3	Refrigerator-chiller and refrigerator with a 0-star compartment
4	Refrigerator with a 1-star compartment
5	Refrigerator with a 2-star compartment
6	Refrigerator with a 3-star compartment
7	Refrigerator-freezer
8	Upright freezer
9	Chest freezer
10	Multi-use and other refrigerating appliances

Household refrigerating appliances that cannot be classified in categories 1 to 9 because of compartment temperature are classified in Category 10.

Table 1. Regulation (EC) No 643/2009, Annex IV, Table 1

Table 2

Household refrigerating appliance classification and relevant compartment composition

Nominal temperature (for the EEI) (°C)	Design T	+ 12	+ 12	+ 5	0	0	− 6	− 12	− 18	− 18	Category (number)
Compartment types	Other	Wine storage	Cellar	Fresh food storage	Chill	0-star/Ice making	1-star	2-star	3-star	4-star	
Appliance Category	Compartments composition										
REFRIGERATOR WITH ONE OR MORE FRESH-FOOD STORAGE COMPARTMENTS	N	N	N	Y	N	N	N	N	N	N	1
REFRIGERATOR-CELLAR, CELLAR AND WINE STORAGE APPLIANCE	O	O	O	Y	N	N	N	N	N	N	2
	O	O	Y	N	N	N	N	N	N	N	
	N	Y	N	N	N	N	N	N	N	N	
REFRIGERATOR-CHILLER AND REFRIGERATOR WITH A 0-STAR COMPARTMENT	O	O	O	Y	Y	O	N	N	N	N	3
	O	O	O	Y	O	Y	N	N	N	N	
REFRIGERATOR WITH A 1-STAR COMPARTMENT	O	O	O	Y	O	O	Y	N	N	N	4
REFRIGERATOR WITH A 2-STAR COMPARTMENT	O	O	O	Y	O	O	O	Y	N	N	5
REFRIGERATOR WITH A 3-STAR COMPARTMENT	O	O	O	Y	O	O	O	O	Y	N	6
REFRIGERATOR-FREEZER	O	O	O	Y	O	O	O	O	O	Y	7
UPRIGHT FREEZER	N	N	N	N	N	N	N	O	Y (a)	Y	8
CHEST FREEZER	N	N	N	N	N	N	N	O	N	Y	9
MULTI-USE AND OTHER APPLIANCES	O	O	O	O	O	O	O	O	O	O	10

Notes:
Y = the compartment is present;
N = the compartment is not present;
O = the presence of the compartment is optional;
(a) also includes 3-star frozen-food cabinets.

Table 2. Regulation (EC) No 643/2009, Annex IV, Table 2

Table 4

Storage temperatures

Storage temperatures (°C)							
Other compartment	Wine storage compartment	Cellar compartment	Fresh-food storage compartment	Chill compartment	One-star compartment	Two-star compartment/ section	Food freezer and three-star compartment/ cabinet
t_{om}	t_{wma}	t_{cm}	t_{1m}, t_{2m}, t_{3m}, t_{ma}	t_{cc}	t*	t**	t***
> + 14	+ 5 ≤ twma ≤ + 20	+ 8 ≤ t_{cm} ≤ + 14	0 ≤ t_{1m}, t_{2m}, t_{3m} ≤ + 8; t_{ma} ≤ + 4	− 2 ≤ t_{cc} ≤ + 3	≤ − 6	≤ − 12 ([a])	≤ − 18 ([a])

Notes:

t_{om}: storage temperature of the other compartment
t_{wma}: storage temperature of the wine storage compartment with a variation of 0,5 K
t_{cm}: storage temperature of the cellar compartment
t_{1m}, t_{2m}, t_{3m}: storage temperatures of the fresh-food compartment
t_{ma}: average storage temperature of the fresh-food compartment
t_{cc}: instantaneous storage temperature of the chill compartment
t*, t**, t***: maximum temperatures of the frozen-food storage compartments
storage temperature for the ice-making compartment and for the '0-star' compartment is below 0 °C
([a]) for frost-free household refrigerating appliances during the defrost cycle, a temperature deviation of no more than 3 K during a period of 4 hours or 20 % of the duration of the operating cycle, whichever is the shorter, is allowed

Table 3. Regulation (EC) No 643/2009, Annex IV, Table 4

Table 5

Thermodynamic factors for refrigerating appliance compartments

Compartment	Nominal temperature	$(25 - T_c)/20$
Other compartment	Design temperature	$\frac{(25 - T_c)}{20}$
Cellar compartment/Wine storage compartment	+ 12 °C	0,65
Fresh-food storage compartment	+ 5 °C	1,00
Chill compartment	0 °C	1,25
Ice-making compartment and 0-star compartment	0 °C	1,25
One-star compartment	− 6 °C	1,55
Two-star compartment	− 12 °C	1,85
Three-star compartment	− 18 °C	2,15
Food freezer compartment (four-star compartment)	− 18 °C	2,15

Notes:

(i) for multi-use compartments, the thermodynamic factor is determined by the nominal temperature as given in Table 2 of the coldest compartment type capable of being set by the end-user and maintained continuously according to the manufacturer's instructions;

(ii) for any two-star section (within a freezer) the thermodynamic factor is determined at $T_c = -12$ °C;

(iii) for other compartments the thermodynamic factor is determined by the coldest design temperature capable of being set by the end-user and maintained continuously according to the manufacturer's instructions.

Table 4. Regulation (EC) No 643/2009, Annex IV, Table 5

3.4 Annex IV Categories

Annex IV describes the full method for calculating the energy efficiency index (EEI) but also defines, as a part of that description, a part of the scope by defining the categories, i.e. combinations of compartments, that are being regulated.

At the moment there are 10 categories that are given in the figure 1 and 2 of the previous section. Some NGOs have voiced that there should be fewer categories (preferably one) in order to increase the transparency towards the customer of what energy consumption (s)he can expect. The reasoning is that the 'equivalent volume' calculations, which take as a basis the nominal storage temperature of the various compartments (and the correction factors) should be enough.

On the other hand, and this is also clear from the categorisation made by consumer associations, the end-user perceives a clear functional difference from a 1 or 2 door appliance (e.g. 'refrigerator' versus 'refrigerator-freezer') and from the a top-opening door, allowing long term storage of large items, and a front-opening door (e.g. 'chest' versus 'upright' freezer). Technically, also apparent from the commercial database, there is a difference in energy efficiency depending on the number and position of the doors. And it makes a difference whether, in a fridge-freezer, the top or bottom of a -18 °C freezer is adjacent to a +5°C refrigerator compartment or to +25°C ambient.

On the other end of the spectrum there are researchers from IEA-4E benchmarking project that believe that in especially the larger appliance range the EU has too few categories to incentivise the manufacturers. They point to countries like the U.S., which has more than 40 categories and where the larger categories of fridge-freezers are reportedly more efficient than in the EU.

The European industry association CECED believes that a reduction in categories is feasible and has proposed to reduce the current 10 categories to 4 or 5; the latter if it is decided to incorporate wine storage appliances in the ecodesign regulation. The purpose is not only a simplification but also, like in the US, to create room for also 4 new 'built-in' categories (without the chest freezer) next to 4 or 5 'free-standing' categories and to eliminate the built-in correction factor.

The idea is to combine the current categories 1 to 5, as well as a part of category 10, into one single 'refrigerator' category. As the market analysis in the following chapter shows, the number of models –also indicative of the sales—in categories 2 to 5 is very small and this new category is dominated by the category 1, i.e. fresh-food refrigerators without a 0, 1 or 2 star frozen-food (sub-)compartment (categories 3,4,5) and without a wine storage or cellar (sub-)compartment (category 1). Also categories 1,2 and 3 have the same reference line and –in terms of requirements—can be easily defined. Category 10 products have typically 3 or more compartments. The reference line must be taken from the coldest compartment. This is usually category 7, but in a few cases –which are the ones in this new first category—it is the reference line from current categories 1/2/3.

The second category of 'refrigerator-freezers' would comprise the current categories 6 (refrigerator with 3 star frozen food sub-compartment) and 7 (refrigerator-freezer). The latter is by far the largest in sales numbers, not only of this category, but of the whole household refrigeration appliances product-group. Also included are category 10 products that have at least one freezer compartment.

The third new category proposed by CECED is 'wine storage appliances', currently in category 2. The main reason for this separate category is again the glass door that is placed in the majority (not all, solid doors) of these appliances and would warrant –if it comes to that—a separate ecodesign limit value.

The fourth and fifth CECED categories are respectively upright and chest freezers.

In order to avoid confusion, CECED proposes not to use numbers but abbreviations (R, RF, W, Fu, Fc) for the categories.

For the built-in appliance categories a letter 'b' is added (Rb, RFb, Wb, Fub). CECED proposes to lift the current limitation that 'built-in' applies only products with width ≤58 cm. The rationale of CECED's proposal will be discussed later, i.e. in correlation with the current built-in (BI) correction factor that CECED thinks could be replaced by this new categorisation.

Considerations (for stakeholder comments):

- The CECED proposal for the reduction of categories would simplify the regulation, increase the transparency and facilitate market surveillance. This is especially true for the 4 categories of refrigerators (R), refrigerator-freezers (RF), upright freezers (Fu) and chest freezers (Fc).
- As regards the newly proposed category of 'wine storage appliances' (WI) there are some serious doubts. The matter of the glass doors and thus separate (lower) requirements is well understood, but this can simply be tackled by setting more lenient ecodesign requirements for *'refrigerators (R) with only wine storage compartments'* without defining a whole new category and reference line for this niche product. Also in terms of consistency, this does not seem a logical way forward, because there are cellar (also 12°C nominal storage temperature) and pantry (17°C) compartments for which then new categories could be claimed.
- The CECED proposal to mirror the categories also in 'built-in' version (except for chest freezers) will be discussed later, i.e. when weighing pros and cons of this proposal versus the current concept of a single correction factor.

4 Standards (Task 1.2)

4.1 Introduction

The current nomenclature and status of the applicable test standards is complex. At the moment there are three relevant standards:

1. The harmonised standard **EN 62552:2013** [17]published in the Official Journal in January 2014[18]. It is the legal basis for the current assessments for market surveillance. This standard is based on IEC 62552:2007 [19] but with some European adaptations. It was developed following European Commission mandate M/459, issued in 2009.
2. The new global standard **IEC 62552:2015** (February 2015)[20], which should harmonise household refrigeration testing and calculations around the world and to which the EU standardisation experts have made a considerable contribution.
3. A new **draft EN 62552** [21], which is based on the new IEC 62552:2015 standard. It is drafted by CENELEC TC 59 X, Working Group 8. The parallel vote for this draft is currently stopped at EU level, awaiting a new specific mandate.

Note that before the introduction of the harmonised standard EN 62552:2013 in 2014, a transitional method was communicated by the European Commission in 2010. This transitional method references mainly EN 153:2005 [22].

For noise measurement (relevant for the energy label) the Communication mentions IEC60704-2-14 [23], but this reference was corrected later on in 2010 and expanded with IEC 60704-1 [24] and IEC 60704-3 [25].

[17] EN 62552:2013 Household Refrigerating Appliances - Characteristics And Test Methods (IEC 62552:2007, Modified + Corrigendum Mar. 2008).
[18] OJ C 22, 24.1.2014, p. 32–33
[19] IEC 62552:2007, Household refrigerating appliances - Characteristics and test methods, 13 Dec. 2007. TC 59/SC 59M - Performance of electrical household and similar cooling and freezing appliances (replaced by IEC 62552:2015 in Feb. 2015, IEC 62552:2007 is a copy of ISO 15502:2005)
[20] IEC 62552:2015, Household refrigerating appliances - Characteristics and test methods, Divided in three parts. Part 1: General requirements, Part 2: Performance requirements, Part 3: Energy consumption and volume, 13 Feb. 2015.
[21] Work Item (WI) of CENELEC TC 59 X, WG 8.
[22] For Definitions, general test conditions, collection and disposal of defrost water, storage temperatures, determination of dimensions and volumes, energy consumption, temperature rise time, freezing capacity, built-in appliances, rated characteristics and control procedure, test report and marking.
[23] IEC 60704-2-14, Household and similar electrical appliances — Test code for the determination of airborne acoustical noise — Part 2-14: Particular requirements for refrigerators, frozen-food storage cabinets and food freezers. Version of 13 Dec. 2007 [WITHDRAWN], New 2013 version IEC 60704-2-14:2013; latest amendment 1.1.2015: IEC 60704-2-14:2 013/A11:2015 (contains Annex ZZ for harmonisation purposes)
[24] IEC 60704-1:2010, Household and similar electrical appliances — Test code for the determination of airborne acoustical noise — Part 1: General requirements, 24 Feb. 2010.
[25] IEC 60704-3:2006, Household and similar electrical appliances — Test code for the determination of airborne acoustical noise — Part 3: Procedure for determining and verifying declared noise emission values, 13 Feb. 2006.

For power consumption in standby and off modes the reference is Commission Regulation (EC) No 1275/2008.[26]

The measurement method for wine storage appliances, as well as the humidity measurement of wine storage compartments, is defined in the Communication, Part 2.

Considerations (for stakeholder comments):

The 2007 version of IEC 60704-2-14 has been replaced by the 2013 version. As the year of publication was not mentioned in the Commission Communication on the (corrected) transitional method, this does not necessitate a new Commission Communication. However, the new amendment A11:2005 is prepared for harmonisation and it is now unclear if test standards for noise parameters should still be referenced if indeed IEC 60704-2-14:2013/A11:20 is going to be harmonised.

Commission Regulation (EU) No 1275/2008 has been amended by Commission Regulation (EU) No 801/2013 on networked standby. Although network connectivity of household refrigeration appliances is currently not a commercial reality, it might become so in the future (compare: 'smart appliances'). It would be therefore probably prudent to expand the transitional method in that respect.

The humidity measurement method described in the transitional method is not part of IEC 62552:2015. It is unknown whether it will be added to the new draft EN 62552.

The figure below shows the history of the new IEC standard.

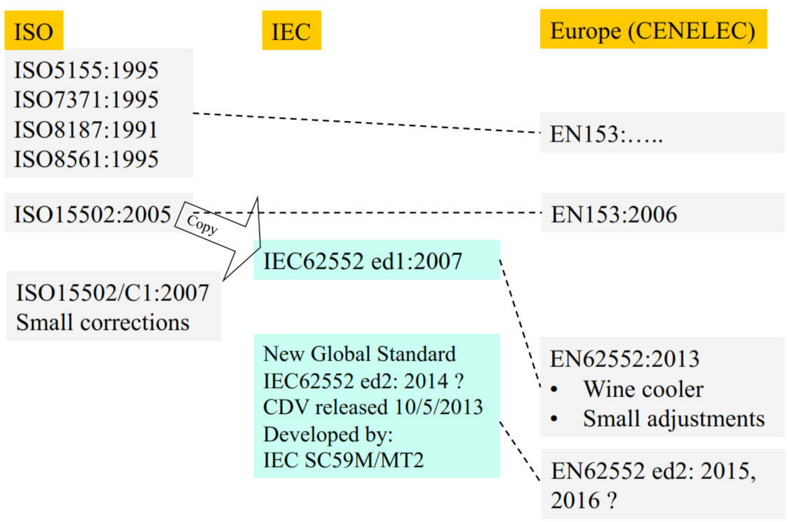


Figure 1. History of IEC 62552 (source: M. Janssen, 2013[27])

[26] OJ L 339, 18.12.2008, p. 45–52

[27] M. Janssen, Refrigerator testing: IEC 62552 ed. 2 development and AUS/NZ Round Robin testing, Presentation 13402 / RE24 / V2, Re/genT BV, 17/10/2013

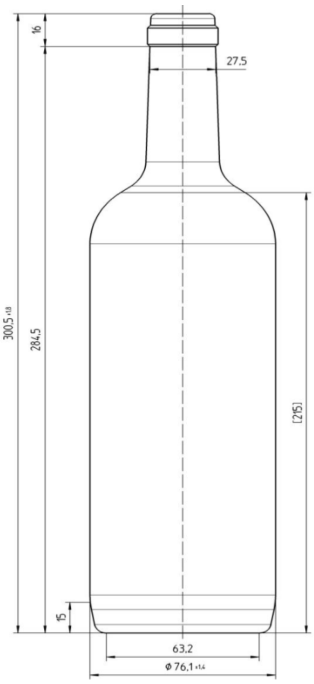
The IEC 62552:2015 standards and the draft EN 62552 are the most relevant for this study and will the subject of the rest of this section.

4.2 What is new?

From the perspective of the EU, the most important changes between the current EN 62552:2013 and the IEC 62552:2015 are given below.

4.2.1 IEC 62552-1 (Definitions)

- The test will no longer be conducted at a single ambient temperature of 25 °C but instead there will be two energy consumption tests, one at 16°C and one at 32°C, whereby the reference ambient temperature will be calculated according to a regional weighting factor;
- The fresh food target temperature is changed from 5 to 4 °C;
- The frozen food target temperature is changed from measurement inside the warmest package to a measurement without packages and an average air temperature of 5 or more distributed sensors;
- Inclusion of new types of compartments such as pantry (14-20°C, nominal 17°C) and –now not only in EN but also in IEC standards—wine storage as well as zero star compartments;



The standards (especially the Annexes) contain detailed specifications of the test set-up and –room, test packages (0.5 kg ‘M-packages’ with sensors, other packages without sensors), location and type of sensors, standard wine bottles to determine bottle capacity (see figure) , etc.. Note that Annex G is dedicated to definitions for wine storage compartment tests and describes the narrow temperature ranges and the vibration reduction.

It does <u>not</u>, however, describe provisions for the humidity control (between 50 and 80%) that is part of the current EU-regulations for wine storage compartments.

Figure 2. IEC 62552 standard wine bottle

4.2.2 IEC 62552-2 (General performance tests)

Storage tests, at various ambient temperatures, should ensure that the appliance is fit for purpose, i.e. can keep the storage temperature(s) within the required range.

Freezing and cooling capacity tests have been defined with test packages, distributed uniformly over the compartments. For freezing capacity also ballast (M-packages) will be present. The ambient temperature is 25 °C. The freezing capacity, in kg/12h, is tested with a predefined mass (3.5 kg per 100 l freezer volume) and a test load to be cooled from 25°C to -18°C. The cooling capacity is tested with a predefined mass (4.5 kg per 100 l refrigerator volume) and test load to be cooled from 25°C to 10°C.

The standard describes an **automated ice-maker test**, i.e. an item not referenced in the EU regulations.

There are a number of (optional) tests in the Annexes:

Pull-down test (IEC 62552-2, Annex A), aiming to measure the time it takes for a refrigeration appliance to cool down from 43°C --and at ambient 43°C—to the highest allowed storage temperature value for each compartment, e.g. 8°C for a fresh food compartment, -12°C for a 3 or 4 star freezer. This test is typical for very hot climates and has no added value for the EU.

Wine storage appliance test (IEC 62552-2, Annex B), designed to verify that under normal operation the set storage temperature stays within the ±0.5 K bandwidth and that during defrosting it does not exceed the ±1.5 K bandwidth.

Temperature rise test (IEC 62552-2, Annex C), aims to measure the time it takes, at 25°C, for the temperature inside a 3 or 4 star package to go from the nominal temperature of -18 °C to a temperature of -9 °C when the appliance is switched off.

Consideration (for stakeholder feedback): The temperature rise test is currently not incorporated in EU regulations, but might be useful in the context of promoting so-called 'smart appliances', i.e. where the utilities might externally switch off certain appliances to reduce energy demand in peak periods.

Water vapour condensation test (IEC 62552-2, Annex D) to determine the extent of condensation of water on the external surface of the refrigerating appliance under specified ambient conditions. Note that this relates to the external surface and is probably less relevant in the more temperate EU climate conditions.

4.2.3 IEC 62552-3 (Energy efficiency tests)

The main components of energy consumption determined in accordance with this standard are

- Steady state power consumption P , in W, at ambient temperatures of 16 °C and 32 °C (Annex B).
- Defrost and recovery energy and temperature change in ΔE_{df} , in Wh (Annex C)

- Defrost frequency/interval Δt_{df} in h rounded to the 1st decimal (Annex D)
- Specified auxiliaries energy ΔE_{aux}, e.g. an ambient-controlled anti-condensation heater or an automatic ice-maker, in kWh/year (see Annex F)

Also, for certain regions a load processing energy $\Delta E_{processing}$ is defined in Annex G.

The formula for the daily (24h) energy consumption E_{daily}, in Wh is

$$E_{\text{daily}} = P \times 24 + \frac{\Delta E_{df} \times 24}{\Delta t_{df}}$$

Consideration (for stakeholder feedback):
An important change is in the separate assessment of the defrost and recovery energy and interval, instead of it being integrated in an overall test (with a few defrosting cycles). This means that defrosting/recovery energy ΔE_{df} (in Wh) and interval Δt_{df} (in h, rounded to the first decimal) are known, which gives the legislator a whole new option, instead of only through a correction factor, to regulate no-frost energy consumption.

The same goes for ΔE_{aux} , where the legislator may choose not to regulate, regulate separately or regulate as an integrated part of the daily energy. The determination of ΔE_{aux} does require, if it is regulated, the setting of some 'regional' EU parameters, e.g. for the amount of ice produced.

The annual energy consumption, in kWh/year, shall be calculated as

E_{16} *f*365+ E_{32}*(1-f)*365, where

- E_{16} is the daily energy consumption, in kWh/d, at 16 °C ambient test,
- E_{32} is the daily energy consumption, in kWh/d, at 32 °C ambient test,
- f is a weighting factor, appropriate for regional/local usage and climate conditions; implicitly it indicates the average ambient temperature

The energy efficiency tests in the new IEC standard are in principle optimised for shorter test times and more robust results, but in order to achieve that goal, a few simple 24h test are no longer sufficient. Instead, the standard gives specific boundary conditions for the definition of a period of stable operating conditions, which are subsequently aggregated to arrive at a daily energy consumption. Tools are provided for the mathematical operations.

Secondly, the IEC-standard allows to obtain the best possible temperature setting for the compartments. In order to achieve this, at expense of the previously mentioned shorter testing time, the standard allows –within boundaries-- a mathematical optimisation from 2 (linear interpolation) or 3 (triangulation) tests for multi-compartment appliances. This is not a simple task and it is recommended to use (Excel) tools for the mathematics. The option to derive the daily energy consumption from a single test (per ambient temperature) is also still given in the standard.

Consideration (for stakeholder feedback): This leads to a considerable increase in testing costs, i.e. not just for the manufacturer but also for the market surveillance *authority. For instance, taking the case of triangulation (3 tests per product) and assuming that a product fails the first test and 3 other products of the same model have to be tested (cf. Annex V of the ecodesign regulation) the testing costs for compliance may become very high. How to deal with that?*

A third characteristic is that there are several choices left to the region where the standard is applied. E.g. the annual energy consumption (kWh/a) will be calculated from the energy consumption tests at 16 and 32 °C through a weighting factor F (of f), but depending on the region there may be an addition for the energy consumption E_{aux} of auxiliary devices (e.g. an ambient-temperature operated anti-condensation heater) and/or the extra energy consumption $\Delta E_{processing}$ from load processing efficiency.

<u>*Consideration (for possible stakeholder comments):*</u>
The EU Standardisation working group has decided in its draft EN standard not to include E_{aux} and $\Delta E_{processing}$, but Asian countries and Australia do include at least $\Delta E_{processing}$. One reason is probably historical, i.e. the European approach has always been that the 25°C ambient is 3-4°C higher than the actual ambient temperature to compensate for the door openings (the test is at closed doors) and loading of ambient temperature foodstuffs. And also in the draft EN standard, following the new IEC standard, they decided to employ a weighting factor F=0.438 which comes down to an average 25 °C (160 'days' at 16°C, 205 'days' at 32°C).[28]

Another reason is that it is perceived that the load processing test has little added value. For instance, the energy required for cooling of a warm load from 16 or 32°C to 4 or -18°C is only for a part dependent on the (load processing efficiency of the) refrigerating appliance; for a considerable part it simply depends on physics, i.e. the minimum energy required as a function of the specific heat capacity of the load, a possible phase-change energy (from liquid water to ice) and the start- and end temperatures of the operation.

In Japan, for instance, the tradition (e.g. JIS is to test <u>including</u> the extra energy consumption $\Delta E_{processing}$ (a load of PET-bottles filled with water at ambient temperature) and –using the new IEC standard—they plan to employ a weighting factor that results in a calculated average temperature of 22.7 °C, i.e. 2.3 degrees lower than in the EU[29].

The standard contains a circumvention clause to avoid manipulation of the test (see box). Test laboratories should detect circumvention devices and include them in their test report. The standard states that '*circumvention devices, where present, may be subject to regional regulations and requirements. ...Any additional energy consumption associated with the circumvention device may be added to the measured energy consumption and there may be penalty factors associated with the additional energy associated with the circumvention device.'*

[28] Decided at the Frankfurt meeting of CENELEC TC 59X, WG8
[29] While Japan has a warmer average climate than the EU.

> A circumvention device is any control device, software, component or part that alters the refrigerating characteristics during any test procedure, resulting in measurements that are unrepresentative of the appliance's true characteristics that may occur during normal use under comparable conditions. Generally, circumvention devices save energy during an energy test but not during normal use. Examples of circumvention may include, without limitation, any variation to normal operation when the appliance is subjected to testing, and includes devices that—
>
> a) alter compartment temperature set points during the test; or
>
> b) activate or de-activate heaters or other energy-consuming devices during the test; or
>
> c) manipulate compressor cycle time or other operating parameters during the test; or
>
> d) manipulate the defrost interval.
>
> Devices that operate over a restricted range of conditions and which are—
>
> i) required for the maintenance of satisfactory food preservation temperatures within compartments (e.g. temperature compensation heaters in fresh food compartments that operate at low ambient conditions); or
>
> ii) intended to reduce energy consumption during normal use
>
> will generally not be treated as circumvention devices where the legitimate basis for their operation during normal use and under the test procedure for energy consumption is declared and can be demonstrated by the supplier.

4.3 CECED views on the impact of the global standard

The changes have a number of important implications for the EU:

- The EU has to determine the regional weighting factor F for the EN-version of the IEC standard. As mentioned, the CLC TC 58X, WG has made a recommendation in its new draft standard, but the final decision will have to be made in a political context. For now, the recommendation is a factor F aiming at the current ambient temperature of 25°C, but the assessment goes beyond a simple linear interpolation.
- Linked to this, the EU will have to determine how much more energy the lowering of the fresh-food storage temperature (4°C instead of 5°C) will cost, which again could go beyond a simple linear interpolation.
- Similarly, to reach an average air temperature in a freezer compartment, within a restricted time period, costs less energy than reaching the same target temperature inside the warmest package inside that same freezer compartment.

CECED has elaborated the impact of the above, which will be briefly discussed hereafter. The full CECED reports are given on the project website[30] [31].

[30] Janssen, M., Ecodesign and labelling review Cold – Product categorisation and correction factors, Re/genT Note 15116/CE12/V5, April 2015.

[31] Janssen, M., Impact of the new IEC 62552-1,2,3:2015 global standard to cold appliance energy consumption rating (second study), Re/genT Report number: 15127/CE40/V1, 13 April 2015.

In principle, there are (at least) three possible approaches:

- A simple average between the 16 and 32 °C tests, i.e. a weighting factor F=0.5 leading to a calculated average of 24 °C.[32]
- A linear calculation to achieve an ambient temperature of 25 °C, which would result in a factor F=0.4375 (rounded 0.438)[33] as currently included in the draft EN 62552.
- A weighting factor that would yield the same energy consumption as today's single test at 25°C. As the relation is not linear, because the COP changes non-linearly with the source and sink temperatures[34], this would yield a factor different from F=0.4375.

The second approach is currently chosen in the draft EN 62552, because

a) the first approach (24°C) seems too relax the test requirements (q.e.d.),

b) a linear calculation staying at 25 °C is simple to communicate,

c) because reference lines for the categories have to change anyway, increases in energy consumption can easily be taken into account.

The result(s) for the third approach can be obtained from

a) an experimental assessment, for which CECED uses the test results –according to the new IEC 62552:2015 and the current EN 62552:2013 standard—of 72 appliances.

b) a theoretical calculation, taking into account the changes in COP based on an estimate for a fairly good configuration, and/or

According to the experimental assessment the results for the new standard (at interpolated 25 °C ambient) compared to the existing standard (at actual 25°C ambient) are as follows:

- Category 1 (refrigerator): 19% more energy, because of lower compartment temperature (4 instead of 5°C, effect 5%), reduction of COP (7%) and interpolated values being lower than actual test values (7%). Negligible effect on volume.
- Category 7 (fridge-freezer), static (one thermostat): 9% more energy. Very small effect on volume (max. 5% of freezer volume).
- Category 7 (fridge-freezer), static (two thermostats): 7% more energy (after elimination of one anomaly). Very small effect on volume (max. 5% more freezer volume). Note that the negative impact of the lower fridge compartment is partially compensated by the positive impact of the new conditions for the freezer compartment.
- Category 7 (fridge-freezer), frost free (two thermostats): 9% more energy, reflecting new defrost-cycle being more stringent and the relatively high impact of

32 (16+32)/2=24

33 Average temperature = 0.4375*16 + (1-0.4375)*32 = 25

34 COP is Coefficient of Performance. The key formula is $COP_{carnot}= (T_{cold} + 273.15)/(T_{hot}-T_{cold})$

defrosting on the very efficient products in this group.[35] The effect on volume is small, except for 3 products (out of 16) where the current EN 62552:2013 test was done with baskets in place.

- Category 8 (upright freezer), static: 1% less energy, because of measurement in air and not inside the warmest package (thus 'warmer' freezer) and the effect that interpolated energy consumption values are 3-5% higher than at actual tests at 25°. The effect on volume differs. For a small product (100 l) with large baskets the effect was 15%. Otherwise the impact is small.
- Category 8, frost free: 2% more energy due to the more stringent defrost test (shorter interval), amplified by the fact that for very efficient products the defrosting counts relatively more. Most products were currently already measured without baskets thus the effect on the volume was small.
- Category 9 (chest freezers): 2% less energy.

The theoretical calculation, in Appendix A of the CECED report, takes into account the in-/decrease in heat load because of the lower/higher compartment temperatures. It also takes into account that the Coefficient of Performance COP (the 'efficiency') of the Carnot cycle is better when the temperature-difference between source and sink temperature is smaller. The key formula is

$COP = \eta \cdot (T_{cold} + 273.15)/(T_{hot}-T_{cold})$

where

- η is the real-life Carnot system efficiency

-T_{cold} is the evaporator temperature inside the compartment [in °C], with

$T_{cold}= T_{ref} - \Delta T_{cold}$,

where

- T_{ref} is the reference air temperature of the compartment (4 or 5°C for refrigerator, -18°C for freezer) and
- ΔT_{cold} is the temperature difference between the evaporator and the average air in the compartment (15°C for refrigerator, 12°C for freezer and 8°C for fridge-freezer).[36]

-T_{hot} is the air temperature at the condenser [in °C], with

$T_{hot}= T_a + \Delta T_{hot}$,

where

- T_a is the ambient temperature (16, 25 or 32°C) and
- ΔT_{hot} is the temperature difference between the ambient air temperature and the condenser (10°C for refrigerator and fridge-freezer 12°C for freezer).

-273.15 is a constant to convert Tcold from °C to Kelvin (K), as is required in the original Carnot formula.[37]

[35] Defrosting means to heat up the evaporator >0°C, melt the ice and bring the temperature down again to a stable regime. Only a part of the required energy depends on the refrigerator efficiency.

[36] Here the CECED values are taken as a reference; depending on the heat transfer efficiency of the evaporator or condensor the values may change.

Using the formula above, at the same compartment temperature Tref, it is found that the COP at 25°C ambient is not the same as the linear temperature-based interpolation from the COPs at 16° and 32°C (c.p.).

In formula, keeping in mind the weighting factor of 0.438 established previously:

$$COP(T_a\ 25°C) \neq 0.438 \cdot COP(T_a\ 16°C) + (1\text{-}0.438) \cdot COP(T_a\ 16°C)$$

CECED calculates that the impact of the COP shift alone (without taking into account changes in heat load) between the EN 62552:2013 and the IEC 62552:2015, both at (interpolated) ambient temperature of 25°C based on the above, is in the order of

- 7% more energy for refrigerators (Category 1-3);
- 2-7% more energy for fridge-freezers (Category 7) and
- 0-0.5% less energy for freezers (Category 8-9).

The study team has checked, and can confirm the order of magnitude of these numbers in Annex B.

In its Appendix A, more or less in line with a similar calculation in the standardisation platform by L. Harrington, the CECED report states that the equivalent F-factor for the new standard should be 0.5 for refrigerator-freezers (interpolated temperature 24°C) and 0.47 for freezers (interpolated temperature 24.5°C). The study team finds 0.44 (25°C, see Annex B) for freezers, which is also confirmed by the best match with experimental data for categories 8-9.

As regards refrigerators, including the COP shift due to the lower compartment temperature (different heat load), there are several numbers. The 2015 CECED report finds F=0.5 (24°C). A previous 2013 CECED report finds F=0.55 (23.1°C). The study team finds, in Annex B, F=0.6 (22.4°C). Note that according in an iteration with the experimental data the best match with the current EN 62552:2013 data is found at F=0.61 (22.2°C).

In view of the above, the F-factor 0.5 (24°C) for refrigerator-freezers seems plausible. It depends of course on a the relative sizes of compartments, defrosting, etc., but also the experimental data for the static (2 thermostat) and no-frost (also separate temperature control) models in Category 7 show the best match at F=0.52 (23.7°C), which seems close enough. The single thermostat models would be at a disadvantage (would consume 10.6% more at F=0.5, filtered) and are more likely to be phased out. This is a good thing not only from the perspective of functionality but certainly from the viewpoint of energy conservation, so there appears to be no reason to correct for that.

<u>Consideration (for stakeholder feedback):</u> *In order to obtain the biggest continuity in the metric between the current and future test standard it makes sense to use a weighting factor F=0.5 for the whole population. Alternatively, also separate values per category could be considered, e.g. F=0.44 for freezers, F=0.6 for refrigerators and F=0.5 for refrigerator-freezers. This would give an even better match, but would complicate the regulation a bit more.*

[37] CECED has made this simplified formula in °C because it is a unit that most non-engineers would recognise. The Carnot formula uses degree Kelvin.

4.4 International standards

The new global standard IEC 26552: 2015 is unique, in the sense that it brings global harmonisation and facilitates direct comparability between the energy efficiency figures between EU, Japan, China, Australia, etc.. It should also shorten testing times and thus testing costs.

The figure below illustrates the considerable differences in test conditions that existed (and still exist until new legislation is adopted everywhere) in 2011 when the first proposals for the new IEC standard were tabled. Note that the EU uses an adapted version of IEC 62552:2007, but with 25 °C ambient and a fresh food temperature of 5 °C.

		IEC 62552 (2007) China & Korea applied IEC 62552 (2007)	IEC 62552 (revised) Proposal (2011)	AS/NZS 4474.1 (2008)	AHAMHRF-1 (2008)	CNS 2062 (1995) CNS 9577 (1989)	JIS C 9801 (2006)
Ambient temp.		25 or 32℃	16 & 32℃	32℃	32.2℃	30℃	15 & 30℃
requirement	Fresh food	+4℃	+4℃	+3℃	+7.2℃	+3℃	+4℃
	Freezer*	-6℃	-6℃	-9℃	-9.4℃		-6℃
	Freezer**	-12℃	-12℃	-15℃	-15℃	-12/-15℃	-12℃
	Freezer***	-18℃	-18℃			-18℃	-18℃
Test packages		Loaded	Water Loaded	Unloaded	Unloaded	Unloaded	Loaded
Door openings		None	Yes	None	None	None	Yes

Figure 3. Overview of main parameters in global standards. (Source: Kiyoshi SATO (JEMA): Energy Efficiency Improvement in Household Refrigerator, presentation at IEA 4E 10th ExCo & Annex Meeting, 8 Nov. 2012, Tokyo, Japan)

Based on the new IEC standard:

- China will introduce energy label and limit by 1.1.2016, based on a 16/32 weighting at 23.7 °C (and load-processing test). [38]
- Japan is expecting new measures in 2016. The Japanese weighted average between the 16/32 °C tests is 22.7 degrees C plus a correction for the load processing test.
- Australia, with load processing test at 32 °C, will introduce new limits in 2017, based on an average weighting equivalent to 22 °C.
- The US introduced new limits in Sept. 2014; under US rulemaking the US (non IEC) test standard should then be used for at least 6 years, but the US standard is very similar to the new IEC test standard.

[38] See also CECED informative papers on the Chinese measure published on the project website.

5 Legislation (Task 1.3)

5.1 EU-legislation overview

With an implementation date in 1995, household refrigerating appliances were the first product group to be regulated under the first framework directive on energy labelling 92/75/EC. The reference lines for the Standard Annual Energy Consumption SAEC, which determine the Energy Efficiency Index still in the current Ecodesign and Energy Label regulations stem from a data analysis in the preparatory study by the Group for Efficient Appliances in 1992 (EEI=100).

The energy label has been, confirmed most recently by the IEA-4E Benchmarking study and in contrast with the situation in other parts of the world, the main driver of energy efficiency in this product group in the EU. A separate 1996 Council Regulation set a minimum efficiency performance standard (MEPS), following the US example at the time, but by its implementation date in 1999, the vast majority of products already complied, due to the impact of the energy label.

The energy label for household refrigerating appliances was also the first where it was necessary to update the energy label in 2003[39], with some extra classes 'A+' and 'A++' because the share of appliances in the highest existing classes A and B was so high that it offered little differentiation for consumers and too little challenge for manufacturers that wanted to excel.

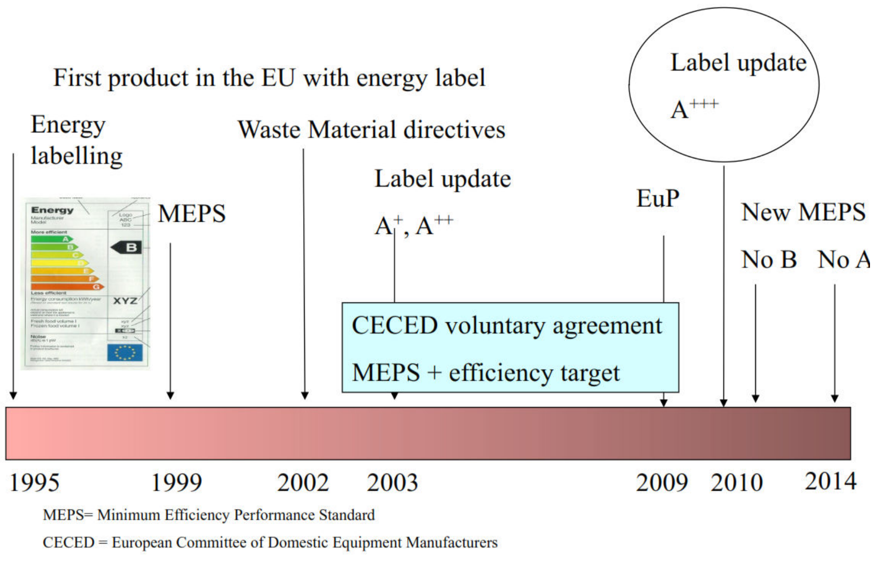


Figure 4. Short history of EU Energy Label and Ecodesign measures
(Source: M. Janssen, Refrigerator testing: IEC 62552 ed 2 development and AUS/NZ Round Robin testing, Presentation 13402 / RE24 / V2, Re/genT BV, 17/10/2013)

[39] Commission Decision 2003/66/EG

At the same time and as a follow-up of the 1999 MEPS, the manufacturer's association CECED entered into a voluntary agreement with its own MEPS to remove the worst performing products. CECED ended this agreement in 2009 when a mandatory regulation under the first Energy-using Products framework directive 2005/32/EC offered a more robust alternative.[40]

In 2010 the Energy Label for household refrigerating appliances was regulated under the new Framework Directive 2010/30/EU, amongst others introducing a new 'A+++' labelling class to again offer more differentiation.

At roughly the same time, the Ecodesign regulation 643/2009/EC phased out the models with energy class 'B'. In 2014 all models with Energy Class 'A' were phased out, and the lower limit of the 'A+' class, the limit for Ecodesign, was increased from EEI 44 to EEI 42. At the moment there are still 3 labelling classes active, i.e. A+/A++/A+++ at lower class limits of EEI 42/33/22.

Today, at the 20th anniversary of its first implementation, the household refrigeration energy label is one of the success stories of the EU energy efficiency policy, boosting an average EEI of 39. This is a 61% efficiency improvement compared to 1992 and compared to the normal pace of improvement without measures, it is still an improvement of 50%. [41]

At the same time, the energy label became the main commercial driver in the market, allowing the EU industry to compete not only on price but also on at least one important quality aspect. It is likely that this has kept EU industry and its employment in place against extra-EU competition, in contrast with the situation with other consumer durables (e.g. electronics) and in comparison with the situation in other parts of the world (e.g. the US) where large market shares in the white-goods sector were lost to low-cost Asian competition.

However, given the urgent calls for an update of the energy label both by industry and NGOs, this is not the end of the story. 'Cold appliances' are still significant energy users and already there are models with an EEI below 20, 44% below average, on the market.

The Energy Label Framework Directive is currently being reviewed.

Ecodesign and energy label regulations are certainly not the only legislation regarding refrigerators. Following the 1989 Montreal Protocol, Regulation (EC) No 2037/2000[42] set out to ban ozone depleting (ODP) substances. For refrigerators this meant a ban on 'freon' both as a refrigerant (CFC-12) and as a blowing agent (CFC-11) for insulation foam. In preparation for this ban, in the 1990s, the refrigeration industry initially went for alternative refrigerants that were less energy efficient, but soon found R-134a, zero-ODP but higher on Global Warming Potential (GWP 1300), and later isobutane R600a, zero-ODP and very low on GWP (3.3). In 2013, as mentioned in the Omnibus study, 98% of all household refrigeration appliances were using isobutane. Only for some very large side-by-side appliances the isobutane content is reaching critical levels in terms of anti-flammability legislation and R134 was used. but

[40] Note that CECED actually preferred a mandatory regulation, because the voluntary agreement offered too much possibilities for non-complying 'free-riders'.

[41] According to the VHK EIA-study 2014, the 'BAU' (Business-as-Usual) scenario would have yielded an EEI of 78 in 2015.

[42] Regulation (EC) No 2037/2000 of the European Parliament and the Council of 29 June 2000 on substances that deplete the ozone layer.

now these are also phased out, unless there is a justified claim for an exemption, under the new regulation EU No. 517/2004 [43] . As blowing agent cyclopentane, zero-ODP and GWP<25, is used.

As most other electrical and electronic equipment (EEE) is subject to recovery and recycling targets under the WEEE-legislation, first introduced in 2002, but in this case separate collection is '*a matter of priority, for temperature exchange equipment* (i.e. refrigerators, freezers, etc.) *containing ozone-depleting substances and fluorinated greenhouse gases'* (Art. 5, WEE-recast 2012[44]). This means that special treatment facilities were set up to recover the refrigerant and –without significant emissions to outside air—shredder the foam (and cabinet).
From 2016 the minimum collection rate is set at 45%[45] (weight basis) and in 2019 it should be 65%. Of the collected refrigeration appliances (category 1) 80% shall be recovered and 70% recycled between August 2012 and August 2015. After that, also after 2018, 85% shall be recovered and 80% shall be prepared for re-use or recycled.

In terms of hazardous substances, regulated under the RoHS directive, or substances of very high concern, regulated under the REACH directives, refrigerators are not very critical. Of course, the lead (Pb) in solder of the electronic control boards is banned. Under REACH no specific refrigerator-related substances could be identified. A few years ago, some refrigerator-manufacturers thought it would be a good idea to include a minute quantity of silver-ions (Ag) in the inner-liner of refrigerators as an anti-bacterial agent, but this practice was short-lived because of possible negative health and environmental impacts[46] and attention of the legislator to 'nanosilver' under the Biocide Regulation. [47]

As regards electrical safety household refrigerating appliances are subject to the Low Voltage Directive[48] and for electro-magnetic compatibility there is the EMC Directive[49]. Being a food-storage device the materials that come into contact with food should be safe to human health. This means e.g. that 'food-grade' plastics (mainly PS) should be used for the inner-liner and that safety-measures should be in place to avoid e.g. refrigerant leakage.

In the future, the refrigerator lamp –for reasons of consistency and avoidance of loopholes rather than energy saving—might be subject to a revised Ecodesign Regulation of light sources. Status displays may be included in the Regulation on electronic displays, but –unless at very large sizes and probably other uses than status displays (e.g. TVs)—not at a level or in a way where this might have an impact.

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[43] Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006. OJ L 150, 20.5.2014, p. 195–230

[44] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) Text with EEA relevance
OJ L 197, 24.7.2012, p. 38–71

[45] Or between 40 and 45% for several Eastern-European Member States

[46] European Commission, Scientific Committee on Emerging and Newly Identified Health Risks SCENIHR, Opinion on nano-silver: safety, health and environmental effects and role in antimicrobial resistance, Approved 10 -11 June 2014.

[47] Biocides Regulation (EC) No.528/2012 by September 2013. Silver-containing active substances (SCAS) were identified and therefore included in the second phase of the review programme for biocidal active substances (Reg. (EC) No. 1451/2007)

[48] Directive 2006/95/EC of the European Parliament and of the Council of 12 December 2006 on the harmonisation of the laws of Member States relating to Electrical Equipment designed for use within certain voltage limits. OJ L 374 of 27 December 2006

[49] Directive 2004/108/EC relating to electromagnetic compatibility and repealing Directive 89/336/EEC, OJ L 390 of 31 December 2004

Also still in the future there may be Union legislation that addresses durability and reparability of the appliances. JRC-IES (Ispra) has laid down the methodology for these aspects[50], but if this methodology is applied correctly –and refrigerator energy efficiency continues to improve at the current rate— it is recommendable that the household refrigeration appliances should be exempted. Continued use or re-use of old refrigeration appliances is at the moment still counter-productive from a holistic standpoint, as it blocks the introduction of more energy efficient new appliances and keeps old energy-guzzlers going (see also chapter 7. Task 3). Having said that, the European Commission recently (28.5.2015) opened a public consultation on durability of –amongst others—white-goods, in view of the 'circular economy'.[51]

5.2 Non-EU legislation

Note that all legislation for household refrigerating appliances placed on the EU market is at EU-level, i.e. there is no legislation at Member State level.

Switzerland has adopted legislation that is similar to the EU but more stringent, setting minimum requirements at A++ lower class level (EEI 33).

The Standards & Labelling (S&L) database www.clasponline.org distinguishes 280 different energy efficiency measures such as minimum efficiency requirements, comparative energy labels and endorsement labels. Countries with active energy efficiency policy tend to address household refrigeration appliances.

Many of these countries have energy labels that are based on or inspired by the EU-example.[52] This includes China and Korea. Other countries, notably in the Americas, take the US programs as example, or are following their own variation of these two programs. Japan's Top Runner programme, setting long-term improvement targets often beyond what is optimal in terms of Life Cycle Costs, is special.

Due to the variation in metrics, it is impossible to compare the details of each programme. The best approximation of such a comparison, currently available, is the IEA 4E Benchmarking programme. It attempts to compare the results of the efforts in several countries, based on a normalised kWh/year Annual Unit Energy Consumption.

[50] Ardente, F., Mathieux, F., Environmental assessment of the durability of energy-using products: method and application, Journal of Cleaner Production, Volume 74, 1 July 2014, Pages 62–73 [authors from EC JRC-IES]

[51] http://ec.europa.eu/environment/consultations/closing_the_loop_en.htm (Consultation for all interested stakeholders from 28.5.2015 to 28.8.2015).

[52] European Commission Conference on Product Policy –Ecodesign & Energy Labelling, 20-21 Feb. 2014, misc. lectures.

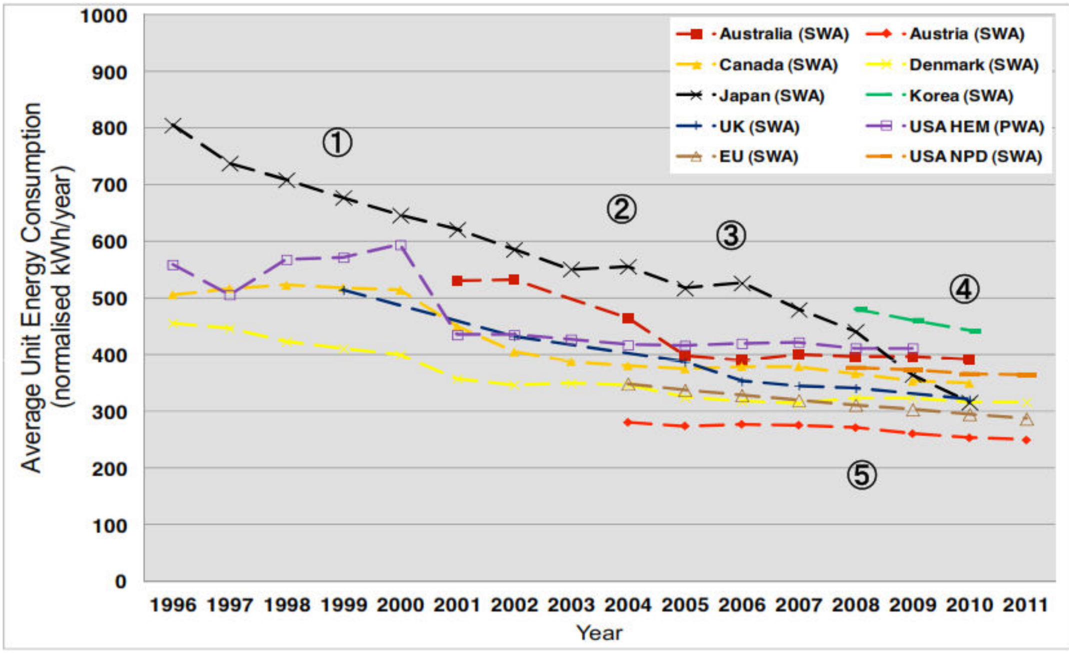

Figure 5. Average Unit Energy Consumption in selected countries and regions (Source: IEA 4E M&B, version 2014)

As shown, the results for EU countries –Austria in front-- are amongst the highest for energy efficiency in refrigerators and fridge-freezers. The IEA 4E authors are concerned over the fact that the EU efficiency curves seem to be flattening out, while e.g. the Japanese is catching up and even better than some EU countries. They explain this phenomenon by the fact that the Top Runner programme is unique, in the sense that it does not set targets on the basis of Least Life Cycle Costs (like the EU and US) but goes beyond that and ---not only for the best models but fleet-wide-- employs techniques like variable speed compressors and vacuum insulation panels (VIPs) that may not be economical (have a reasonable payback period) yet.

Especially regarding larger (volume) appliances, the IEA-4E thinks that the EU might take an example of the US and define more product categories, targeting also the bigger ones (e.g. side-by-side refrigerator-freezers). Alternatively or in addition, instead of a linear reference lines, it is suggested to use exponential reference curves in describing the Standard Annual Energy Consumption SAEC according to the calculation annexes of the EU regulations.[53]

For freezers, the IEA-4E concludes that the EU is definitely in front, possibly because these product groups only have a limited variation in design and –often—in size. For that reason, the EU legislative tools are (still) optimal.

[53] Reference lines are the lines in a diagram (actually the formulas with M and N) of kWh versus equivalent volume in litres that describe the Standard Annual Energy Consumption SAEC. The EEI=100 x AEC/SAEC, meaning that SAEC is the line where EEI=100. If you draw this line differently or with a different shape (e.g. curved) it will change the value of EEI.

5.3 Ecodesign metrics

The Energy Efficiency Index (EEI) is the ratio of the Annual Energy Consumption AE of a product and a calculated Standard Annual Energy Consumption SAE, both in kWh/a:

$EEI = AE/SAE$

with $AE = E24 \times 365$, where E24, in kWh/24h, is the 'daily'(24h) consumption according to the test of a specific model.

The SAE is calculated by

$SAE = Veq \times M + N + CH$

Where

- M (in kWh/litre/a) and N (in kWh/a) are category-specific indicators for the reference lines (see table below),
- CH is the chill-compartment compensation of 50 kWh/year, if a chill-compartment of >15 litres is present.
- Veq is the equivalent volume (in litres), with

$Veq = \sum[Vc \times (25 - Tc)/20 \times FFc] \times CC \times BI$

Where

- Vc is the net volume of compartment c ('c' is the index of the compartment),
- Tc is the nominal temperature of compartment c,
- FFc is the frost free correction factor 1.2, if the compartment c has automatic defrosting (otherwise FFc=1),
- CC is the climate correction factor 1.2 ('tropical' T), 1.1 ('sub-tropical' ST) or 1 (otherwise, i.e. N or SN)
- BI is the built-in correction factor 1.2 if the appliance is made for, and tested accordingly, to be built-in (enclosed by kitchen cabinets), and if the width is less than 58 cm.

Table 7

M and N values by household refrigerating appliance category

Category	M	N
1	0,233	245
2	0,233	245
3	0,233	245
4	0,643	191
5	0,450	245
6	0,777	303
7	0,777	303
8	0,539	315
9	0,472	286
10	(*)	(*)

Note:

(*) for Category 10 household refrigerating appliances the M and N values depend on the temperature and star rating of the compartment with the lowest storage temperature capable of being set by the end-user and maintained continuously according to the manufacturer's instructions. When only an 'other compartment' as defined in Table 2 and Annex I, point (p), is present, the M and N values for Category 1 are used. Appliances with three-star compartments or food-freezer compartments are considered to be refrigerator-freezers.

Table 5. Regulation (EC) No 643/2009, Annex IV, Table 7

Essentially, the definition of the EEI, i.e. the factors M, N and correction factors, is as important for setting minimum requirements and energy label class limits as the value of the EEI.

One could say that it is a 'political' parameter that should be discussed only in Task 7 or the Consultation Forum, like the values of EEI. Nonetheless, the definition of the EEI is not 'free' but derived from a statistical/technical definition, and that is why we are requesting already stakeholder input at this stage.

The factors M and N are derived from a statistical assessment of the linear trends of the commercially available models in 1992 in the 10 categories.

The correction factors, also unchanged since the first energy label, are based on a technical assessment of what would be fair compensation for these features.

The multiplier (25-Tc)/20, is a technical parameter derived from the heat load of any compartment compared to the heat load of the fresh food compartment. The ambient temperature is 25 °C, the fresh food compartment temperature is 5°C, and thus the temperature difference inside-outside of 20°C. If the compartment is a fresh food compartment then the multiplier is 1. If it is a 3 or 4 star freezer, with nominal temperature -18°C and then the value of the multiplier is 2.15.

CECED, recognising the calls by stakeholders and following discussion with the study team, has made a first proposal which is still incomplete but already open for stakeholder feedback.

In summary, CECED proposes:

- To eliminate the climate correction factor CC completely;
- To redefine the chill-compensation CH in a fixed part Nch and a variable part (depending on Veq) Mch, which on average equals the current compensation but aims at more correct distribution
- To redefine the frost free compensation FF to make it no longer dependent on the equivalent volume Veq but to link it directly to the standard annual energy SAE. The value of such a parameter would still need to be established
- For the Built-in appliances to use different categories and thus also different reference lines (factors M and N or similar).
- To introduce a multi-door compensation for appliances with 3 or more doors. The proposal is to add a term MD to the existing M-factor, i.e. make it volume dependent with values for MD of 0.03 (3 doors), 0.05 (4 doors) and 0.06 (5 or more doors).

Apart from the above, CECED makes some preliminary calculations that give an impression of how the new reference lines (the factors M and N) could develop in a linear trend.

The CECED proposal, including extensive argumentation, is published on the project website. Stakeholder feedback and/or alternative proposals for this part of the metric are welcomed.

6 Market Analysis (Task 2)

6.1 Production and trade (Eurostat)

The table below gives the volume production and trade data for household refrigeration appliances as recorded by Eurostat. After a decrease by one-third in the period 2006-2009, the production volume has remained stable at a level of about 15 million units/year. In the period 2006-2009 the imports increased, but has stabilised at a level of 13 million units/year. Exports are at a level of 4 million units and thus the resulting apparent consumption of the EU market has been at a level of around 24 million units in the last 4 years.

Table 6. EU Production and trade in 1000 units (source: Prodcom, Eurostat, May 2015)

Production	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
27511110 - Combined refrigerators-freezers, with separate external doors	7293	7822	7107	5891	5727	6213	6036	6560
27511133 - Household-type refrigerators (incl. compression-type, electrical absorption-type) (excl. built-in)	5415	5865	4116	3019	2859	2518	2889	2503
27511135 - Compression-type built-in refrigerators	3340	3251	2256	2247	2784	2683	2669	2633
27511150 - Chest freezers of a capacity <= 800 litres	3536	3122	1825	1844	2490	2404	1895	1903
27511170 - Upright freezers of a capacity <= 900 litres	2388	2290	1893	1717	1721	1622	1449	1649
TOTAL PRODUCTION	**21972**	**22350**	**17198**	**14719**	**15581**	**15440**	**14938**	**15248**
Import								
27511110 - Combined refrigerators-freezers, with separate external doors	2895	3349	2987	3584	4326	4188	4554	5040
27511133 - Household-type refrigerators (incl. compression-type, electrical absorption-type) (excl. built-in)	6082	9610	9126	5602	6279	6226	5525	5232
27511135 - Compression-type built-in refrigerators	125	252	256	225	279	313	359	454
27511150 - Chest freezers of a capacity <= 800 litres	272	477	487	575	641	647	643	756
27511170 - Upright freezers of a capacity <= 900 litres	710	1636	1096	1175	1560	1461	1502	1657
TOTAL IMPORT	**10084**	**15323**	**13952**	**11161**	**13085**	**12834**	**12584**	**13138**
Export								
27511110 - Combined refrigerators-freezers, with separate external doors	1404	1559	1204	785	1103	1219	1405	1639
27511133 - Household-type refrigerators (incl. compression-type, electrical absorption-type) (excl. built-in)	1782	1462	1312	1195	900	878	796	679
27511135 - Compression-type built-in refrigerators	120	129	133	120	145	168	193	215
27511150 - Chest freezers of a capacity <= 800 litres	811	699	701	580	658	734	875	993
27511170 - Upright freezers of a capacity <= 900 litres	281	356	374	343	391	387	408	422
TOTAL EXPORT	**4398**	**4206**	**3723**	**3024**	**3198**	**3385**	**3676**	**3949**
Prod+import-export=Apparent consumption								
27511110 - Combined refrigerators-freezers, with separate external doors	8785	9613	8890	8690	8950	9182	9185	9960
27511133 - Household-type refrigerators (incl. compression-type, electrical absorption-type) (excl. built-in)	9715	14012	11931	7427	8239	7867	7619	7056
27511135 - Compression-type built-in refrigerators	3344	3374	2380	2352	2918	2828	2836	2871
27511150 - Chest freezers of a capacity <= 800 litres	2997	2900	1611	1839	2473	2317	1664	1665
27511170 - Upright freezers of a capacity <= 900 litres	2817	3569	2615	2549	2890	2696	2543	2884
TOTAL APPARENT CONSUMPTION	**27658**	**33468**	**27427**	**22857**	**25468**	**24889**	**23846**	**24437**

The value of the production and trade, in manufacturer selling prices excl. VAT, is given in the table below. After a strong decline in the period 2006-2009 the production value has been rising at a rate of 5% per year since 2009 and is currently back at the 2008 level at a value of 4.15 billion euros. Imports are stable at a level of almost 2 billion euros. Exports are also rising in recent years and are now at a level of 1.05 billion euros. The apparent EU consumption is just over 5 billion euros.

Table 7. EU Production and trade, value in million euros (source: Prodcom, Eurostat, 2015)

Production	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
27511110 - Combined refrigerators-freezers, with separate external doors	1804	2002	1861	1463	1460	1651	1632	1841
27511133 - Household-type refrigerators (incl. compression-type, electrical absorption-type) (excl. built-in)	1125	1262	881	646	625	578	601	548
27511135 - Compression-type built-in refrigerators	682	700	500	600	635	689	800	800
27511150 - Chest freezers of a capacity <= 800 litres	747	604	407	397	501	476	442	451
27511170 - Upright freezers of a capacity <= 900 litres	531	541	499	486	486	493	458	515
TOTAL PRODUCTION	**4888**	**5108**	**4148**	**3592**	**3707**	**3888**	**3933**	**4155**
Import								
27511110 - Combined refrigerators-freezers, with separate external doors	787	828	722	762	910	917	1024	972
27511133 - Household-type refrigerators (incl. compression-type, electrical absorption-type) (excl. built-in)	651	759	647	615	724	657	606	568
27511135 - Compression-type built-in refrigerators	17	28	31	25	33	34	41	54
27511150 - Chest freezers of a capacity <= 800 litres	38	59	69	71	76	77	79	91
27511170 - Upright freezers of a capacity <= 900 litres	91	122	122	146	205	201	228	242
TOTAL IMPORT	**1584**	**1796**	**1590**	**1618**	**1948**	**1886**	**1978**	**1926**
Export								
27511110 - Combined refrigerators-freezers, with separate external doors	347	419	399	261	330	397	462	505
27511133 - Household-type refrigerators (incl. compression-type, electrical absorption-type) (excl. built-in)	321	315	250	197	189	172	174	153
27511135 - Compression-type built-in refrigerators	35	41	43	40	48	63	73	84
27511150 - Chest freezers of a capacity <= 800 litres	122	126	119	109	116	127	160	179
27511170 - Upright freezers of a capacity <= 900 litres	74	94	100	103	111	119	134	137
TOTAL EXPORT	**899**	**995**	**910**	**710**	**794**	**878**	**1003**	**1058**
Prod+import-export (Apparent Consumption)								
27511110 - Combined refrigerators-freezers, with separate external doors	2244	2411	2184	1964	2039	2171	2193	2308
27511133 - Household-type refrigerators (incl. compression-type, electrical absorption-type) (excl. built-in)	1455	1706	1278	1064	1161	1063	1032	962
27511135 - Compression-type built-in refrigerators	664	686	487	585	621	659	768	771
27511150 - Chest freezers of a capacity <= 800 litres	663	537	357	358	461	427	362	362
27511170 - Upright freezers of a capacity <= 900 litres	549	570	521	529	579	575	553	621
TOTAL APPARENT CONSUMPTION	**5574**	**5910**	**4828**	**4500**	**4861**	**4895**	**4909**	**5023**

The next table shows the most important EU-trade partners for household refrigeration appliances in 2014, in value (million euros). The Eurostat source is slightly different (Trade statistics by CN8) from the one used above.

It shows that China (44%) and Turkey (36%) are the largest importers. Exports are rather fragmented, but the Russian federation (16%) is an important destination for EU exports.

The Eurostat statistics do not allow a meaningful split up by volume (number of units)[54].

[54] Eurostat data are given per 100kg of product weight, not per number of units.

Table 8. Extra EU27-Trade 2014 by main Partner, value in million euros
(source: Eurostat, Trade Statistics CN8 *)

CN8 code	Import value	China	USA	Russia	Turkey	Other	TOTAL
84181020	Combined refrigerator-freezers, > 340 l, multi-door	154	10	0.0	202	166	532
84181080	Combined refrigerator-freezers, <= 340 l, multi-door	272	7	0.0	205	102	586
84182110	refrigerators, compression-type, > 340 l	7	3	0.0	48	25	84
84182151	refrigerators, compression-type, table model	79	0.0	:	8	3	90
84182159	refrigerators, compression-type, built-in	36	0.1	0.0	11	8	55
84182191	refrigerators compression-type, <= 250 l	148	0.3	0.0	64	10	222
84182199	refrigerators, compression-type, > 250 l but <= 340 l	11	0.3	0.0	33	13	58
84182900	refrigerators, absorption-type	39	1	0.0	76	3	119
84183020	Chest freezers, <= 400 l	72	2	0.3	5	6	85
84183080	Chest freezers, > 400 l but <= 800 l	6	2	0.4	3	2	14
84184020	Upright freezers, <= 250 l	85	3	0.0	70	8	165
84184080	Upright freezers, > 250 l but <= 900 l	18	17	0.0	32	33	100
	TOTAL IMPORT VALUE	**927**	**44**	**1**	**758**	**379**	**2110**

CN8 code	Export value	China	USA	Russia	Turkey	Other	TOTAL
84181020	Combined refrigerator-freezers, > 340 l, multi-door	3	14	48	2	92	159
84181080	Combined refrigerator-freezers, <= 340 l, multi-door	20	1	43	10	198	271
84182110	refrigerators, compression-type, > 340 l	3	0.5	8	2	30	44
84182151	refrigerators, compression-type, table model	0	0.2	2	0.2	5	7
84182159	refrigerators, compression-type, built-in	2	5	11	1	60	80
84182191	refrigerators compression-type, <= 250 l	0	11	2	3	24	40
84182199	refrigerators, compression-type, > 250 l but <= 340 l	2	1	5	0.2	31	39
84182900	refrigerators, absorption-type	0	8	2	1	28	39
84183020	Chest freezers, <= 400 l	0	3	5	31	74	112
84183080	Chest freezers, > 400 l but <= 800 l	0	1	7	1	23	33
84184020	Upright freezers, <= 250 l	1	1	9	7	35	53
84184080	Upright freezers, > 250 l but <= 900 l	2	4	8	2	46	63
	TOTAL EXPORT VALUE	**34**	**49**	**149**	**60**	**647**	**939**

**= only meaningful datafields; : = data not available.*

Note that in the Eurostat data, the production and trade figures are heavily 'contaminated' with small table-type and special refrigerator models that the industry and specialised market institutes like GfK would not consider in the scope. Therefore, it is not possible to draw hard conclusions from the Eurostat data for the purposes of this study.

6.2 Market

The latest publicly available GfK data are from 2012 and show sales of 14.3 million refrigerators (incl. fridge-freezers) and 3.7 million freezers in 23 countries of the EU (EU-23). In total, including an estimate for the missing countries[55], this means sales of around 19 million units per year for the EU-28. Assuming a 2% annual increase, this means around 19.5 million units in 2015.

This is confirmed in VHK's Ecodesign Impact Accounting 2014 (EIA), a harmonised calculation of key data from preparatory and Impact Assessment studies for all ecodesign regulated products, which sets 2015 sales at 19.4 million units. The installed 2015 stock in the EU is calculated at 303 million units, which means a market

[55] Luxembourg, Cyprus, Malta, Bulgaria, Croatia

penetration of around 1.4 refrigerating appliances per EU household[56] and –including secondary and vacant homes—1.3 refrigerating appliances per EU dwelling. [57]

For wine storage appliances, no new sales data could be found since publication of the Omnibus report, despite extensive desk-research, and thus the best estimate is still sales of 0.18 million units per year (EU28 in 2015). This is less than 1% of total household refrigeration unit sales. The CECED database features 0.6% of models in Category 2 (cellar and wine storage appliances), i.e. 100 models. The Omnibus 2014 study estimates that less than 1% of households owns a wine storage appliance (1.7 million stock on a total of 210 million households in EU-2015), but the sales trend is rising. Around 70-80% of wine storage appliances have glass doors; the others have solid doors.

Absorption refrigerators sales of 0.25-0.3 million units annually are still assumed to be correct.

The average product life of household refrigeration appliances is 16 years, including second-hand use and secondary use (e.g. in a garage)[58]. Anecdotal data suggests a primary useful life (until replacement in a kitchen environment) of 12-13 years and a second-hand/secondary use of on average 3-4 years. A secondary use outside the EU (e.g. old units repaired and shipped to Africa) is not taken into account.

The average net volume is estimated at 278 litres (EU 2015), increasing at a rate of 1.2% per year[59]. The estimated 'equivalent volume' *Veq*, calculated according to the current regulations, 377 litres. The average Standard Annual Energy Consumption *SAEC* (where EEI=100) is estimated at 545 kWh/year.

The total EU-2015 (household) refrigerated net volume at nominally +5°C is 65.8 million m³. The total freezer volume at nominally -18°C is 18.6 million m³, making a total of 84.4 million m³ of refrigerating appliance net volume. This volume is growing at a rate of 1.8%/year due to growth in the number of households/dwellings, the increased market penetration (more refrigerating appliances per household) and the 1.2% annual growth in volume of the average appliance mentioned earlier.

The table below shows the trends identified in the EIA study.

Table 9. Market and load characteristics

Parameter	Unit	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
SALES	x1000	**17500**	**19100**	**19400**	**19700**	**20000**	**20300**	**20600**	**20900**	**21200**	**21500**
STOCK	x1000	**268**	**298**	**303**	**308**	**313**	**318**	**322**	**327**	**332**	**337**
Net volume Vnet	ltr	203	259	278	297	316	337	358	380	401	422
Equiv.vol. Veq	ltr	274	350	377	401	428	456	485	514	542	571
SAEc (EEI=100)	kWh/a	468	526	545	563	582	602	623	644	664	685
EU total fridge net volume	Mm³@ 5C°	42.3	60.2	65.8	71.3	77.1	83.5	90.1	96.9	103.8	110.9
EU total freezer net volume	Mm³@ -18C°	11.9	17.0	18.6	20.1	21.8	23.5	25.4	27.3	29.3	31.3

56 Assuming around 210 million households in 2015

57 Based on an extra 12% stock of secondary dwellings; vacant dwellings (another 8%) are not assumed to still have a refrigerating appliance (dwelling data from VHK MEErP-Part 2, 2011, table 33)

58 VHK, EIA-study, 2014.

59 See Omnibus study, Figure 5-5 (source CECED), showing a compound aggregate growth in net volume of 15% over the 2001-2012 period.

The EIA-study estimates the EU-2015 market value in consumer prices (incl. VAT and levies) at around 10.1 billion euros. Of this, around 4 billion euros are industry revenue, 0.3 billion goes to wholesalers and 4 billion euros to the retail sector (incl. repair & installation). The rest, 1.8 billion euros, is spent in taxes and levies[60].

Premium products, i.e. with an above-average price, are built-in appliances (20% more), no-frost feature (10% more) and wine storage appliances. The latter cost roughly twice as much as normal refrigerators of the same size.[61]

6.3 Actors, jobs and trends

6.3.1 Actors

Important manufacturers with EU production facilities are Electrolux[62], Bosch-Siemens, Whirlpool[63], Candy and Liebherr. Rapidly-growing importers are Arcelik/BEKO of Turkey, Samsung and LG of South Korea. The latest development, in late 2014, is the acquisition of Indesit (IT)[64] by Whirlpool, a US based firm with its EU-headquarters in Italy. [65]

Whirlpool subsidiary Embraco is a major producer of compressors, used as an input in the production of refrigerators and freezers. Other compressor suppliers are Secop, Huayi/Jiaxipera, LG and Samsung.

End-product manufacturers do not only assemble but usually also make the main cabinet-components in-house, i.e. the blow-formed inner-liner, insulation, the folded steel coil cabinet, the roll-bonded or Z-bonded evaporator and the condenser. Refrigerator/freezer doors require a special production-line, which may be in-house or at an external supplier. Other parts, like interior-elements (glass-shelves, containers, lamps, etc.) and electronics are likely to be bought from external suppliers, also outside the EU.

The suppliers of raw materials are producers of poly-urethane (insulation), food-grade polystyrene (inner-liner), pre-painted steel coil (outer cabinet), aluminium and copper for the compression circuit, etc..

Almost all manufacturers are large companies. Only in market niches, such as wine storage appliances and related luxury refrigeration/conditioning (for cheese, chocolate, fur-coats; also humidors), SME companies can be found such as Eurocave[66], FRIO

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[60] Including levies for recovery/recycling (F. 'recupel')

[61] R. Ducoulombuer, Comment s'est démocratisé l'usage des caves à vin ?, 13/10/2014.
'Pour une cave de service, il faut compter un budget de 300 à 600 euros et 800 à 1500 euros pour une cave de vieillissement. Plus onéreuses, les caves polyvalentes se trouvent aux alentours de 1500 à 2500 euros. Deux ou trois zones distinctes permettent d'adapter la temperature en fonction du type de vin: 8 à 12°C pour les vins blancs, 13 à 16°C pour les vins rouges....Les caves polyvalentes ou multi-températures remplissent les deux fonctions.'

[62] Brands: Electrolux, Zanussi, AEG, Rex, etc.

[63] Whirlpool brands: Whirlpool, Bauknecht, Ignis, Maytag, Laden, Polar and Privileg. Indesit brands: Indesit, Hotpoint / Hotpoint-Ariston and Scholtès.

[64] previously part of Merloni Elettrodomestici

[65] EC, 'Mergers: Commission approves acquisition of Italian domestic appliances producer Indesit by Whirlpool', http://europa.eu/rapid/press-release_IP-14-1133_en.htm

[66] Eurocave (France): 20 million euros turnover. 20-50 employees. 80% export (mainly Asia). 35% sales to professional. Sources: M-A Depagneux, EuroCave profite de la consommation du vin au verre, 7 Oct. 2014. http://acteursdeleconomie.latribune.fr/strategie/industrie/2014-10-07. and http://www.societe.com.

Entreprise (Brands: Climadiff/Avintage/La Sommeliere) competing with the large companies, amongst which also the large Chinese company Haier is an important contender.

In the traditional retail sector the position of larger retail chains such as Metro (MediaMarkt), Carrefour, etc. is increasing. For built-in appliances (29% of the market) kitchen suppliers are important. Internet sales exist but the growth rate, especially for the more expensive no-frost appliances, is not higher than for the other distribution channels of this product group.

The European industry association is CECED [67]. Consumers associations are represented at EU-level by ANEC/BEUC. Other NGOs include ECOS, EEB, TopTen, CLASP

6.3.2 Jobs

The total employment in household refrigeration is estimated at 147 000 jobs (EU 2015), of which 66 000 in retail (incl. maintenance), 1000 in wholesale, 80 000 in industry. Of the industry-related jobs roughly one-third is direct employed by end-product manufacturers (25-30 000), one-third goes to suppliers (25-30 000, of which roughly half extra-EU based[68]) and one-third to business services (accountants, advertising agencies, caterers, IT specialists).

6.3.3 Trends

In its retail report on the 1st quarter 2015 market researcher GfK notes that '*In contrast to a difficult second semester in 2014, the market for major domestic appliances is on the rise again. During first sales period in 2015, prices were sharper than ever before, resulting in a modest market growth. In the cooling category divergence between underlying product groups was observed. We recorded a decline in Refrigerators, whereas a firm boost was seen in freezers sales.*'

This is a snapshot of the current market situation. The long term trend is that there is a slow recovery since 2009 with some modest and fluctuating growth.

Built-in appliances are showing a steady growth. The same goes for no-frost appliances, and wine storage appliances are definitely also a growth market.

The following is a straight count of the most recent CECED database[69], showing trends in energy efficiency related features.

67 www.ceced.eu

68 EC Impact Assessment 2009, SEC(2009)1021

69 The CECED database is an inventory of products sold in the EU market and has been used for preparatory studies etc. for over a decade. For 2014 it contains 18.000 models and covers 75-80% of the market.

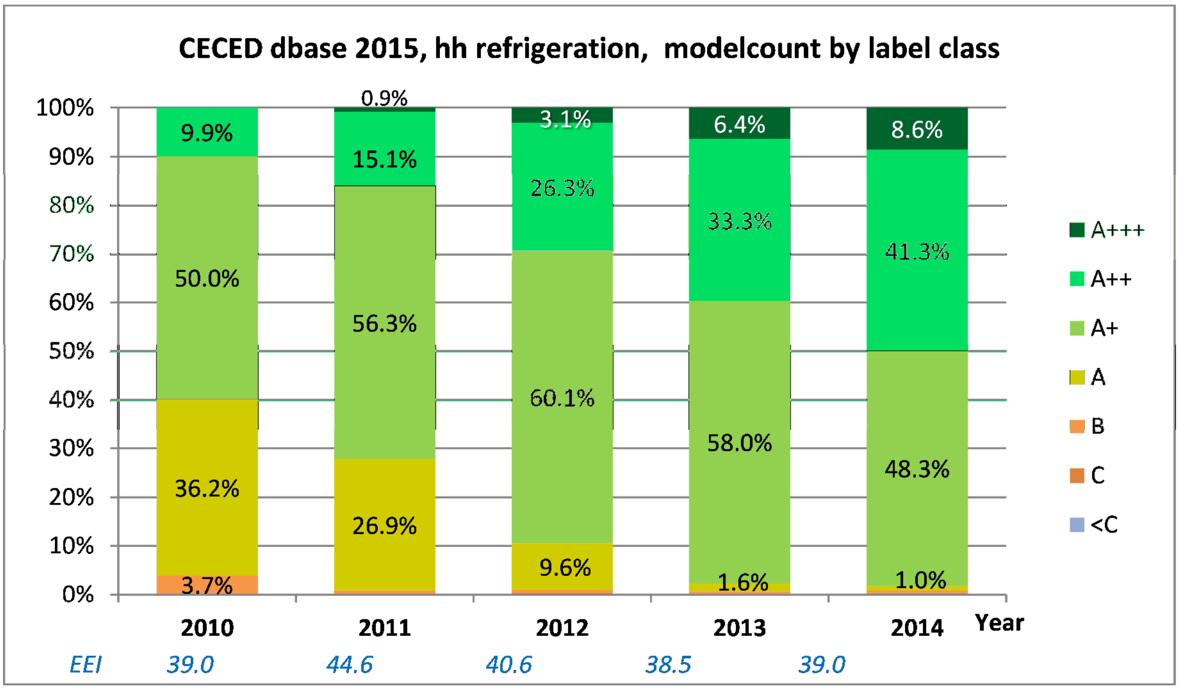


Figure 6. Counts by label class (source: VHK on basis of database CECED 2015)

Note that the 2010 CECED database is small, there are many data blanks and thus can be considered less reliable. From 2011 (EEI 44.6) to 2013 (EEI 38.5) the database population is more or less constant in size (n= 9 to 11k models). In 2014 many more new models were introduced (n=18k) and the average EEI is slightly rising to EEI 39.

The actual sales figures per class, only available up from 2011 to Feb. 2013, show that the sales may be trailing a few per cent behind.

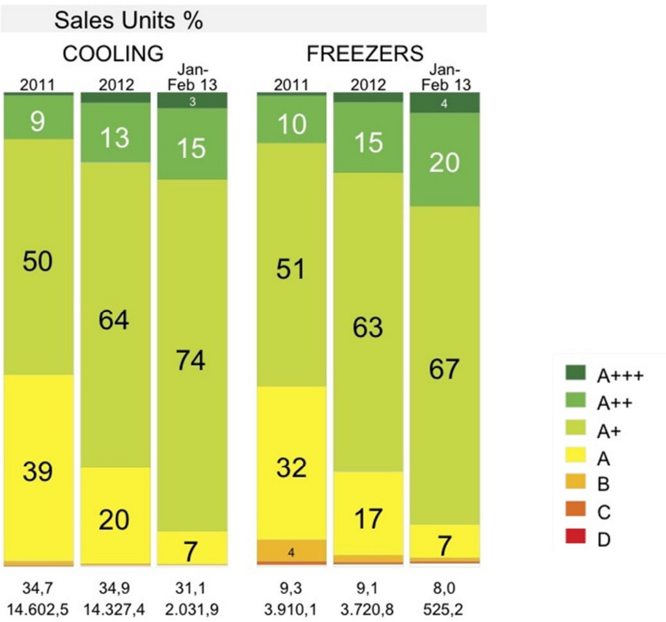


Figure 7. Sales data per label class (GfK for EU23, in TopTen 2013)

For comparison, the relevant outcomes of the EIA 2014 study –a harmonised dataset and calculation based on the 2008-2009 preparatory study and impact assessment— are given below.

Table 9. Household Refrigeration Appliances: Energy and Global Warming Potential GWP
(source: VHK, EIA-study, 2014)

EFFICIENCY SALES ECO	unit	**1990**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
unit electricity & efficiency sales															
AE	kWh elec/a	477	242	236	217	210	202	196	165	139	117	76	76	76	76
EEI	-	**102**	**46**	**44**	**41**	**39.0**	**37.4**	**36**	**29**	**24**	**19**	**12**	**12**	**11**	**11**
unit electricity & efficiency installed stock															
AE	kWh elec/a	490	332	319	305	292	280	270	221	183	153	123	99	82	76
EEI	-	**109**	**66**	**63**	**60**	**57**	**54**	**52**	**41**	**33**	**27**	**21**	**16**	**13**	**12**
total primary energy and electricity EU															
Primary energy	TWh prim	343	259	254	240	230	222	214	179	151	128	105	86	72	67
Electricity	TWh elec	**137**	**103**	**101**	**96**	**92**	**89**	**86**	**71**	**60**	**51**	**42**	**34**	**29**	**27**
GWP per kWh and EU total															
GWP/kWh elec	kg CO_2/kWh	0.500	0.410	0.407	0.404	0.401	0.398	0.395	0.380	0.360	0.340	0.320	0.300	0.280	0.260
GWP	Mt CO_2	**69**	**42**	**41**	**39**	**37**	**35**	**34**	**27**	**22**	**17**	**13**	**10**	**8**	**7**

The EIA study projections for the EEI, in the 2nd data row, show a good consistency with CECED data for the period 2011-2013. Only in 2014 it was not foreseen that the EEI would stagnate at 39 and the EIA study expected an EEI of 37.4.

The figures below give further details of the CECED database.

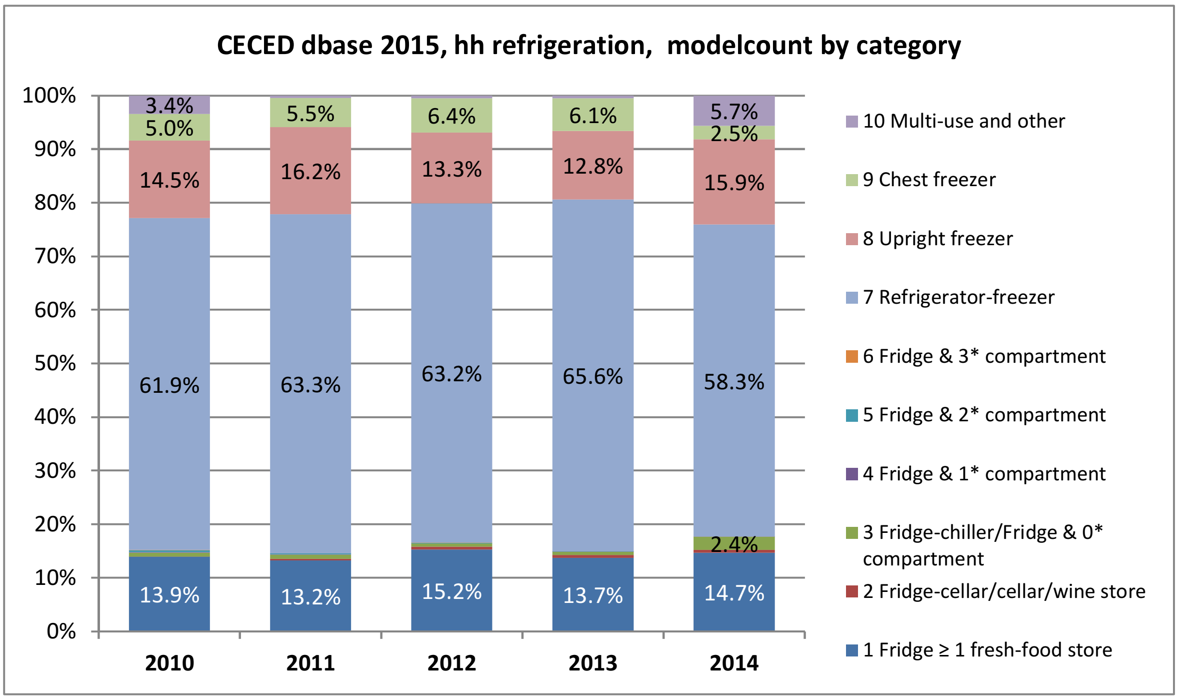


Figure 8. Counts by category(source: VHK on basis of database CECED 2015)

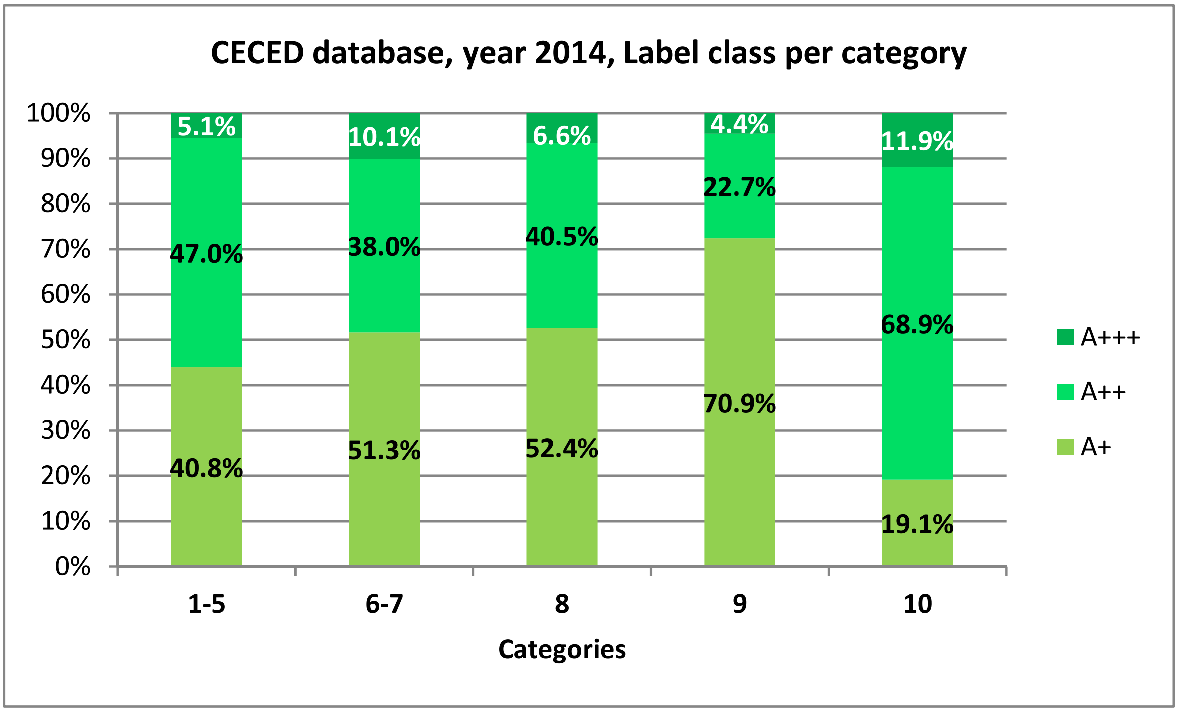


Figure 9. Counts by category and class (source: VHK on basis of database CECED 2015)

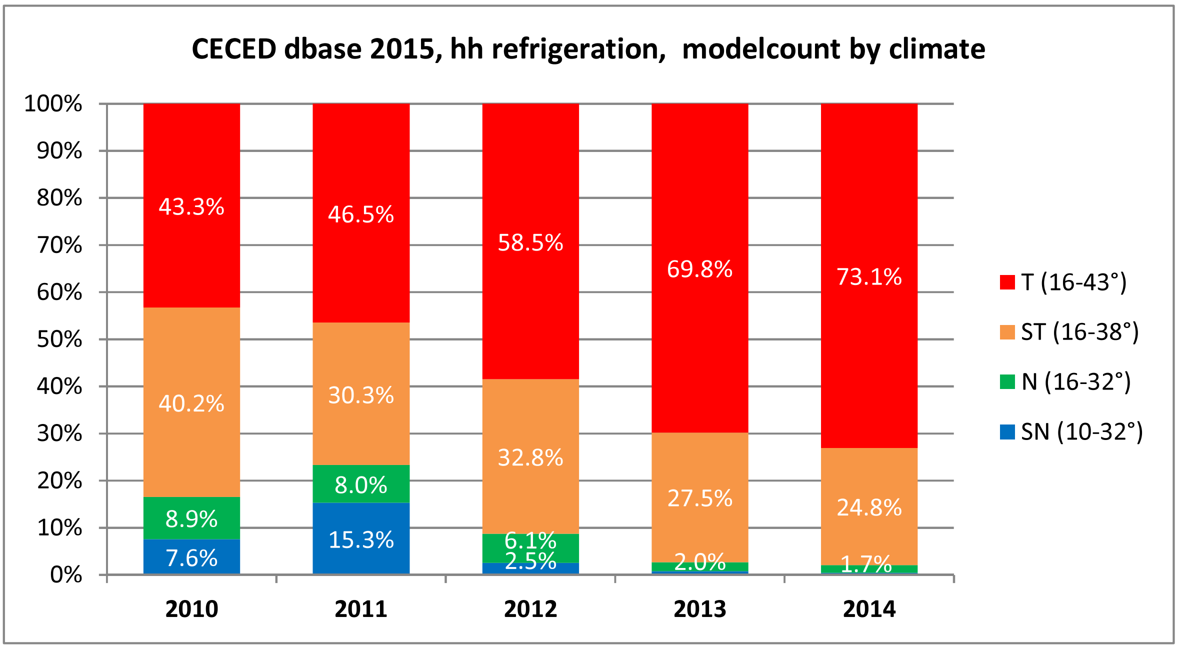


Figure 10. Count climate correction 2010-2014 (source: VHK on basis of database CECED 2015)

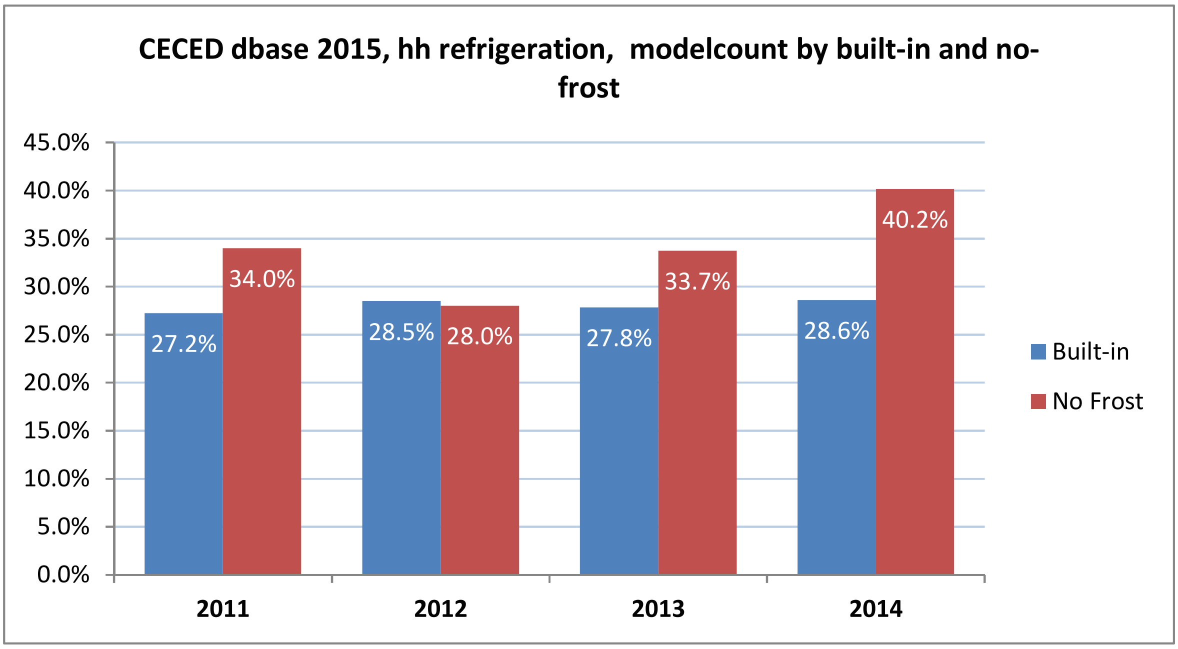


Figure 11. Count Built-In and No-frost appliances (source: VHK on basis of database CECED 2015)

As regards the main features driving the purchase, energy efficiency is still number one, as has also been mentioned in previous preparatory studies. The figure below is a more recent update from the UK, showing that 65% (in other countries up to 75%) of consumers are looking for energy-efficient models. In second place is 'brand' and perhaps surprisingly the 'variety in compartments' is the most important functional feature.

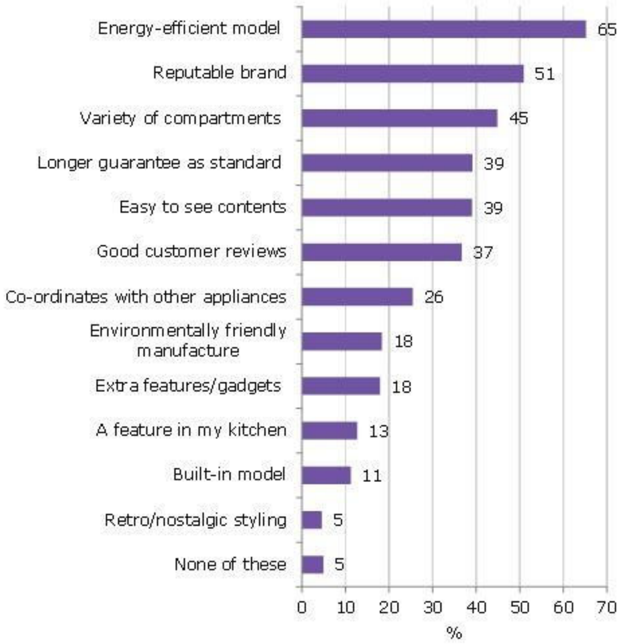


Figure 12. Factors influencing the choice of refrigeration appliances (source: GMI/Mintel "Fridges and freezers – UK", April 2014, in 'Energy efficient products – helping us cut energy use')

The trends in energy efficiency are a necessary input for Tasks 5, 6 and 7. The trends in energy efficiency are a necessary input for Tasks 5, 6 and 7. Furthermore, they give an impression, from commercial data, of the technology progress in the sector since 2009, as requested by the contract.

6.4 Prices & rates

The EIA-2014 study gives the projected price (consumer price incl. VAT) for the average household refrigeration appliances, all types, for the period from 2010 onwards. This price is based on the inter-/extrapolation of 3 anchor points, BC (Base Case) point, mid point and BAT (Best Available Technology) point. Each anchor point represents values for both the price and the energy consumption, i.e. the price is linked to the energy efficiency of the sales. The price is inflation corrected and expressed in 'Euros 2010'. Furthermore, the calculation takes into account a learning/volume effect in the production by which the price is decreased by 1% per year (parameter 'Dec').

The table below gives the anchor points and the value of the price for key years. In 2015 the price is € 552, pertaining to an energy index 36 (see table above) which is probably too optimistic (and thus the price is a bit too high).

Table 10. Anchor points and PriceDec (VHK, EIA, 2014)

UNIT PRICE (in euro 2010)	unit	BC	BC	mid	mid	BAT	BAT	dec	inc	PriceDec
		€	EF	€	EF	€	EF	€/EF	€/EF	%
		€	kWh/a	€	kWh/a	€	kWh/a	€/kWh/a	€/kWh/a	

RF Household refrigerator and freezer	€	421	430	487	242	706	76	0.35	1.32	1%

Table 11. Price trend (VHK, EIA, 2014)

	Unit	1990	2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040	2045	2050
Price	€	421	487	491	510	514	518	**522**	533	537	534	551	524	498	474

For comparison, the most recent figures for Germany in April 2014 are given below, for refrigerators (‘Kühlschränke’). The figures are not representative for the EU, but Germany has the highest share of A+++ appliances in the EU (>20%) and thus, as volume and price are related, should give a fair impression of price difference between the classes.

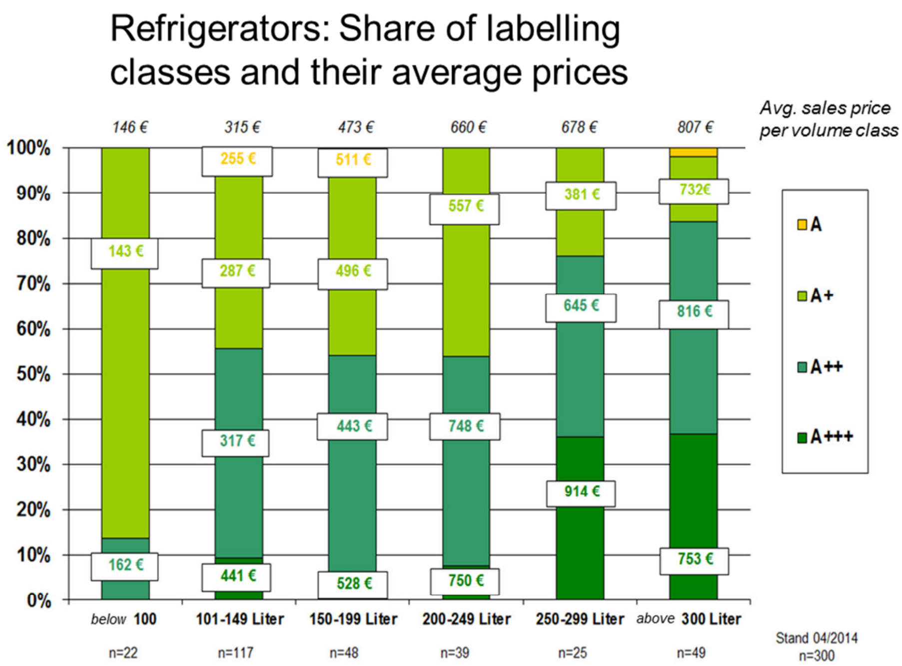


Figure 13. Refrigerator energy classification and prices, Germany 2014.
(source: Verbraucherzentrale Rheinland Pfalz, 2014)[70]

For refrigerators the share of A+++ has risen to 15% (2012: 3%). Most A+++ are in sizes>250 litres (25%). In smaller sizes the share is only 10%.

In the size class <100 litres no A+++ appliances are found. Efficient A++ appliances start at € 162. The price difference between A+ and A++ is almost € 20. The difference in annual electricity consumption is 28 kWh/a so in Germany (electricity costs € 0.28/kWh) the payback period is ~2.5 years.

In the size class 100-150 litres A+++ appliances cost on average €441. A+ appliances cost € 154 less at on average €287. The energy saving between the two is 65 kWh/a and payback in Germany would be 8.5 years.

70 Elke Dünnhoff, Katrin Negatsch, Carmen Strüh, Ramona Wiese, Energieverbrauchskennzeichnung von elektrischen Geräten –Ergebnisse des dritten Marktchecks im Dezember 2013, Verbraucherzentrale, April 2014.

The average net volume is 192 litres (see figure below). Average electricity consumption is 137 kWh/a.

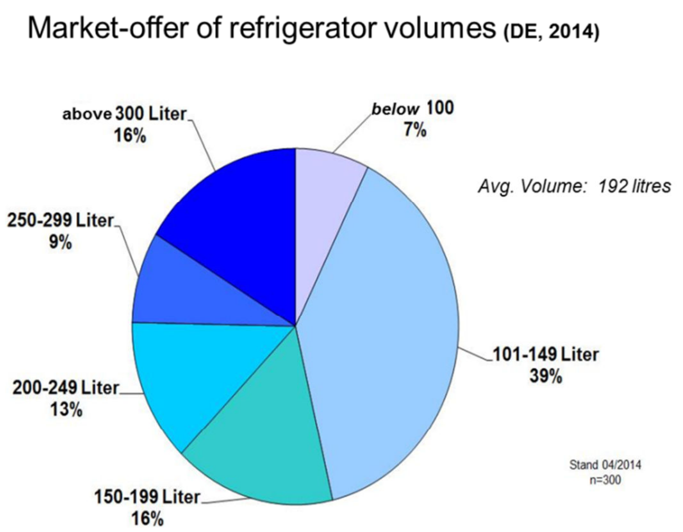


Figure 14. Refrigerator volumes on offer, Germany 2014.
(source: Verbraucherzentrale Rheinland Pfalz, 2014)

Most fridge-freezers are offered in the size class 300-350 litres. The A+++ appliances cost on average €710, i.e. €191 more than A+ appliances. Electricity consumption is, however, only 50%. At an energy saving of 140 kWh/a (€ 39.20 in Germany) the payback time is less than 5 years.

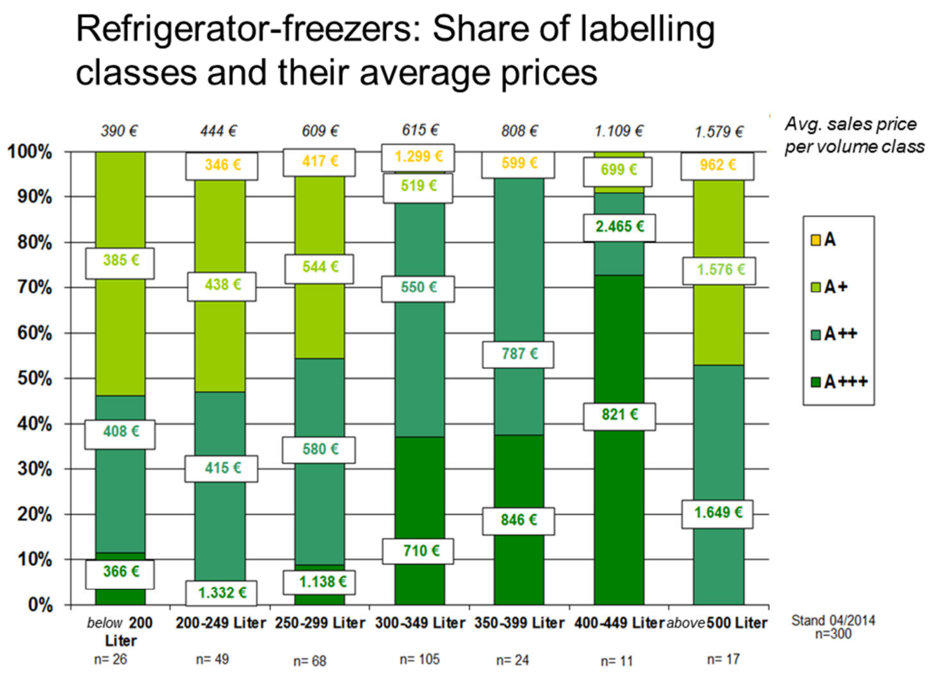


Figure 15. Refrigerator-freezers, energy classification and prices, Germany 2014.
(source: Verbraucherzentrale Rheinland Pfalz, 2014)

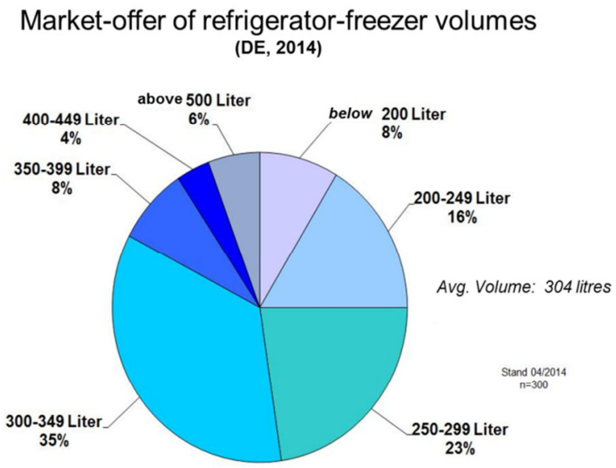


Figure 16. Refrigerator-freezer volumes on offer, Germany 2014.
(source: Verbraucherzentrale Rheinland Pfalz, 2014)

The table below gives the nominal electricity rates (Eurostat, residential) up to 2013.

Table 12. NOMINAL Electricity rate in €/kwh elec and inflation index

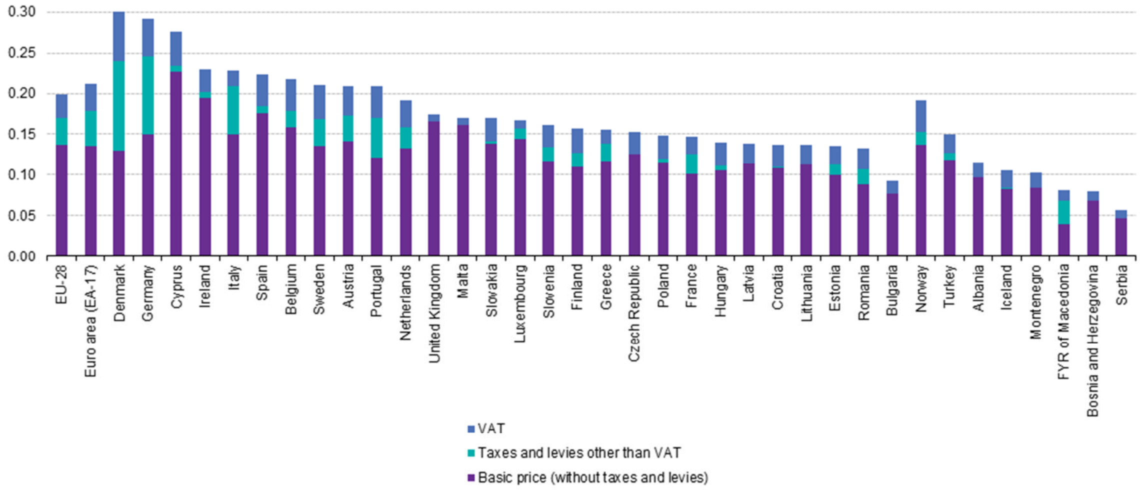
		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Electricity rate	**€/kwh elec**	0.12	0.13	0.13	0.14	0.15	0.16	0.16	0.16	0.17	0.18	0.19	0.20
Inflation	**inflation index (2010=1)**	0.67	0.74	0.82	0.91	0.92	0.94	0.96	0.98	**1.00**	1.02	1.04	1.06

For use in modelling of scenarios these rates need to be inflation corrected to one year, in this case 2010. These 'real' rates, from 2013 projected with an increase of 4%, are given below.

Table 13. REAL Electricity rates, residential (in 2010 euros, inflation corrected)

		Inc. %/a	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
El. Rate	**€/kwh elec**	4%	**0.178**	**0.170**	**0.205**	**0.249**	**0.303**	**0.369**	**0.448**	**0.546**	**0.664**	**0.808**

Note the above are average EU-rates. The figure below, for the 1st half of 2013, illustrates the differences between Member States.



(1) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
(2) Provisional.
Source: Eurostat (online data code: nrg_pc_204)

Figure 17. Electricity prices for household consumers, first half 2013 (1) (EUR per kWh) (source: Eurostat 2015)

Prices and rates are a necessary input for LCC calculations in Task 5, 6 and 7.

7 User analysis (Task 3)

This chapter deals with Task 3 of the MEErP.
The MEErP requires in Task 3.1 to deal with system aspects that have a direct impact on the energy consumption of the product. In task 3.2 the indirect resources consumption effects should be considered. Task 3.3 deals with the end-of life. For Task 3.4 the interaction with the local infra-structure should be discussed.

7.1 System aspects, direct energy use of the product

The MEErP distinguishes several approaches to the system aspects affecting the direct energy use of the household refrigerating appliances.

7.1.1 Strict product approach

A strict product approach is adopted in the current EU regulations and test standard EN 62552:2013: an appliance with a fixed or no load, no door openings and a fixed ambient temperature. The variable elements (warm load, door openings) are 'emulated' by choosing an ambient temperature of 25 °C that is a few degrees higher than the real-life ambient temperature (e.g. 21°C). The only deviation from a steady-state regulation may come from defrosting cycles and –for a 4-star freezer compartment—a freezing capacity test.

A simple example:
How much do door-openings and cooling down a warm load contribute to the Annual Energy Consumption?

As an illustration of the effect of door-openings and warm loads a simple example with worst case estimates of consumer behaviour is given.

From physics we take the constants for the specific heat capacity of water (assumed also for foodstuffs) 4.2 kJ/kg/K, specific heat capacity of air 1 kJ/kg/K or (considering the density of air (at 20°C) 1.2 m³/kg) 0.83 kJ/m³/K. The appliance is a 300 litre fridge (200 litres net volume)-freezer (100 litres net volume). The ambient temperature in the kitchen of 20 °C. The full volume of the fridge of freezer air (ignoring volume of content) is substituted by the kitchen air at every door-opening.

Door openings
The fridge is assumed to be opened 20 times per day and the freezer 4 times per day, 365 days per year. This means there is 20 x 0.2 x 365=1460 m³ of fridge air and 4 x 0.1 x 365= 146 m³ of freezer air that needs to be reheated because of door openings.
At every door opening the air in the fridge has to be heated up by 15 K (20°C-5°C) and the freezer by 38 K (20°C--18°C). The energy demand for that is 1460 x 0.83 x 15= 18165 kJ for the fridge and 146 x 0.83 x 38= 4605 kJ for the freezer. In total this is 22770 kJ or 6325 Wh (1 Wh=3.6 kJ)= 6.325 kWh per year. The electricity needed to provide this 6.3 kWh is --assuming a (bad) COP of 2.5-- thus 2.53 kWh/year.

Warm load
No statistics could be found, but let us assume (VHK estimate on basis of FAU Food Balance), that the average European buys around 650 kg of food & beverages that go into the refrigerator or freezer. If we add some 40-50% for food that was heated up during use (left on the table, leftovers, etc.) a ballpark estimate is the equivalent of 1000 kg per year per person. At a little less than 2.5 persons per household this means 2500 kg per fridge/freezer per year that needs

to be heated up from shop-temperature to fridge/freezer temperature. Assume that this temperature differences is 15 °C (from 20 to 5 or for a freezer from -3 to -18 degrees)
The annual energy demand per frdige-freezer to (re)cool warm load is thus 2500 x 15 x 4.2 = 157500 kJ = 158 MJ. This equals 43 kWh/year. The electricity use, at average COP=2.5 would be 43/2.5= 17.2 kWh/year.

Conclusion
In total and in this worst-case example, our fridge-freezer would thus consume 6.3+17.2 = 23.5 kWh of electricity for door openings and heating warm load. This is less than 10% of the average annual electricity consumption of installed appliances of 270 kWh (see par. 6.3.3) and thus amply compensated by the 5°C extra high testing temperature: The test temperature is 25°C versus a 20°C real kitchen temperature, meaning 25% more heat load for a refrigerator and 13% more heat load for the freezer (on average 20-21% more).
Of course, as the appliances become more efficient the relative share becomes higher (even if the COP improves). Compared to an A+++ 300 litre refrigerator-freezer with an average energy use of 160 kWh/year, 23.5 kWh is almost 15% but still compensated enough by the higher test temperature.

7.1.2 Extended product approach

Extended product approach is what is foreseen with several elements of the new IEC test standard IEC 62552:2015. Two separate tests at two different heat loads. The difference comes from testing at 16°C and 32°C ambient, but it might as well come from different inside loads (e.g. warm food, frequent and long door openings). The appliance has to do well at both heat loads to have a high score. This is more realistic and means that appliances with two thermostats and –better still—variable speed compressors that keep a high COP also at part load are at an advantage. The new standard is also prepared for variable defrosting cycles, i.e. 'defrost-on-demand'.
There are several optional tests, not only for freezing capacity but also for cooling capacity that could show how well the appliance is prepared to deal both with peak loads and low-power steady state control.

7.1.3 Technical system approach

Technical system aspects consider that the product is part of a larger technical system. The refrigerator and/or freezer is installed in a habitable area of dwellings and that its waste heat (from the condenser) contributes to the space heating of the dwelling. This is the case for most energy-using products in the home (dishwasher, washing machine, TV, light sources, etc.) and this is not commonly considered in ecodesign regulations, because it would lead to a sub-optimisation of the individual energy-using product: Instead of using a dedicated heating system (boiler, heat pump) the waste heat is often not generated at the times and in quantities that the consumer needs. For instance, refrigerator and/or freezer operate 24/7 in a space that is usually occupied only a few hours a day and the rest of the time the waste heat is not necessarily useful.

Another possible consideration in this context is the fact that the refrigerator/freezer is part of a kitchen. This means that aesthetics play an important role and lead either to the refrigerator/freezer being built-in, using the overall kitchen front door design, or that as a freestanding and large object it has an attractive design. If the appliance is built-in, the free passage of convection air to the condenser is restricted. The air cannot enter from the sides of the appliance and there is a relatively narrow spaces below and above the appliance for entry and exit of the cooling air. This is taken into account in the specific test procedure for built-in appliances and leads, for the same appliance, to energy consumption that may be up to 10% higher in comparison to a freestanding appliance test. A second issue is the fact that the refrigerator/freezer has to match the metric format (base module 60 cm width, with steps of 15 cm) of the kitchen, which –at a minimum usable storage volume—sets practical limits to the insulation thickness, which again has an impact on energy efficiency. This latter factor, and the fact that built-in appliances can achieve a considerable higher price in an already expensive kitchen, makes it likely that high U-value insulation, such as vacuum insulation panels (VIP) or a full vacuum appliance, will be first applied in built-in refrigerators.

But there are other possible solutions. An easy solution would be to enhance the natural convection by introducing a very-efficient (2 W?) fan to aid the air flow. Another solution, used typically in professional or commercial cooling, is to employ a remote condenser unit. This is condenser-unit that is not at the back of the appliance but can be placed at a distance of a few metres, i.e. in a place that is more convenient and effective for cooling the condenser. Also there might be some extra space gain at the back of the appliance. A possible disadvantage is that a solution has to be found to avoid possible refrigerant leakage. In a professional environment the lines between a condenser unit and the cabinet are mounted in-situ and leakage is possible. In a domestic environment the lines are factory-mounted and factory-tested for practically no leakage, an asset that should preferably be maintained. Furthermore, the refrigerant lines should be very well insulated.

7.1.4 Functional systems approach

A function systems approach considers that there are several ways –and better ways—to realise the same basic function.

In this case it should be considered that the refrigerator's function is not to create a low-temperature box but food preservation and preparation. This is especially important because, as identified by the FAO[71], 30% of the world's food is wasted, of which half or one third (10-15% of total, depending on country and habits) by households. This is not only a moral issue in view of world hunger, but also a waste of valuable resources (land, water, energy) that are needed in large quantities for food production. Household refrigeration can help by optimising the storage temperature or by food planning.

Storing the food at the correct temperature. The fresh food temperature of 4-5 °C is actually suboptimal for most fresh food products, except possible dairy products (milk, butter, eggs, some cheese). Greenleaf-vegetables and citrus fruits like to be stored at a lower temperature (1-2 °C) and adjusted humidity, soft fruits and non-leaf vegetables (tomatoes, peppers, courgettes, etc.) actually like higher temperatures (8-10 °C). A chill compartment (around 0 °C) is best for fresh meat and fish. For most beverages 4-5 °C is definitely too cold for health, optimal taste and –often--conservation. Temperatures of 8°C (beer, soft-drinks) or higher (wine, from 12 °C upwards, with 50-65% humidity) would be much better.
The fact that the new standard is now accommodating high temperature compartments like cellar and pantry is a welcome development in this respect. If an accurate analysis of the average fridge content was available, it would probably show that we do not need that much 4 °C fresh food space, but rather a big cellar, a

[71] FAO, Global Food Losses and Food Waste - extent, causes and prevention. Food and Agriculture Organization of the United Nations, Rome, 2011.

medium-sized fresh food (with meat/fish chiller inside or separate) and a freezer compartment that –with a view of reducing transportation effort for shopping—might well be larger than it is today. This 3- or 4 door solution may well be less efficient from the standpoint of the strict product approach (more doors give more leakage) and it might be bigger, but the overall impact could well be positive: not only in combatting food waste but also the average higher storage temperature might result in a lower energy consumption. Finally, the cellar cooling may well be coupled with the 'waste cold' from the freezer/refrigerator defrosting cycle and thus cost no or little extra energy.

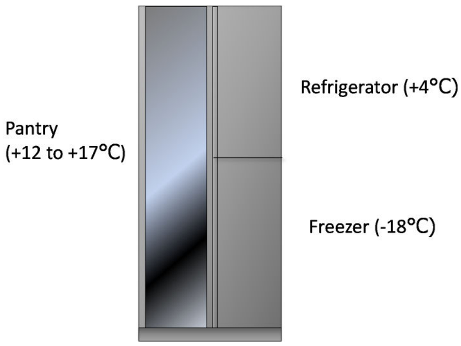


Figure 18. Illustration of a pantry/refrigerator/freezer (VHK 2015)

Auxiliary food preservation techniques: Examples are humidity control or, e.g. in the chiller sub-compartment, creating an oxygen-poor environment (with CO2).

Food planning: Many people forget expiry dates, well hidden left-overs, etc. If the fridge had a scanner that could read bar- or QR codes of foodstuffs and a small display it could help to fight food waste. This might also help the fight against obesity or other eating disorders, both serving health and diminishing food demand.

The lesson is not that we can incorporate all the possible options tomorrow, but it would be wise to keep the options in mind when deciding on things like new categories or correction factors.

7.2 System aspects, indirect energy use

For a refrigerator, it is difficult to make the difference between direct and indirect energy use, because they are interconnected. One could say that aspects such as food waste and shopping-transportation energy, discussed in the previous section, might just as well be discussed here. Alternatively, different food preservation techniques could be discussed (cans, salting, pickling, adding sugar, drying, etc.) but the simple truth is that refrigeration is the consumer preference for tasty, fresh food, and the only alternative for frozen products.

In conclusion, other than relating to food-waste and shopping transport, this section of the MEErP does not add new considerations for a possible regulation.

7.3 End-of-Life/recycling

As mentioned in Chapter 6 (Market) the total product life of the average refrigerating appliance is in the order of 16 years, i.e. 12-13 years up to first replacement (in the kitchen) followed by 3-4 years in secondary use (second-hand sale in the EU, transfer to the garage, student homes of the children, etc.). Furthermore, there is an unknown fraction of repaired refrigerating appliances being shipped to e.g. Africa for further prolonged third-hand use.

From the point of view of the environment this is an extremely negative development. Not only does it keep ozone depletion substances (freon) on the market and moves it to environments that are difficult to control/surveil in terms of responsible recovery, but on a more permanent basis it also blocks the introduction of new, much more energy-and carbon efficient refrigerating appliances on the market. The figure below, from a Japanese life cycle inventory clearly shows the negative impact of prolonged use of a 1999 appliance, disposing it in 2014 instead of replacement in 2010. In the year 2014 this means an increase in total environmental burden of 40%(!).

Notwithstanding the generally valid concept of 'circular economy', a responsible strategy for this product group would be to discourage repairs and re-use by consumers if their refrigerating appliance is older than e.g. 10 years.

Stakeholder feedback on this issue is requested.

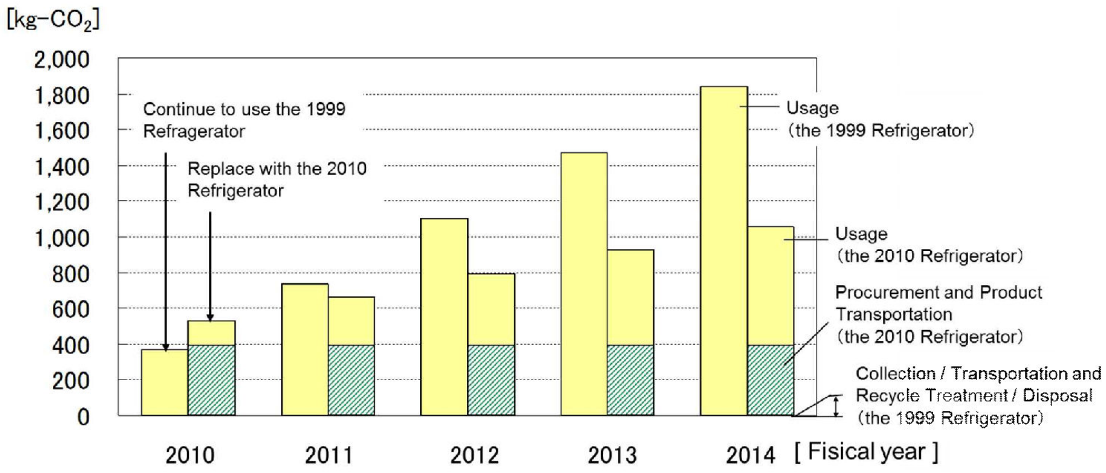


Figure 19. Greenhouse gas balance of life time extension: Continued use of 1999 refrigerator in 2010 versus replacement by 2010 refrigerator.
(source: JEMA, Report on Life Cycle Inventory (LCI)--Analyses of Refrigerators, The Japan Electrical Manufacturers' Association, The Environmental Technical Expert Committee, The LCA-WG (Life Cycle Assessment – Working Group), Japan, June 2014)

As mentioned in Chapter 5 (Legislation) the WEEE Directive will require, when the refrigerating appliances currently placed on the market, a recovery (heat recovery from incineration + recycling) rate of 85% and a recycling rate of 80%.

For this product group, this is a difficult target. As can be seen from the bills-of-materials, more than 25% (weight) of the product is made up of PUR (poly-urethane) foam and PS (polystyrene) inner-liner.

PUR offers, except for vacuum panels, the best insulation solution (U-value) compared to other materials, but it is not really a 'plastic' (thermoplast). It is a thermoset material, processed from 2 main components. In itself, this makes it very difficult to recycle, certainly not in a 'closed loop' (recycled foam in new foam).

To illustrate this point: In the US, where the EPA is requiring a minimum (9%) recycled content, the manufacturers try to meet the requirement not by using recycled foam, but by using polyols (one of the components) from recycled chemicals. [72]

End-of-life PUR can be recycled chemically (costly and potentially polluting) or mechanically (crushed and compressed to form wood-like blocks). [73] Most end-of-life PUR comes from dismantled flexible PUR-parts of furniture (sofa's), matrasses, carpet under-coverings or from hard PUR-panels (e.g. roof insulation).

In the case of refrigerating appliances the PUR foam is stuck between the steel cabinet and the PS inner-liner and cannot be dismantled.[74] The most used solution, also to recover the foaming agent responsibly, is to shredder –in a special, closed environment-- the base cabinet to fine grains, recovery the steel parts through

[72] http://www.foam-tech.com/about_ft/environment.htm
[73] http://www.intcorecycling.com/How-to-recycle-pur.html
[74] Please note that the sandwich construction of St-PUR-PS is vital for the mechanical strength and rigidity of the cabinet structure. A bad idea, both thermodynamically and in terms of material resources, would be to use separate panels in a self-sustained steel cabinet, which would need to be much heavier.

magnetic separation and incinerate (with heat recovery) the PUR-PS particles that remain. [75]This means that also the PS will not be recycled, but only used for heat recovery.

Given that 25% of the product is not (easily, economically) recyclable and that the target is 80% recycling creates a problem for manufacturers. The simplest solution would be to increase the weight of the rest, i.e. to employ extra resources to make sure that the PS-PUR fraction stays below 20%. We are not aware that any manufacturer is willingly engaged in such a practice and designers will always try to find weight-increasing elements that also offer a functional bonus. However, the recycling target does implicitly reward e.g. the use of glass shelves (instead of the previous light steel racks) and the use of new models with stainless steel cabinets (instead of using thin pre-painted carbon steel).

Stakeholder feedback is requested on the above recycling issues.

As regards ODP and GWP issues at end-of-life and as mentioned in par. 5.3 there are no remaining issues in this sector. New products all use low-GWP carbons: 98% is using isobutane as refrigerant and 100% is using hydrocarbons (cyclopentane) as a blowing agent. In 2013, according to the Omnibus study, R134 was only used in some of the biggest side-by-side appliances for fire safety reasons (2% of the market), but now these are also phased out, unless there is a justified claim for an exemption, under the new regulation EU No. 517/2004 [76]

7.4 Infrastructure, smart appliances:

As discussed in paragraph 4.2.2 the new IEC 62552:2015 offers a 'temperature rise test' which, in areas and with consumers where utility company would be allowed to 'smartly' disengage certain appliances in periods of grid peak demand, tells the consumer and those utility companies how long they can switch off the freezers before any real damage to the food may occur.

Stakeholder feedback is requested whether this test should play a role in future legislation.

[75] Ron Zevenhoven, TREATMENT AND DISPOSAL OF POLYURETHANE WASTES: OPTIONS FOR RECOVERY AND RECYCLING, Helsinki University of Technology Department of Mechanical Engineering Energy Engineering and Environmental Protection Publications (TKK-ENY-19), Espoo 2004

[76] Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006. OJ L 150, 20.5.2014, p. 195–230

8 Technical analysis (Task 4)

8.1 Technical product description

8.1.1 Existing products (working towards definition of BaseCases)

8.1.1.1 Refrigeration working principle

Domestic refrigeration appliances, refrigerators, freezers and combination, are used to store food at cold temperatures. A refrigeration system is used to maintain temperatures inside the appliances at acceptable temperature ranges.
Most products use a mechanical compression vapor cycle with an electrical compressor.

The components of such a cycle are shown in (Figure 20) and the refrigeration process is as follows:
- A cold refrigerant fluid, at low temperature and pressure evaporates in the evaporator, capturing the heat to be removed from the appliance indoor volume to maintain the cold temperature.
- The vapor refrigerant leaving the evaporator is sucked by the electrical compressor; it is compressed at high pressure and temperature.
- The high temperature and pressure refrigerant is cooled down and condensed to a high pressure liquid state in the condenser.
- The refrigerant then enters the expansion valve (a tube of small diameter which infers a pressure loss to the fluid). The refrigerant fluid leaves the expansion valve at low pressure and in biphasic state (partly liquid and vapor).
- The refrigerant finally flows back to the evaporator.

Hence, thanks to the electric input of the compressor, the refrigerant flows through the refrigeration circuit, capturing the heat of the indoor volume and rejecting it to the kitchen / room air.

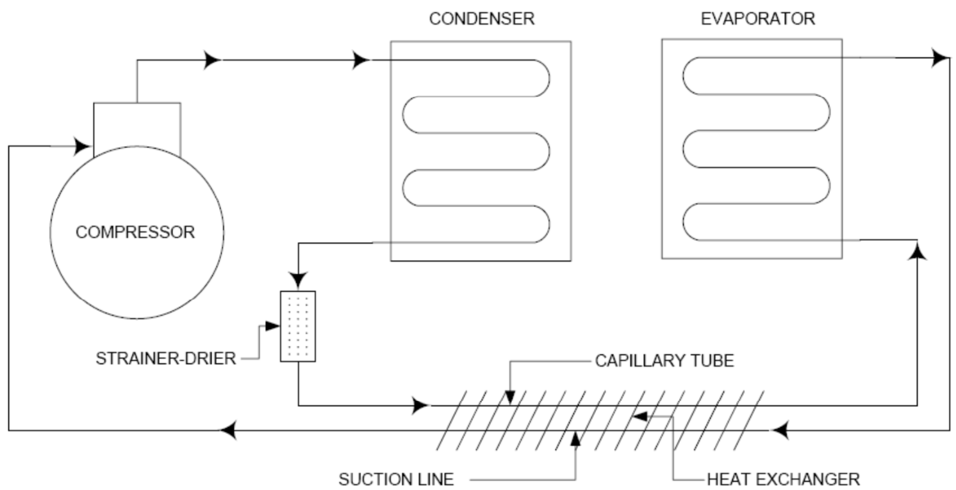
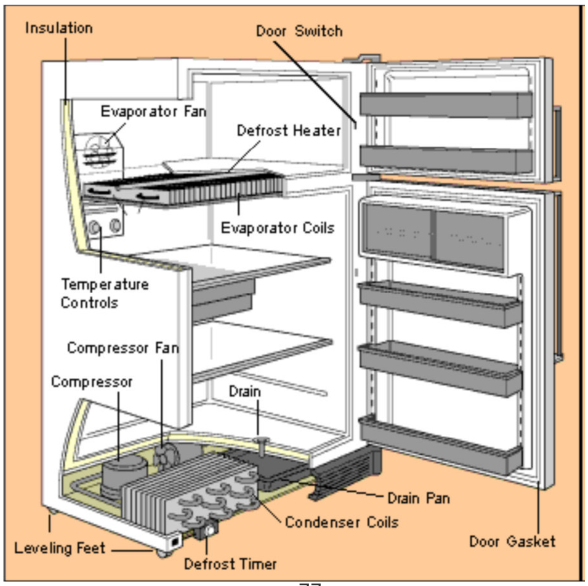


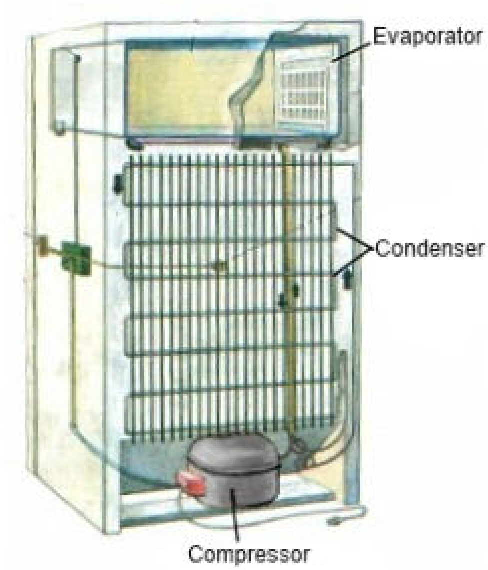
Figure 20. Refrigeration circuit
(Source: American Society of Heating, Refrigeration and Air-Conditioning Engineers, 2006 extracted from Technical Support Document for the Final Rule on Residential Refrigerators, Refrigerator-Freezers and Freezers. U.S. Department of Energy, 2011)

A few products use the absorption cycle. In that case, the electric compression is replaced by a chemical compression based on the absorption principle. Electric energy input is replaced by a heat input from gas or liquid fuel combustion.

Figure 21 shows the typical physical arrangement of the different components in a typical top-mounted refrigerator freezer.



Source: RemodelGuide.com[77]



Source : Solarhomestead.com[78]

Figure 21. Typical refrigerator freezer top-mounted, with forced convection condenser and freezer (left) and static condenser (right)

The main components / characteristics are then described: Refrigerant fluid, Insulation, Heat exchangers, Compressor, Control and defrost management.

8.1.1.2 Refrigerant fluid

The EU 517/2014 regulation requires that all the domestic refrigerators and freezers use a refrigerant with a GWP (Global Warming Potential) less than 150 starting from the 1st of January 2015. Therefore, all the refrigerators put on the market in 2015 use R-600a as refrigerant (hydrocarbon). Studies have shown that the performance of refrigerators using R-600a was equal or better than refrigerators using R-12[79] and those using R-134a[80].

8.1.1.3 Insulation

Heat losses can are mainly linked to conduction through the walls of the appliances.

Most refrigerators and freezers use polyurethane foam insulation for both the walls and the door. As CFC-11 and HCFC-141b have been banned, Cyclo-pentane and n-pentane (HC) are currently used in Europe. The new European regulation (UE N° 517/2014) will lead to the exclusive use of hydrocarbons, HFC with GWP more than 150 will be banned in 2020.

77 RemodelGuide.com. HomeTips, LLC, Glendale, CA. <http://www.remodelguide.com/improve/appliances/refrigerators/refrigerators_works.html>

78 Solarhomestead.com. Make Your Refrigerator More Efficient, March 8, 2013. <http://solarhomestead.com/make-your-refrigerator-more-efficient/>

79 Jung, D., Kim, C-B., Song, K., and Park, B. "Testing of propane/isobutane mixture in domestic refrigerators," International Journal of Refrigeration, 2000, 23 (2000) 517-527

80 Behrens, N., Dekleva, T.W., Hartley, J.G., Murphy, F.T., and Powell, R.L. "The R-134a energy efficiency problem, fact or fiction," USNC/IIR-Purdue Refrigeration Conference, 1990, pp. 365-372

Improvements in the sector of insulation began by increasing the thickness of foam to increase the energy efficiency of the products. Currently, an increased insulation thickness is a standard option.

Improved door gaskets are part of the standard options. Gaskets have been designed taking into account the improvement of thermal efficiency performance and the easy opening of the door. Extra-strong gasket magnets may be used in some models but savings have not been assessed.

Heat transfer through the metallic frame (known as edge effect) are thought to have limited impacts in standard designs in Europe[82].

8.1.1.4 Control and defrost management

Temperature control: mechanical or electronic thermostats ensure that the temperature in the cold volume is maintained at the adequate temperature. The electrical signal from the thermostat is sent to the control of the equipment through a PCB (printed circuit board). The controller then adjusts the compressor and fan (if any) power in order to supply the correct refrigerating capacity. In most cases, the compressor is simply cycled on and off.

Frost and defrost: inside refrigerators and freezers, the evaporator temperature is very cold and hence below the dew point of humid air. Thus, any vapour depositing on the surface of the heat exchanger is likely to freeze, which decreases the heat exchanger conductivity, which in turn requires higher temperature difference between cold air and refrigerant, which increases power consumption. Defrost is then required to minimize the energy consumption. Defrost can be manual (the end-user has to remove the ice manually), semi-automatic (the end-user has to trigger a defrost cycle pushing a button) or automatic (with a timer for instance every 12 hours, or using adaptive systems based on temperature and other parameters). Forced air evaporators with automatic defrost are called "frost-free" or "no-frost". In all 3 cases, once the defrost begins, the ice melts. Water is evacuated by the drain at the bottom of the refrigerator (Figure 21 left) or in a tube. It is then directed to a collector located above the compressor and water evaporates thanks to the heat of the compressor (note it can also be vaporized over the condenser in case of forced air circulation condensers[81]).

Expansion valve: the expansion valve is a capillary tube of small diameter, in most cases non insulated. According to Greenblatt[81], it is commonly soldered to the compressor suction line (Figure 21), which allows superheating the fluid leaving the evaporator to avoid compressor to suck liquid.

Anti sweat heaters are commonly used in standard-size refrigerators and freezers to prevent water to condense on the external walls close to the doors and the door gasket. Models using a hot gas or warm liquid refrigerant loop allow to eliminate direct electricity consumption (unlike models with electric resistance heaters). It is the case of nearly all standard size refrigerators and freezers in Europe and in the USA[81,82].

[81] Greenblatt, Jeffery B.. Technical Support Document for the Final Rule on Residential Refrigerators, Refrigerator-Freezers and Freezers. U.S. Department of Energy, 2011.
[82] Preparatory Studies for Eco-design requirements of EuPs (Tender TREN/ D1/ 40-2005), Lot 13: Domestic refrigerators and freezers, Task 6: Technical Analysis Rev 4.0, October 2007.

8.1.1.5 Heat exchangers

Condenser: The condenser is a heat exchanger which enables to extract the heat from the refrigerant fluid. There are 3 main types of condensers. In Europe, a wire and tube static condenser located on the rear wall of the refrigerator (Figure (right)) is the standard design. Heat is released through natural convection (which creates air speed along the fridge rear wall and helps extracting the heat) and radiation. Freezers can use a hot wall integrated in the mounting of the unit[81]. In the US[81], the condenser is located below the refrigerator, typically using forced convection to extract heat (Figure (left)).

Evaporator: the evaporator is a heat exchanger which extracts the heat inside the unit. There are 3 main different types. Cold wall evaporators, attached to the wall of the cooled volume, are static heat exchangers using natural convection. it is made of tube serpentines. Roll bond evaporators are typically used in refrigerator with a freezer part, where they enrol the freezer zone. In general, heat transfer is based on natural convection but in some cases, a fan can be added to increase the convection. Forced convection heat exchangers are aluminium or copper tube and fins located behind a panel or in the part separating the compartments.

8.1.1.6 Compressors and fans

Compressor

The compressor is normally located at the rear bottom of the appliance (Figure 21). It can be cooled by a fan. It normally does not accept liquid (or only a small amount for short periods of time) so that the vapour entering the compressor has to be overheated.

Domestic refrigeration appliances mostly use single speed hermetic compressors. The nominal cooling power of single speed compressors typically ranges from 60 W to several hundred, depending on the size and efficiency. The 2007 preparatory study[82] estimated that in 2005, isobutane compressors had already been improved to reach 1,3 COP (ASHRAE conditions) for A class appliances and 1,5 COP for A+ models and were available from most major compressor suppliers. Now that A+ models are the minimum efficiency level, it is believed a COP of 1,5 or a compressor global (motor + isentropic losses) efficiency of 0,55 is the standard.

Greenblatt[81] reviewed the compressors available for the US market using R-134a and R-600a in 2006. It appeared that low capacity compressors were less efficient starting from around 600 Btu/h (around 175 W), with efficiency going down to EER as low as 2,3 in Btu.h^{-1}.W^{-1} at 140 Btu.h^{-1} (or a COP about 0,67 at 40 W). This does not directly apply to R-600a compressors, which in general are 5 to 6 % more efficient than R-134a compressors, but still represented very low efficiency values for small compressors.

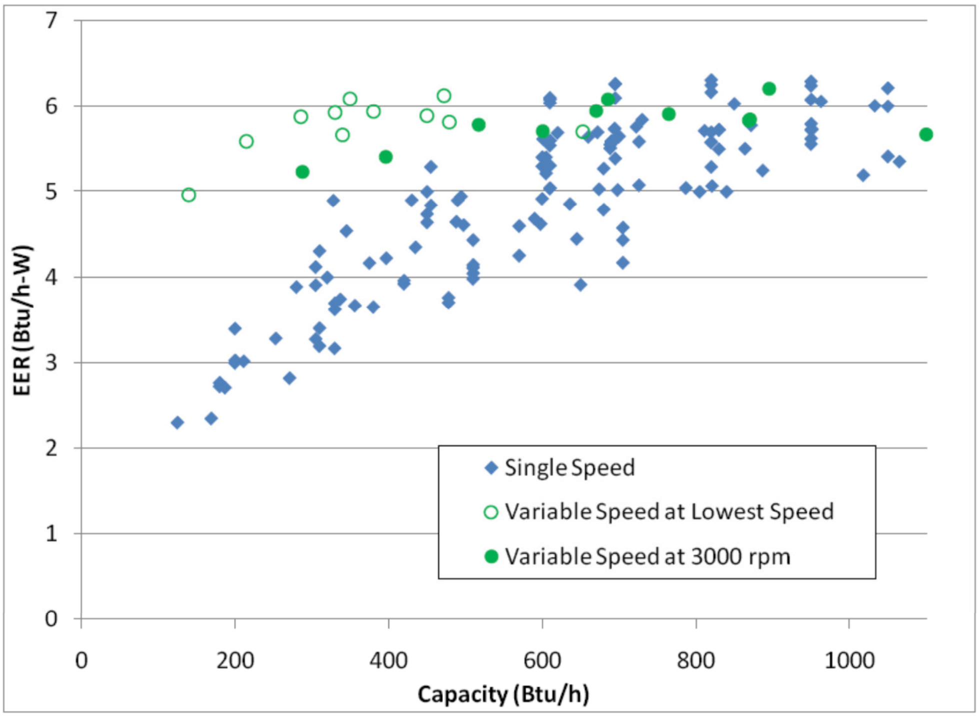


Figure 22. R-134a hermetic reciprocating compressor efficiency data
(Source: Embraco data 2006)

The situation for fix speed compressors much improved in 2015 on the low capacity side. Down to 60 W, the COP (ASHRAE conditions) of R-600a compressors remains in the same performance range, approximately [1.3 ; 1.85] (Figure).

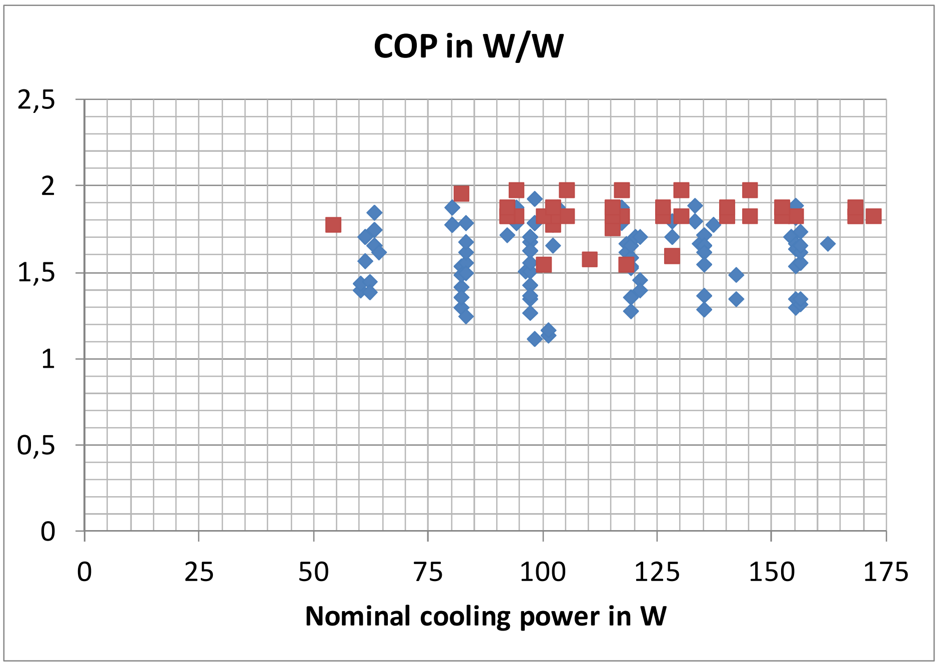


Figure 23. R-600a hermetic reciprocating fixed speed compressor efficiency data
(Source: Embraco and Jiaxipera data 2015)

Fans
The Lot 13 preparatory study[82] gives indications of fan power used in 2005 for no-frost applications (from 6 to 10 W in A class models) and for "brewed" compartments of static appliances (5 W).

8.1.1.7 Trends in design

Pushed by the labelling (REGULATION (EU) No 1060/2010) and Ecodesign (REGULATION (EC) No 643/2009) measures, efficiency of domestic refrigeration appliances increased significantly. Average efficiency levels increased from efficiency indexes 55 to 65 (base cases in Lot 13 preparatory study[82]) down to A + levels or efficiency indexes lower than 42.

The number of built in appliances represents about 30 % of the CECED models in the 2014 database and no-frost about 40 % (see Task 2 of this study). If climate class are now mainly T or ST, many appliances can operate over the complete temperature range 10 - 43 °C. This trend means that the nominal power of compressors is likely to increase. This in turn gives more incitation to adopt efficiency options enabling improved part load performances as variable speed drive.

Regarding energy efficiency:

- Many A +++ appliances now use variable speed compressors (including the LG variable speed linear compressor).
- Manufacturers are proposing innovations regarding defrosting of static freezers to make it easier, but without "consuming supplementary energy as for the no-frost products". The freezer evaporator may be replaced by tube in walls in order to reduce the temperature difference between the air and the wall (Low Frost option, Bosch). The "stop frost" option (Whirlpool) "concentrates" the frost in a small box easily accessible, to be defrosted using hot water.
- Super insulation has become a criteria for freezers: the time the freezer can maintain food frozen without power is indicated; there are large variations amongst products. The magnitude of these variations suggests the use of phase change materials in some products.

Regarding options to improve the quality of food conservation thanks to a better control of temperature and humidity controls:

- Manufacturers intend to homogenize the temperature of compartments. Fans are becoming more common inside the refrigerators to that purpose, even for static refrigerators. In no frost refrigerators, the air flow may be distributed at each shelf in order to improve the temperature distribution; LG also proposes an "Air Curtain" function in order to limit the temperature change of food products when the door is opened.
- Fast refrigerating and fast freezing functions are now common; they enable to preserve food at a more constant temperature (after a door opening) and less time is required to condition new food; they sometimes appear in the product range with variable speed compressors.
- To better conserve food and avoid it may be dried, not only temperature but also humidity can be controlled; crispers are closed compartment which enable to conserve more humidity.
- All in all, there are more compartments and accordingly, the number of doors is also increasing.

Electronic:

- Generalization of LCD screens with digital temperature setting,
- Possibility to control several zones precisely,
- Automatic alarms for a door stayed open (based on abnormal temperature evolution)

Communications:

- The connection of fridges to the internet / to other appliances[82] has not been generalized;
- The concept of having the fridge buying food when it is missing via internet connection did not really generalize.
- Nevertheless, new functions appeared regarding an easier maintenance; a diagnostic can be done by connecting the fridge to a phone with a specific application (Smart Diagnosis™, LG)

[The Base Case(s) will be defined in a subsequent version when Task 5 will be included.]

8.1.2 Products with standard improvement (design) options

8.1.2.1 How to reduce of the environmental impact of domestic refrigeration appliances?

<u>CO2 emissions</u>
The two main environmental impacts of domestic refrigeration freezers[82] are energy consumption and GHG emissions, which arise mainly from the electricity consumption during the product life but also from the fugitive emissions of refrigerants at the different life cycle stages. Because most appliances already use isobutane, which has a very low global warming potential index, greenhouse gas emissions are mainly linked to electricity consumption. So reducing electricity consumption is the main way to reduce GHG emissions.

<u>Energy consumption</u>
The refrigerating system has to maintain the indoor temperature of the inside volume which, without a cooling system, tends to increase, because of the heat losses though the appliance envelope. It is thus necessary to struggle against through the walls (conduction heat transfer) and gasket (conduction heat transfer and cold air leaks) heat losses. In some cases, when the door is opened (which is not the case in standard performance tests), strategies can be adopted to stop the cooling system, which would then become very inefficient.

Heat load of the coldest zones in the appliance can also be minimized, by ensuring proper insulation with neighbouring compartments at higher temperatures. The final gain in consumption then depends on the refrigeration system design.
Once heat losses are reduced to a minimum, the main energy consuming component of a domestic refrigeration appliance is the compressor. In order to reduce its consumption, it must work with the lower pressure difference between the low side and high side pressures.

Pressures are directly linked to the temperature levels of the refrigerant fluid in the heat exchangers. For the condenser, the condensing temperature is higher than the ambient from a few degrees Kelvin. More efficient condensers will allow to reduce that temperature difference, thus the refrigerant high pressure and in turn the electricity consumption of the compressor will be lower. The same is true on the evaporator side.

Of course, the efficiency of the compressor, including the component itself, its motor and control, can also be improved to reduce the consumption. This is also true for fans, for appliances incorporating one or several fan(s).

Further improvements can come from the control of the active components (compressor and fans) with for instance variable speed control, and of the defrost cycles.

The refrigerant system energy consumption can also be reduced through alternative cycle designs (for instance separate cycles for the refrigerator and freezer) and alternative technologies to mechanical vapour compression refrigeration systems (for instance magnetic cooling).

8.1.2.2 Insulation

Larger insulation thickness still appears as an option to improve the efficiency. However, its applicability may be limited as it changes interior volumes or exterior dimensions. This option would probably not be applied at least to built-in products. Thickness increase of 10 and 20 mm were considered in 2007[82].

8.1.2.3 Control and defrost management

Temperature control

Electronic thermostat
Mechanical thermostat is still common in European fridges. Using an electronic thermostat may help to improve the efficiency of the unit, as it may include more variables in the control than just the indoor compartment temperature thus enabling the adoption of ad-hoc strategies in case of door opening for instance but also to manage more intelligent defrost strategies, compressor control. According to the Lot 13 preparatory study[82], there is no direct gain to adopt electronic control but it is a necessary improvement for several options (some are quoted before). Note that according to Greenblatt[81], it is not necessary to adopt electric control to implement a variable speed drive compressor.

Air distribution control
Homogeneous temperatures in the compartments enable to limit the temperature difference between the food and the air and thus to raise the evaporator temperature. Directing cooling exactly towards the parts where it is needed may also increase efficiency[92]. Fans inside the unit and/or mufflers and ducting systems may do this too. This is illustrated with the apparition of "brewed" appliances, which are neither static nor forced convection units, but in which a fan is used to get more homogeneous temperature conditions; experimental results[83] show typical vertical temperature variations of 4 to 5 K for static cold versus 2 to 3 K admitted for brewed compartments. Given the low cost of a low consuming small fans, this is certainly an option to improve the energy efficiency of static designs and to improve food conservation, already applied in many refrigerators and freezers.

Defrost

Defrost techniques for no-frost appliances

[83] O. Laguerre et al./International Journal of Refrigeration 25 (2002) 653–659

In 2012, an experimental study was carried out in order to evaluate the performance of defrost systems on no-frost household refrigerators[84]. Results show that defrost efficiency is similar for all the types of electrical heaters (aluminium tube, tubular metal sheathed or glass tube), independently of the operating mode (integral power, power steps or pulsing power). The authors recommend the "calrod" heater (tubular metal sheathed) because of its low cost and easy to install but, from defrost efficiency point of view, it does not seem possible to identify a clear improvement option. The analysis of the operating modes was not fully conclusive for real life application: the step control gives a better defrost efficiency (about 50 % versus 30 % in the worst case) but requires a longer defrost time and may lead to higher loads when the evaporator fan restarts.

Adaptive defrost control for no-frost appliances

Adaptive-defrost systems use sophisticated electronic controls that integrate analysis of several parameters (including the number of door openings, the compressor operation time and the room temperature) to optimise timing of the defrost cycle's initiation. In 2000 in Europe, there was considerable uncertainty about the scale of in situ defrost energy savings arising from the use of adaptive defrosting and from the inadequacy of the standard. The ISO 15502:2005 standard introduced a method to evaluate the impact of adaptive defrost, which is refined in the coming standard IEC 62552:2015. In the Lot 13 preparatory study[82], adaptive defrost was considered as an option, but was supposed not to be cost effective. More information has been made available in the US[81] so the option could be explored again with updated costs and performance. Savings are in the range of a few percent over the consumption of the appliances.

"Low frost" technique for static appliances

Most European appliances still use static cold. According to previous studies, "for the vast majority of European refrigerator compartments (+4 °C according to the revised standard), automatic defrosting is achieved simply by regulating the time between compressor 'on' cycles in such a manner that the evaporator temperature passively rises above 0 °C long enough for any frost to melt. This system uses no direct energy but does have implications for optimization of the compressor cooling power, percentage running time, cycle duration and evaporator configuration that can influence the overall energy efficiency. There is scope to optimize these configurations beyond the average arrangement, but the scale of savings that might be expected cannot be easily generalized."

There is little publication regarding defrost and there does not seem to be published data to evaluate the interest of defrosting options for static refrigerators, whether alternative techniques or controls.

Anti-sweat heaters

According to the Cold II study[85], "some models are equipped with electric resistance heaters that require additional direct energy consumption, but the most common

[84] MELO Cláudio, T.KNABBEN Fernando, V. PEREIRA Paula, An experimental Study on Defrost Heaters Applied to Household Refrigerators, International Refrigeration and Air Conditioning Conference, Purdue 2012.
[85] COLD II The revision of energy labelling and minimum energy efficiency standards for domestic refrigeration appliances, ADEME and PW Consulting, for the European Commission, Directorate-General for Transport and Energy, Contract no: XVII/4.1031/Z/98-269, December 2000.

solution is to pass the refrigerant discharge pipe through the insulation around the doorframe and close to the metallic shell, to prevent both dew and sticking problems. This solution creates an additional heat load into the cabinet of 2-5W but uses no direct energy and is less energy consuming than an electric resistance heater. The main disadvantage is that it delivers heat to the door seal in a way, which cannot be controlled according to real need. The option of a hot gas discharge tube embedded around the freezer door frame could be re-examined when the introduction of intelligent electronic controls enables heat loads to be reduced. In any case there is still scope to optimize the performance of these systems by careful positioning and design."

Greenblatt[81] retained an improvement option for electric anti-sweat heaters, which is to control the heat required as a function of humidity. Nevertheless, it is probably not applicable to the EU market which seems to use hot refrigerant pipes to that purpose. There is no recent information on this matter and it is then not possible to evaluate the potential improvement potential associated.

8.1.2.4 High efficiency heat exchangers

Heat exchanger efficiency

Heat exchanger heat transfer capacity (in W) can be expressed as the product of U.A (in $W.K^{-1}$, the global conductance of the heat exchanger, with A the surface area in contact with the fluids in square meters, and U the heat transfer capability of the heat transfer in $W.m^{-2}.K^{-1}$) and of the average temperature difference across the heat exchanger.

The COLD II study[85] gives typical temperature difference across condensers and evaporators at that time for B and C appliances. Typical temperature differences are 18 K at the condenser and 10 K at the evaporator for standard natural-convection designs, but are 9 K and 5 K at the condenser and evaporator, respectively, when using fans in the two examples given. It is added that high efficiency forced-air heat exchangers can lead to refrigerant-to-air temperature differences in the range of 5 to 7 K.

Table gives typical products temperature difference across the heat exchangers for recent and well-designed products[86].

	Category 1	Category 8+9	Category 7
Evaporator temperature difference (K)	15	10	8
Condenser temperature difference (K)	10	12	10

Table 14. Temperature difference across heat exchangers
(Source Janssen (2015)[86])

It is clear that the condenser temperature difference was already much reduced, from 18 K to 10 to 12 K. For categories 8 and 9, there is still limited potential to reduce the condenser temperature difference for natural convection heat exchangers. Larger gains could be reached from a shift to forced convection heat exchangers. This was an option considered for upright freezers by the US DOE[81]. Another simple option could be to add a fan to increase the air speed over the static condenser; such an option is

[86] Janssen, M., Impact of the new IEC 62552-1,2,3:2015 global standard to cold appliance energy consumption rating (second study), Re/genT Report number: 15127/CE40/V1, 13 April 2015.

probably interesting to revisit now that high efficiency electronically commutated fan motors are available.

Regarding natural-convection evaporators, there has not been much change in average, in the design temperature difference between the refrigerant and the air (still about 10 K). Here again forced convection heat changers could offer substantial gains.
There are two ways to improve heat exchanger efficiency, by increasing the heat transfer intensity (U value) (e.g. better fin pattern or using copper instead of aluminium), or by increasing the heat transfer surface (A value). Forced convection U values are much higher than for natural convection heat exchangers. Because of this larger intensity, it is possible to have larger heat exchange areas and to decrease the temperature difference. As a counterpart, it is necessary to have a fan ensuring forced convection; in addition, for evaporators, the frost accumulation will be faster (which implies specific solutions as discussed in the defrosting part).

Heat exchangers are constrained in the fridge so that it is difficult to improve the fins (because of frost accumulation inside and because of dust collection at the condenser). It is then simpler to adjust the heat exchanger surfaces.

These observations are in line with the 2007 preparatory study[82]**Error! Bookmark not defined.** improvement options which had proposed a 10-20 % increase for the evaporator surface and a more limited 5 to 10 % value for the condenser.

For forced convection heat exchangers, larger heat exchanger area requires proportionally larger air flow and consequent fan power.

Use of phase-change materials integrated into the heat-exchanger

According to previous EU studies[85], "the phase-change material, which is integrated into the heat exchanger, enables higher average evaporation temperatures to be achieved compared to a conventional heat exchanger, thereby producing significant energy savings. Additional savings can be realized by optimization of the compressor on/off cycling to take account of the accumulation of cold in the heat exchanger".
To be applied, this option requires cycling optimization and electronic control. Estimated savings were of 3 % in 2007[82] and the associated overcost is available. More recent publications suggest higher ranges of savings for this option, between 10 and 30 %[87]. Tests have been made on two A+ single refrigerators using static and forced convection evaporators[88]. Savings for using PCM at the evaporator, after cycling control optimization, are respectively of about 9 and 5 %. Simple payback times are calculated and appear to be lower than one year.

8.1.2.5 High efficiency compressors and fans

Compressors

Highest efficiency compressors in Greenblatt[81] was set at 1,83 COP (ASHRAE conditions), based on 2006 data for R-134a compressors, with lower efficiency values below about 175 W. The analysis of R-600a compressor ranges in 2015 has shown that it is feasible to reach 1.85 at 60 W nominal power and 1.9 and more from about

[87] Leducq, D. and all, Household Refrigerators and freezers with High thermal inertia, 2nd IIR International Conference on Sustainability and the Cold Chain, Paris, 2013.
[88] Y.Yusufoglu, T. Apaydin, S. Yilmaz, H.O. Paksoy, Improving Performance of Household refrigerators by Incorporating Phase Change Materials, International Journal of Refrigeration, 2015.

70 W onwards. The highest value reached is 1.98 (based on Jiaxiperi data as of 2015) in the power range between 80 and 150 W. It is thus possible to improve the COP from 1.5 (standard products) up to 1,85 above the whole domestic refrigeration range for several manufacturers.

The US study[81] gave cost increase for higher efficient compressors (Figure 24). These values should be actualized to 2015 and to the standard size of EU 2015 base cases.

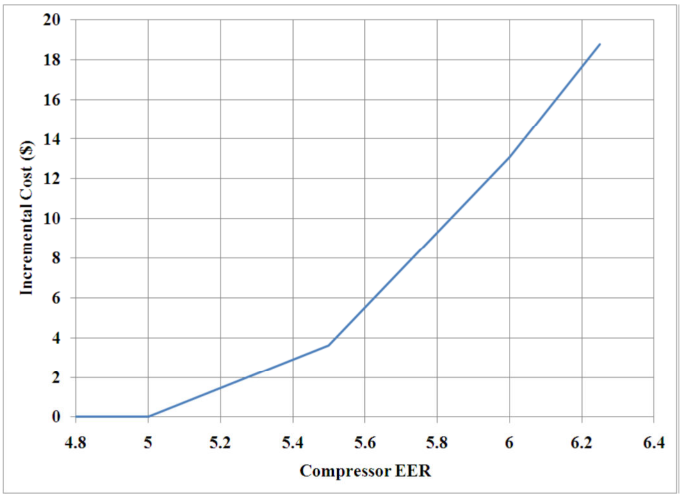


Figure 24. Cost increase of R-134a hermetic reciprocating fixed speed compressor with efficiency (EER in Btu.h-1.W-1).
(source[81] from Embraco source)

Fans

The Lot 13 preparatory study[82]. An option to reduce fan power to 4 W was studied and found cost effective for forced convection evaporators. A further option is to use a 12 V DC input, 1 W fan. However, no such fan was found available in 2005 in Europe with a sufficient mass flow rate for a no-frost appliance. But a 12 V DC input 2 W fan configuration appeared as a viable option in the US in 2008 as a condenser fan for forced convection appliance[81]; at the evaporator, 3 W was feasible. In addition, the Lot 13 preparatory study indicated a 12 V DC input 1W fan could be enough for forced air circulation compartments/ appliances to improve temperature gradient on top-of-range or tall static models.

8.1.2.6 Cycle design for two compartments fridges

There are two principal cooling system approaches for two-compartment appliances: the single-compressor, two-heat-exchanger approach; and the two-compressor, two-heat-exchanger approach[82]. The single-compressor two-heat-exchanger system efficiency is lower than the one of two-compressor two-heat-exchanger because the refrigerant temperature flowing in both heat exchangers is the same. With two compressors, the refrigerator part functions with higher evaporator temperature, which results in lower energy consumption.

An option identified previously[82], with the potential to help reaching significant gains with acceptable costs is the so-called "bi-stable solenoid valve (diverter valve)". According to the Lot 13 preparatory study[82] quoting the COLD II study[85]: *"a bistable solenoid valve is which is a 3-way valve used in association with two capillary tubes, one for each evaporator. The refrigerant flowing from the condenser can be regulated to circulate either through a cooling circuit including the freezer evaporator or through* *one including the refrigerator evaporator. One design also allows refrigerant circulation in both loops simultaneously. Tests performed at the University of Maryland indicated that energy gains of up to 8,5% could be achieved compared to a base-case model where the refrigerant mass flow goes through the two evaporators successively. One limitation of this approach is that it is not possible to optimize both the freezer and the refrigerator loops and as a result this option is less efficient than a conventional two-loop design with two compressors*".

Apparently, there is still a market for these single compressor appliances, which are of lower cost and performance than 2 compressor units. In 2007, this option was supposed to be already applied in about 30 % of the 2005 products of categories 7 and 10. The technical-economic analysis led showed that the magnitude of the gains, estimated to only 2 % did not pay off. However, it has the advantage to enable a better control of the temperature over a large ambient temperature range[75], so it is possible that the remaining part of appliances of category 7 to 10 which did not have it, already applied it with the change in climate classes that occurred these years on the market. The applicability of this option is thus still to be checked.

[An analysis of the impact of the examined options on product prices, as required by MEErP, will be done in a subsequent version when Task 5/6 will be included.]

8.1.3 Best Available Technology BAT (best of products on the market)

8.1.3.1 Best available products

The evolution of best available products on the market for the same base case categories used in the lot 13 preparatory study[82] is shown in the table below. Progression of best available products ranges from 26 to 37 %.

Table 15. Comparison of 2005 and 2015 best available products for categories 1, 7, 8, and 9 ((sources EuP Lot 13 Preparatory study[82] and topten.eu)

2005	Source **Error! Bookmark not defined.**						
	EEI (%)		Cons. (kWh)	Ref. Vol (L)	Chill vol (L)	Freezer. Vol (L)	Climate class
Refrigerator	29,7		115	300	25		16 - 43
Refrigerator-freezer	28		157	236		19	16 - 43
Chest freezer	29,3		172			195	16 - 43
Upright freezer	27,4		155			223	16 - 43

2015	Topten.eu, 2015						
	EEI (%)	EEI incr vs 2005	Cons. (kWh)	Ref. Vol (L)	Chill vol (L)	Freezer. Vol (L)	Climate class
Refrigerator	21,6	27%	71	297			10 - 43
Refrigerator-freezer	17,7	37%	130	205	67	87	10 - 43
Chest freezer	21,8	26%	109			175	10 - 43
Upright freezer	19,8	28%	136			246	10 - 43

8.1.3.2 Insulation

Vacuum Insulation Panels

VIP (Vacuum Insulation Panels) is a technology based on the reduction in conductivity which occurs in low vacuum. It enables to increase insulation without losing too much cold space. Several options have been commercially available since 2000 with different core material such as polyurethane, polystyrene, silica powder or glass fibre. Depending on material, heat conductivity varies from 2,4 mW/m/K to 9,7 mW/m/K, that is to say an insulation up to 8 times higher than conventional foam. VIPs are susceptible to punctures. Suppliers are answering this problem with more durable, protective films which are already on the market[89]. In 2012, a US technological roadmap[90] including refrigerators and freezers recommended a high priority program research to understand the variations in VIP performances (and on how to reduce the costs).

First refrigerator models using VIP in the door appeared on the European market in 2005 (few models according to 2005 preparatory study[82].Due to the high cost of the VIP, they are still in limited number on the 2015 market and only applied on products aiming at being installed in a limited space or when significant higher performance is targeted[91,91]. For that reason, they can be used only for door insulation in order to limit over costs[92].
Some manufacturers propose high end models (A +++ models) with VIP systems and communicate on them. For instance, Evonik[93] use "fumed" silica as core material which should achieve around 8 times better insulating efficiency than foams and have a lifespan about 30 years.

In the USA, VIP have been used in refrigerators for more than 20 years in high-end models and, more recently, in commodity models thanks to a tax credit[81].

Several research studies still regard this technology and its application for domestic refrigeration; the International Vacuum Insulation Symposium takes place every two years to deal with these subjects[94,95]. Works show that VIP technology allows to enhance the energy efficiency of insulating systems and provide savings in energy consumption up to 30 %. According to Yusufoglu[94], "*an optimized combination of VIPs with other energy efficient technologies can allow the appliance manufacturers to create cost effective solutions*".

Costs are given in previous studies[81,82], but should be updated as specific efforts seem to be put to reduce the costs.

To sum-up, VIP technology has been deeply tested for the past 20 years and show a significant reducing energy consumption possibility. It remains one of the BAT, the

[89] Lary Adams, Less Space, Better Insulation, Appliance design 2010. http://www.appliancedesign.com/articles/92394-less-space-better-insulation

[90] William Goetzler, Timothy Sutherland, Kevin Foley, Research & Development Roadmap for Next-Generation Appliances. Report prepared for: Oak Ridge National Laboratory, Oak Ridge, TN 37831, Managed by: UT-Battelle, LLC for the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Office, http://www.eere.energy.gov/buildings, Prepared by: Navigant Consulting, Inc. March 30, 2012.

[91] Heinemann,U., Vacuum Insulation Panels - Potentials, challenges and Applications, 11th International Vacuum Insulation Symposium, September 2013, Empa, Switzerland.

[92] Barthel Claus, Götz Thomas, Technical background and design options to raise energy efficiency and reduce environmental impact of refrigerators and freezers, Appliances Guide, Get super-efficient appliances, December 2012.

[93] Evonik Industries, a VIP refrigerator. https://www.aerosil.com/sites/lists/IM/Documents/PS-50-A-VIP-refrigerator-EN.pdf

[94] Y.Yusufoglu, Application of Vacuum Insulation Panels (VIPs) on Refrigerators, 11th International Vacuum Insulation Symposium, 2013.

[95] Brunner Samuel, Ghazi Wakili Karim and Johansson Pär, Vacuum insulation panels in refrigerator room, freezing room and fridge, 11th International Vacuum Insulation Symposium, September 2013, Empa, Switzerland.

vacuum insulated panels could be in the door or in the cabinet walls. It is to be checked if costs have decreased enough so that they become cost effective for the upper efficiency range.

8.1.3.3 Temperature and defrost management

Expansion valves

There is little impact on performance today of having more precise expansion valves than capillary tubes because appliances are tested for only one outdoor temperature condition. Manufacturers can design the capillary tube to reach a close to zero superheat level for the test ambient temperature. This is likely to change with the new IEC 62552:2015 standard. Performance will be interpolated from measurements at 32 and 16 °C. Different countries are likely to use different indoor temperatures. In order to avoid a redesign of the capillary tube for each country, manufacturers are likely to use thermostatic or electronic expansion valves in order to maintain a correct superheat over the whole temperature range. The energy efficiency gain may be zero for EU condition testing but will be substantial in real life as soon as the kitchen temperature deviates significantly from the rating conditions.

8.1.3.4 High efficiency compressors, motors and drives

Fix speed compressor

BAT COP (ASHRAE conditions) level is 1.98 for a cooling power down to 80 W, and 1.85 between 60 and 80 W nominal cooling power.

Variable speed drive compressors

Compressor on-off control leads to cycling losses of the order of magnitude of 10 %[81]. The magnitude of the losses depends on the ratio between the maximum power of the compressor (to face 43 °C ambient for SN-T climate class fridges) and the required needs at actual ambient. The lower is this ratio, the higher are the losses.
Variable speed drive compressors with Brushless DC motor are available from some time already. Their nominal efficiency lies in the same range of performance as for single speed motors, with COP between 1,5 and 1,9. One product range performance from Embraco is shown in Figure . The extension of speed reduction enables to reach about 40 % capacity through frequency change and before cycling is required.

To evaluate the gains due to variable speed adoption versus on-off cycling, it is necessary to consider:

- the change in compressor efficiency,
- the cycling losses,
- the variation of the compressor performance with frequency (including the consumption of the inverter),
- the variation of the refrigeration cycle pressures as capacity is reduced; at low refrigerant flow rates, temperature differences across condenser and evaporator are reduced; thus the compressor consumes less energy because of this lower pressure difference,
- the management of the fans in case of forced convection heat exchangers; at low loads, it may be necessary to reduce the fan speed in order to optimize the sum of the compressor and fans efficiency.

Estimated gain of 15 to 20 % has been established in the past[81,82].

In addition, variable speed drive BLDC motors now enable to reach very low power levels before cycling on and off the compressor and thus to avoid corresponding losses. Efficiency can be maintained at about 30 W at COP levels of 1.5, and 1.85 at 60 W. The minimum relative capacity that can be achieved under variable speed conditions extends down to 25 %. Depending on the compressor design, reduced speed efficiency can slightly increase or decrease, depending on the specific unit.

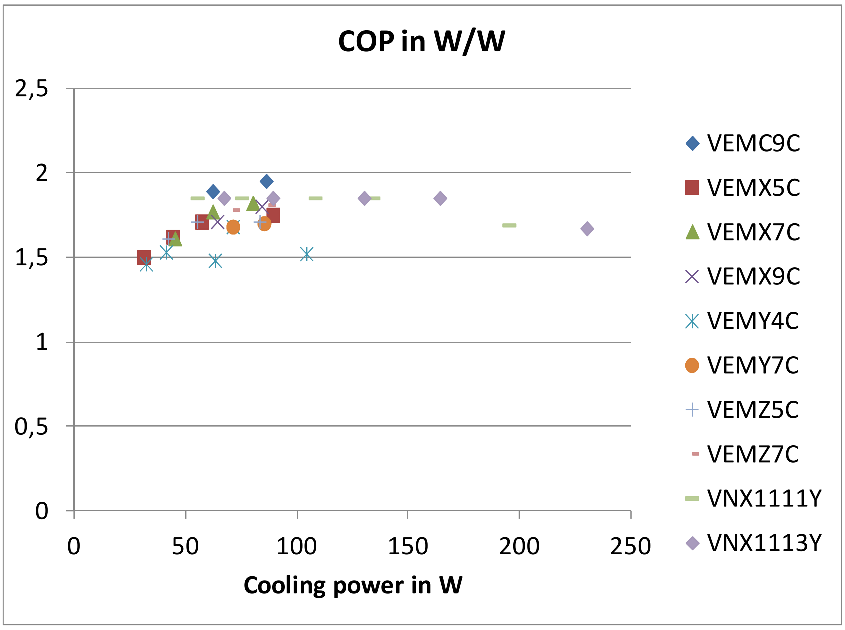


Figure 25. R-600a hermetic reciprocating variable speed compressor efficiency data
(Source: Embraco and Jiaxiperi 2015 data)

Linear compressor

Linear compressors have been developed by compressor manufacturers to avoid mechanical losses existing in the conventional crank-driven compressors. Some of them are already on the market of refrigerator, on LG models. Experimental studies such as Ku&al.[96] confirm the energy efficiency saving of this type of equipment, comparing linear compressor energy consumption with the one of brushless direct-current reciprocating compressor, both being compressors developed for refrigerators. Measures show that the linear compressor has an excellent energy efficiency and the energy consumption reduction is about 10 %, compared to a BLDC motor compressor. This is in line with another estimate of 9 %[81].

VSD fans for no frost appliance

In standard forced air convection appliances, the fan power at the evaporator and condenser sides remains constant whatever the refrigeration load is. This may limit the consumption reduction of the adoption of a variable speed drive compressor. Variable speed DC fan motor can be used in combination with variable speed drive compressors in order to solve this issue[81].

[96] Boncheol Ku, Junghoon Park, Yujin Hwang, Jaekeun Lee, Performance Evaluation of the Energy Efficiency of Crank-Driven Compressor and Linear Compressor for a Household Refrigerator, Purdue e-Pubs, 2010.

8.1.3.5 Cycle design for two-compartment fridges

One simple improvement option is to replace the 1-compressor-2-heat-exchanger arrangement with the 2-compressor one. The recent progress of compressor performance at low capacity certainly makes it more interesting now than in the past. The interest of this option is to be checked. Previous studies questioned the energy efficiency gain[81] and the cost feasibility[82].

8.1.4 Best Not yet Available Technology BNAT (best of products in field tests, labs, etc.)

NOTE: In the frame of this study, the study team will "prepare a Technology Roadmap for household refrigeration appliances, i.e. describe best available and not yet available technologies and trends in usage and markets for a time scope up to the year 2030 and beyond". The technologies below will thus be screened again in more details, including on-going and planned research. The present report simply gives a short overview of possible improvement potential.

8.1.4.1 Insulation

According to the US technical support document[81], works aiming at improving the resistivity of insulation are still carried out. Black carbon addition[97] was already studied and not adopted in the 2000s. Detailed information is not available, this point is to be confirmed.

The option of Gas filled panels (GFP) has been identified in the previous Preparatory study review[82]. This technology was developed at the LBNL (Lawrence Berkeley National Laboratory) in the 1990s[98]. It consists of thin polymer films filled with low thermal conductivity gas such as argon, krypton or xenon to create a system with high thermal insulation properties[99].

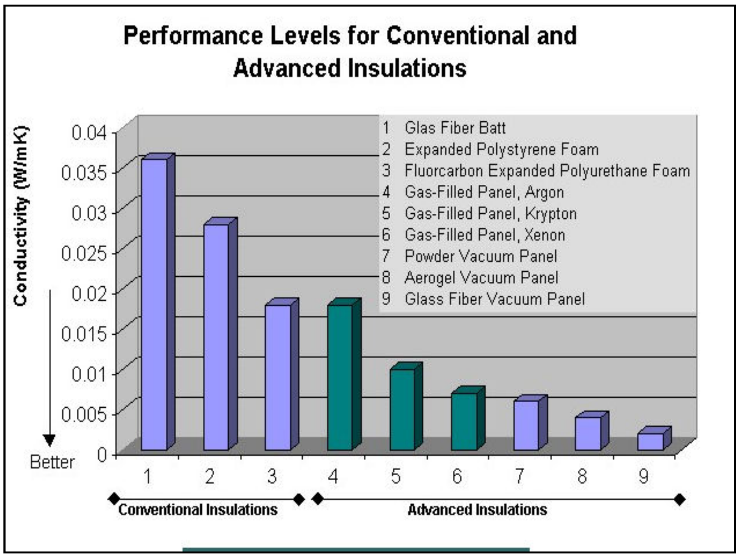


Figure 25. Comparison of thermal conductivity depending on insulation type
(source: http://gfp.lbl.gov)

97 Pisipati, J.S. and Godbey, J.A. "Performance of Carbon Black-Containing Polyurethane Foam in Domestic Refrigerators," Journal of Cellular Plastics, 1996. Vol. 32, No. 2, 108-138.
98 Griffith Brent, Aratesh Dariush, Advanced insulations for refrigerator/freezers: the potential for new shell designs incorporating polymer barrier construction, Energy and Buildings 22 (1995) pages 219, 231.
99 Gas Filled Panels high performance insulation. http://gfp.lbl.gov/default.htm

According to Berkeley Lab newsletter[100], Berkeley Lab researchers and Oak Ridge National Laboratory, performed experiments using prototype refrigerator doors and cabinets equipped with GFPs. Results showed that the use of GFPs in door panels increased the overall energy efficiency of the refrigerator by 6,5%. It is also said that "Projected savings could reach as high as 25 % when GFP insulation is used throughout the entire refrigeration cabinet as well as in the door panels". Unfortunately, we won't be able to find detailed information or a recent publication and are waiting for an answer from the researchers.

The US study[81] underlines that a significant problem of this technology is the lack of structural integrity of the product. This parameter as well as a cost which is similar to VIP could explain that no gas filled panel products have been identified in the refrigeration industry (neither prototype nor commercial products) so far. According to the US study, this technology allows less energy savings than VIP but its cost is similar and no gas filled panel products have been identified in the refrigeration industry. It is proposed not to consider this technology among BNAT anymore.

A patent[101] regarding another mean to create vacuum insulation has been filed in 2012. It deals with a vacuum insulator for parts of the refrigeration cycle of a refrigerator (suction line before the compressor, capillary tube before the evaporator, etc). It is one of the identified BNAT. It aims at improving energy efficiency but we don't know if tests have been carried out to evaluate energy consumption savings.

8.1.4.2 High efficiency compressors, motors and drives

Highest efficiency compressors in the US study[81] was set at 1,83 COP (ASHRAE conditions), based on 2006 data for R-134a compressors. Considering the 5 to 6 % advantage of isobutane compressors versus R-134a, this would translate into a COP value of about 1.94. The highest value reached is 1.93 (based on Embraco and LG data as of 2015) for two manufacturers in the power range between 80 and 100 W.

The linear compressor from LG available on the market presently uses oil, while the initial design was planned to be oil free. On oil free design could help reaching higher efficiency values. Linear free piston compressors using gas bearings are still being developed[96,102,103].

It can be noticed that linear compressors are included as a medium priority topic for further research in the US technological roadmap including refrigerators and freezers[90]. "*The recommended R&D program includes developing and testing an optimized compressor to demonstrate improved energy efficiency over currently available products.*"

8.1.4.3 Alternative cycle and technologies

Lorentz-Meutzner cycle

The idea is to use a zeotropic refrigerant mixture with a large temperature glide during evaporation in order to allow different temperatures of evaporation for the freezer

[100] Lawrence Berkeley National Laboratory. Environnemental Energy Technologies Division. News 2005. http://eetd.lbl.gov/newsletter/nl20/eetd-nl20-tt.html

[101] US Patent "Vacuum insulator for a refrigerator appliance" (US2012060543; US8365551;), March 2012.

[102] US Patent 6966761 B1 published in Nov 2005/ linear compressor with aerostatic gas bearing passage between cylinder and cylinder liner.

[103] US Patent 20110097224 A1 published in April 2011/ linear compressor.

evaporator and refrigerator evaporator mounted in a series arrangement. It appears that the energy efficiency gain is low for efficient appliances[82]. In addition, there has not been much research in this area recently and there is no fluid mixture presently identified compatible with fluid legislation.

Ejector cycle

"A typical ejector consists of a motive nozzle, a suction chamber, a mixing section, and a diffuser." "The working principle of the ejector is based on converting internal energy and pressure related flow work contained in the motive fluid stream into kinetic energy"[104]. It can be used to generate cool from low grade heat. In that direction, it can be a competitor for absorption and adsorption gas and solar machines.
It can also be used to recover the work which is lost in the expansion valve of refrigeration cycles. With the renewed interest of CO2 as a refrigerant, many publications and many patents (by Denso, for automotive air conditioning[105]) can be found. The CO2 cycle would probably lead to limited gains for traditional refrigerators and freezers, a few percent. However, a specific design has been proposed to improve the efficiency of refrigerators and freezers having two different temperature evaporators, i.e. single-compressor-two-heat-exchanger refrigerator/freezer[106]. *"The ejector cycle gives an increase of up to 12.4% in the coefficient of performance (COP) compared to that of a standard refrigerator-freezer refrigeration cycle. The analysis includes calculations on the optimum throat diameters of the ejector. The investigation on the off-design performance of the ejector cycle shows little dependency of energy consumption on constant ejector throat diameters." The cycle used to do so is presented below.*

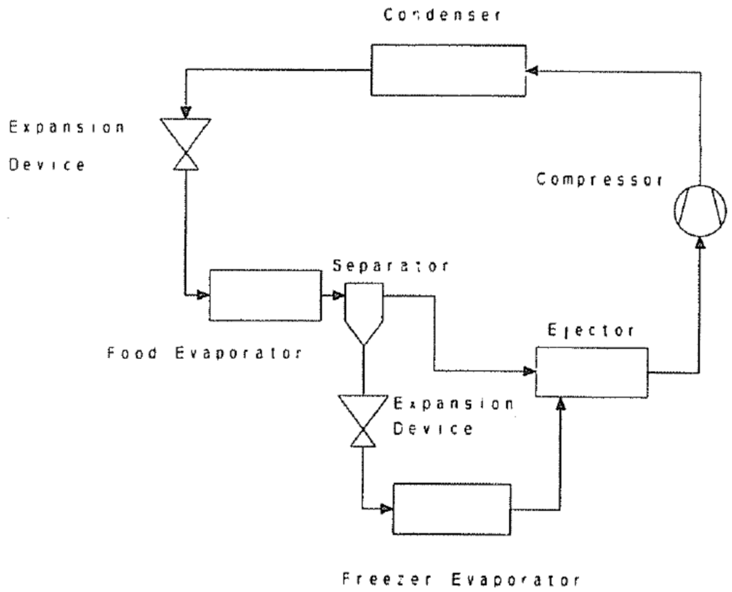


Figure 26. Scheme of a refrigerator-freezer cycle with ejector
(source: Tomasek and Radermacher, 1995)[106]

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[104] Elbel, Stefan and Hrnjak, Predrag, "Ejector Refrigeration: An Overview of Historical and Present Developments with an Emphasis on Air-Conditioning Applications" (2008). International Refrigeration and Air Conditioning Conference. Paper 884. http://docs.lib.purdue.edu/iracc/884

[105] Elbel, Stefan and Hrnjak, Predrag, "Ejector Refrigeration: An Overview of Historical and Present Developments with an Emphasis on Air-Conditioning Applications" (2008). International Refrigeration and Air Conditioning Conference. Paper 884. http://docs.lib.purdue.edu/iracc/884

[106] Tomasek M.-L., Radermacher R., 1995, Analysis of a domestic refrigerator cycle with an ejector, ASHRAE Transactions, Vol. 101, pp. 1431-1438

Thermo acoustic cooling, Pulse tube and Stirling cycles

There is no clear advantage of these alternative technologies above conventional mechanical compression cycle[85]. Stirling motors are also used in other HVAC applications, as cogeneration of heat and power, and consequently research is active. Regarding refrigerators and freezers, a comparison is given by Greenblatt[81] showing that efficiency of Stirling refrigerator is still lower than the one of conventional cycles. It can be noticed that refrigerator using Stirling cycle are included as a low priority topic for further research in the US technological roadmap including refrigerators and freezers[90]. "*The recommended R&D program is to determine the energy savings potential of a Stirling cycle refrigerator by developing and testing a working prototype.*"

Thermoelectric cooling

Thermoelectric cooling is based on the Peltier effect: when electricity circulates in a circuit including the junction of two different types' of materials, this creates a heat flux. However, the COP of thermoelectric devices is limited for the temperature difference ranges of refrigerators and freezers[85]. This limits the scope of application to niche markets including portable coolers.

Magnetic refrigeration

Unlike conventional systems, magnetic refrigeration requires a solid magnetic material as refrigerant. The operation principle of magnetic refrigerators is based on the magneto caloric effect (MCE). The MCE is an effect associated to the exposure and then the withdrawal of a magnetic material in a magnetic field. The MCE implies that the temperature of suitable materials increases when exposing to a magnetic field and decreases when it stops. By applying a magnetic field, material magnetic properties are changed and they release or take in heat, depending on whether the field is being applied or removed.

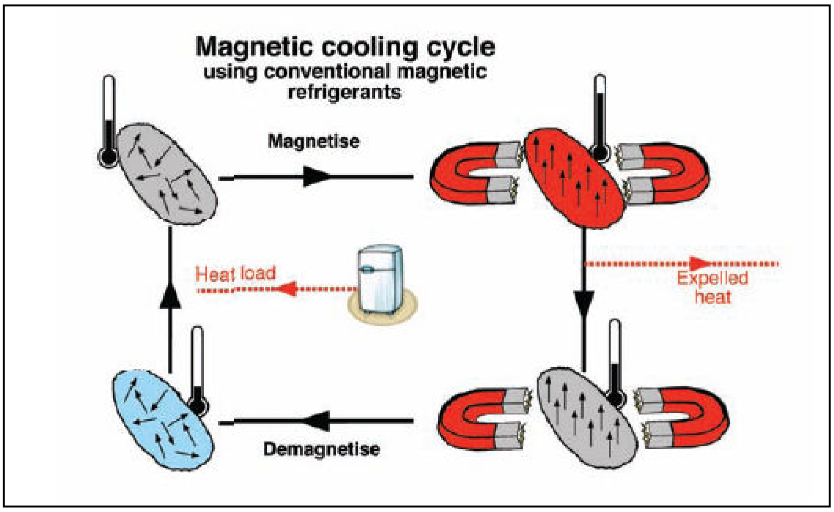

Figure 26. Magnetic refrigeration principle
Source (Sandeman, 2011)[107]

Compared with conventional refrigeration technologies, magnetic refrigeration presents advantages such as compact configuration, low noise (no compressor), high

[107] Sandeman, K., Gas free refrigeration, Magnetics Technology international, 2011.

efficiency and longevity. The thermodynamic efficiency of magnetic refrigeration can reach 30 % to 60 % of Carnot cycle theoretically, i.e. comparable and higher values than the efficiency of vapor compression refrigeration for refrigerators and freezers[108], and much higher than standard cycle for large temperature difference.
Haier, Astronautics Corporation of America and BASF presented a Wine Cooler prototype at the Consumer Electronics Show of Las Vegas in January 2015)[109]. Haier plans to introduce the technology on the market within the next couple of years[110].

Other projects regarding magnetic refrigeration possibilities:

- The ELICiT (Environmentally Low Impact Cooling Technology) Project, began in January 2014, focuses on the application of magnetic cooling technology to domestic refrigeration appliances.
- The FRISBEE project, coordinated by IRSTEA, aims at giving technological contributions to the development of the most suitable refrigeration technologies for the future. Several options regarding energy consumption reductions are studied, such as magnetic refrigeration. Project is ongoing.
- The French company Cooltech launched a fundraising campaign of € 8 million for the development of magnetic refrigeration and claims to have a staff of 30 people.
- Studies presented at the 6th International Conference on Magnetic Refrigeration at Room Temperature (Thermag VI) regard applications of magnetic refrigeration in domestic appliances such as an experimental rotary permanent magnetic refrigerator[111], or a heat transfer by liquid metal in a magnetic refrigerator[112].

It can be noticed that refrigerator using magnetic refrigeration are included as a high priority topic for further research in the US technological roadmap including refrigerators and freezers[90]. "*R&D objective is to determine the cooling capacity required for a magnetic refrigerator". "Recommended R&D Activities are: Further understand magnetic refrigeration cooling principles, Optimize individual components of the system, Test optimized prototype to demonstrate required cooling capacity.*"

8.2 To be completed

Part 8.2 (Task 4.2) and part 8.3 (Task 4.3) are to be completed at a later stage.

8.2 Production, distribution and end-of-life, specifically regarding

8.2.1 Product weight and Bills-of-Materials (BOMs), preferably in EcoReport format (see Task 5)
8.2.2 Assessment of the primary scrap production during sheet metal manufacturing
8.2.3 Packaging materials
8.2.4 Volume and weight of the packaged product

[108] Yu, B.F., Gao, Q., Zhang, B., Meng, X.Z., Chen, Z., 2003. Review on research of room temperature magnetic refrigeration, International Journal of Refrigeration 26
[109] Consumer Electronics Show, Prototype Wine Cooler using magnetic refrigeration. Las Vegas, January 2015
[110] http://www.chemistryviews.org/details/news/7261611/Prototype_of_Magnetocaloric_Wine_Cooler.html

[111] Aprea, C., Cardillo, G., Greco, A., Design and construction of an experimental rotary permanent magnet magnetic refrigerator, September 2014.

[112] Tomc,U., Kitanovski, A., Tusek, J., Experimental analysis of a liquid metal as a heat transfer fluid in a magnetic refrigerator, September 2014.

8.2.5 Actual means of transport employed in shipment of components, sub-assemblies and finished products[44]
8.2.6 Materials flow and collection effort at end-of-life (secondary waste), to landfill/ incineration/ recycling/ re-use (industry perspective)
8.2.7 Technical product life (time-to-failure of critical parts)

8.3 Recommendations for

8.3.1 Refined product scope from the technical perspective (e.g. exclude special applications for niche markets)
8.3.2 Barriers and opportunities for Ecodesign from a technical perspective
8.3.3 The typical design cycle for this product and thus approximately appropriate timing of measures

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ANNEX A: Definitions IEC 62552-1[113]

1. General terms and definitions

1.1
refrigerating appliance
insulated cabinet with one or more **compartments** that are controlled at specific temperatures and are of suitable size and equipped for household use, cooled by natural convection or a forced convection system whereby the cooling is obtained by one or more energy-consuming means
Note 1 to entry: From the point of view of installation, there are various types of household ***refrigerating appliances*** *(free-standing, portable, wall-mounted, built-in, etc.).*
1.2
refrigerator
refrigerating appliance intended for the storage of **foodstuff**, with at least one **fresh food compartment**
1.3
refrigerator-freezer
refrigerating appliance having at least one **fresh food compartment** and at least one **freezer compartment**
1.4
frost-free refrigerating appliance
refrigerating appliance in which all **compartments** are automatically defrosted with automatic disposal of the defrosted water and at least one **compartment** is cooled by a **frostfree** system
1.5
freezer
refrigerating appliance with only **frozen compartments**, at least one of which is a **freezer compartment**
1.6
wine storage appliance
refrigerating appliance that has no **compartment** other than one or more **wine storage compartment**(s)
Note 1 to entry: An appliance containing any compartments which do not fulfil all requirements as specified for wine storage compartments under Annex G cannot be categorised as a wine storage appliance.
1.7
built-in appliance
refrigerating appliance intended to be used whilst fastened in an enclosure or secured in a prepared recess in a wall or similar location
1.8
foodstuff
food and beverages intended for consumption
1.9
rated
value declared by the manufacturer (e.g. **volume, energy consumption**, usage)
1.10
normal use
operation when the **refrigerating appliance** is subjected to a range of different conditions that could occur during use including operation in a range of:
– indoor temperatures (including those defined in the Storage Test, see Clause 6 of IEC 62552-2:—),
– different humidity levels and
– user-related actions, such as door openings (which may be regular, infrequent or a mixture thereof) and the addition and removal of **foodstuff** or other stored items

2. Terms and definitions related to refrigerating system

2.1
refrigerant
fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and at a low pressure of the fluid and rejects heat at a higher temperature and at a higher pressure of the fluid, usually involving changes of phase of the fluid

[113] For copyright reasons the definitions are taken from early drafts. Differences with the published IEC standard may occur and should be checked.

2.2
condenser
heat exchanger from which heat in the **refrigerant** is rejected to an external cooling medium (usually the air surrounding the appliance)
2.3
evaporator
heat exchanger which absorbs heat from the **compartment** to be refrigerated and transfers this to the **refrigerant**

3. Compartments and sections

3.1
compartment
enclosed space within a **refrigerating appliance**, which is directly accessible through one or more external doors, which may itself be divided into **sub-compartments**
*Note 1 to entry: The requirements for the following **compartment** types are specified in Table 2 of IEC 62552-2:— and Table 1 of IEC 62552-3:—*
*Note 2 to entry: Throughout this standard, unless specified otherwise, "**compartment**" shall be taken to mean **compartment** and/or **sub-compartment** as appropriate for the context.*
3.2
sub-compartment
permanent enclosed space within a **compartment** which has a different operating temperature range from the **compartment** within which it is located
3.3
convenience feature
enclosure, or a container (either fixed or removable by the user), in which suitable storage conditions are provided for designated types of **foodstuff**
*Note 1 to entry: These conditions may be different from those of the **compartment** in which it is located.*
3.4
variable temperature compartment
compartment intended for use as two (or more) alternative **compartment** types (e.g. a **compartment** that can be either a **fresh food compartment** or **freezer compartment**) and which is capable of being set by a user to continuously maintain the operating temperature range applicable for each **compartment** type claimed
*Note 1 to entry: A **compartment** intended for use as a singl e type but that can also meet additional types (e.g. a chill compartment that may also fulfil **zero-star** requirements) is not a **variable temperature compartment.***
3.5
freezer compartment
compartment that meets **three-star** or **four-star** requirements
*Note 1 to entry: In certain instances, **two-star sections** and/or **sub-compartments** are permitted within the **compartment.***
3.6
fresh food compartment
compartment for the storage and preservation of unfrozen **foodstuff**
3.7
cellar compartment
compartment for the storage of **foodstuff** at a temperature that is warmer than that of a **fresh food compartment**
3.8
pantry compartment
compartment for the storage of **foodstuff** at a temperature that is warmer than that of a **cellar compartment**
3.9
chill compartment
compartment for the storage of highly perishable **foodstuff**
3.10
ice-making compartment
compartment specifically for the making and storage of ice
*Note 1 to entry: an **ice-making compartment** is classified as a **zero-star compartment** or a **frozen compartment**.*
3.11
ice mould
form in an automated icemaker which is automatically filled with water and from which the ice cubes are automatically ejected
3.12
ice cube tray
removable tray which is manually filled with water and from which ice cubes are manuallyejected
*Note 1 to entry: **Ice cube trays** with water are used as load in order to determine **load processing efficiency**. See Annex G of IEC 62552-3:—.*

3.13
zero-star compartment
compartment in which the temperature is not warmer than 0 °C that can be used for themaking and storage of ice but is not suitable for the preservation of highly perishable **foodstuff**
3.14
wine storage compartment
compartment specifically for the storage and maturation of wine
Note 1 to entry: Temperature requirements for ***wine storage compartments*** *are specified in Annex G.*
3.15
unfrozen compartment
any of the following **compartment** types: **zero-star, chill, fresh food, cellar, wine storage** or **pantry**
Note 1 to entry: although ***ice-making compartments*** *and* ***zero star compartments*** *operate below zero, they areconfigured as* ***unfrozen compartments*** *for energy and performance tests in this standard.*
3.16
frozen compartment
any of the following **compartment** types: **one-star, two-star, three-star, four-star**
Note 1 to entry: ***frozen compartments*** *are classified according to temperature, see 3.16.1 to 3.16.4.*
3.16.1
one-star
compartment where the **storage temperature** is not warmer than –6 °C
3.16.2
two-star
compartment where the **storage temperature** is not warmer than –12 °C
3.16.3
three-star
compartment where the **storage temperature** is not warmer than –18 °C
3.16.4
four-star
compartment where the **storage temperature** meets **three-star** conditions and where the minimum **freezing capacity** meets the requirements of Clause 8 of IEC 62552-2:—
Note 1 to entry: In certain instances, ***two-star sections*** *and/or* ***sub-compartments*** *are permitted within a* ***four-star compartment.***
3.17
two-star section
part of a **three-star** or **four-star compartment**, which is not self-contained (i.e., does not have its own individual access door or lid) and which meets **two-star** requirements
Note 1 to entry: Any ***two-star*** *section in the* ***compartment*** *shall not exceed 20 % of the total* ***compartment volume****.*
3.18
vegetable drawer or crisper
convenience feature provided primarily to retard dehydration of fruits and vegetables
Note 1 to entry: A ***vegetable drawer*** *is usually considered as a removable* ***convenience feature*** *but is normally left in situ for testing purposes.*

4 Physical aspects and dimensions

4.1
top-opening type
refrigerating appliance in which the **compartment**(s) are accessible from the top (usually via a lid)
4.2
upright type
refrigerating appliance in which the **compartment**(s) are accessible from the front
4.3
overall dimensions
space taken up by the **refrigerating appliance** (height, width and depth) with doors or lids closed
4.4
space required in use
space taken up by the **refrigerating appliance** (height, width and depth) necessary for **normal use** with doors or lids closed, including space necessary for air circulation and any handles, as shown in Figure …
4.5
overall space required in use
total space taken up by the **refrigerating appliance** (height, width and depth) necessary for **normal use** with doors or lids open, as shown in Figure …
4.6
volume
space within the inside liner of the **refrigerating appliance**, or a **compartment** or **sub compartment** as determined in IEC 62552-3

4.7
shelf
horizontal surface on which **foodstuff** can be placed
*Note 1 to entry: A **shelf** can be formed by one component or by components fitted side by side, which can be fixed or removable.*
4.8
load limit
surface enveloping a storage space and intended for the storage of **foodstuff** or other items
*Note 1 to entry: A **load limit** may be a natural obvious feature or a marked line.*
4.9
storage plan
arrangement of test packages within a **refrigerating appliance** when testing specific aspects of performance in accordance with this standard

5. Terms and definitions relating to performance characteristics

5.1
energy consumption
energy used by a **refrigerating appliance** over a specified period of time or for a specified operation as determined in accordance with IEC 62552-3 stated in kWh (kilowatt hour
5.2
average power consumption
average rate of **energy consumption** of a **refrigerating appliance** for a specific test condition or operation as determined in accordance with IEC 62552-3 measured in watt (W)
5.3
storage temperature
temperature which the **refrigerating appliance** is capable of maintaining in accordance with 6.5 of IEC 62552-2:—
5.4
target temperature
reference **compartment** temperature which is used for determining energy and **average power consumption** attributes in IEC 62552-3
*Note 1 to entry: **Target temperatures** are air temperatures. See Annex D.*
5.5 Defrosting
5.5.1
automatic defrost
defrosting where no action is necessary by the user to initiate the removal of frost accumulation at all **temperature-control settings** or to restore normal operation, and the disposal of the defrost water is automatic
5.5.2
manual defrost
defrost that is not an **automatic defrost**
5.5.3
cyclic defrost
automatic defrost system where the refrigerated surfaces which cool a **compartment** (usually an **unfrozen compartment)** in an appliance are automatically defrosted and defrosting occurs during each cycle of the refrigeration system
*Note 1 to entry: **Cyclic defrost** systems do not have a **defrost control cycle.***
5.5.4
variable defrost
automatic defrost system designed to minimise **energy consumption** which adjusts the time intervals between successive defrosts under **normal use** to better match the actual frost load on the **evaporator** by the assessment of an operating condition (or conditions) other than, or in addition to, elapsed time or compressor run time
*Note 1 to entry: Demand defrost, (directly measuring the frost on the **evaporator** and defrosting accordingly) is a form of **variable defrost.***
5.6
stable operating conditions
conditions in which a **refrigerating appliance** mean temperatures and **energy consumption** comply with the relevant stability requirements as defined in IEC 62552-2 or IEC 62552-3 as applicable
5.7
steady state
stable operating conditions that meet the criteria as specified in Annex B of IEC 62552-3:—
5.8
ambient temperature
measured temperature in the space surrounding the **refrigerating appliance** under test
*Note 1 to entry: The **ambient temperature** for each test type is measured as specified in Annex A of this Part and its value is as specified in IEC 62552-2:— and IEC 62552-3:— of this standard as applicable for the particular test.*

5.9
control event
change in operating conditions
Note 1 to entry: ***Control events*** *include but are not limited to—*
a) starts, stops or speed changes of compressors;
b) changes of baffle position, fan operation, or other modulating control or device;
c) changes in operation of the ***refrigerant*** *circuit;*
d) defrost heater on and off;
e) icemaker operation.
5.10
frost-free
automatic defrost system to prevent the permanent formation of frost on a remote **evaporator** or **evaporators**
5.11
temperature control
device that is intended to automatically regulat e the temperature within one or more **compartments**
Note 1 to entry: Unless otherwise stated, a two position (e.g. open or closed) control is not included within the meaning of a ***temperature control*** *.*
5.12
user-adjustable temperature control
temperature control intended for adj ustment by the user to vary the temperature within one or more **compartments** within a **refrigerating appliance**
5.13
temperature control setting
setting of a **user-adjustable temperature control** selected for the measurement of energy or performance in accordance with this standard.
5.14
cooling time
time taken for a specified load in a **fresh food compartment** to be cooled as defined in Clause 7 of IEC 62552-2:—
5.15
cooling capacity
rate at which a specified load in a **fresh food compartment** can be cooled as defined in Clause 7 of IEC 62552-2:—
5.16
freezing time
time to freeze in a **freezer** or **freezer compartment** a set amount of load as defined in Clause 8 of IEC 62552-2:—
5.17
freezing capacity
rate of heat extraction by the refrigeration system from a load in a **freezer** or **freezer compartment** as defined in Clause 8 of IEC 62552-2:—
5.18
ice-making capacity
quantity of ice the **refrigerating appliance** is capable of producing in an automatic icemaker in accordance with Clause 9 of IEC 62552-2:—
5.19
temperature rise time
time taken, after the operation of the refrigerated system has been interrupted, for the temperature to increase a defined amount when tested as specified in Annex C of IEC 62552-2:—
5.20
ballast load
combination of test and M-packages already at **storage temperature** and in the **freezer** or **freezer compartment** when the **light load** is added during the **freezing capacity** test
5.21
light load
combination of test and M-packages at **ambient temperature** that are loaded into a **freezer compartment** during the **freezing capacity** test

6 Operating states as shown in Figure 1

6.1
temperature control cycle
definite repetitive swings in temperature caused by operation of a **temperature control** device (on/off or otherwise)
Note 1 to entry: The period of a ***temperature control cycle*** *is the time between a* ***control event*** *and its repetition on the next cycle. Where the* ***control events*** *cannot be discerned, the period of a* ***temperature control cycle*** *is the time between two successive temperature warmest points or two successive temperature coldest points.*
6.2
defrost control cycle

period commencing at the end of **stable operating conditions** prior to the initiation of an **automatic defrost** and terminating at a like point prior to the next **automatic defrost**

*Note 1 to entry: The commencement and finish points of the **defrost control cycle** prior to **automatic defrosting** shall be:*

*a) for a refrigerating system with on/off cycles, the period commencing at the end of the last regular **temperature control cycle** (for example the end of last off period);*

b) for a refrigerating system without on/off cycles but with regular temperature cycles, at the last power /speed/ cooling change that relates to a regular temperature maximum; and

c) for a refrigerating system without on/off cycles and without regular temperature cycles, at the end of stable temperature operation.

*Note 2 to entry: **Cyclic defrost** systems do not have a **defrost control cycle.***

6.3

defrosting operation

period from the initiation of a **defrost control cycle** until the initiation of the refrigeration system cooling after defrosting

6.4

defrost and recovery period

period from the initiation of a **defrost control cycle** until **stable operating conditions** are established

Note 1 to entry: For products that do not reach **stable operating conditions** (for example that have a temperature that is continually decreasing after a **defrosting operation**), the **defrost and recovery period** could be equal to the **defrost control cycle**.

6.5

recovery period

period from the end of the **defrosting operation** until the end of the **defrost and recovery period**

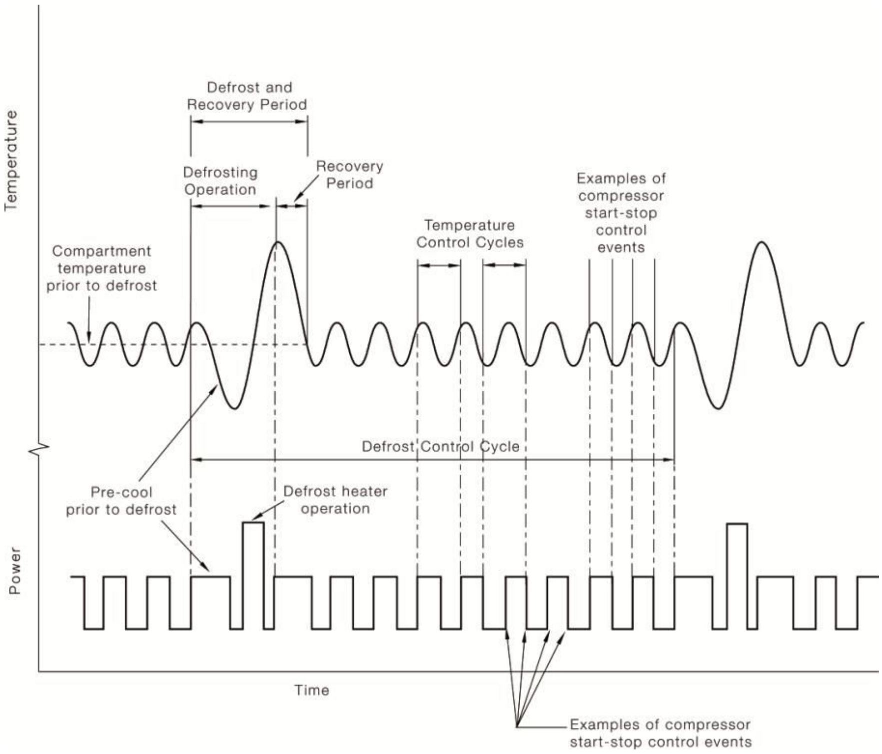

Figure 1 – Illustration of selected definitions

7 Symbols

TMP temperature measurement point

T temperature

t time

i subscript representing a certain sensor location

ANNEX B: COP shift

The table below calculates the COP shift for a refrigerator, using the numbers mentioned in the key formula of Chapter 4.[114]

Table . Calculation of COP shift for regime 5/25 (real test) to regime 4/25 (interpolated from 4/16 and 4/32)

Row	Ta→	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	refrigerator Tref=4°C																	
A	**COP(Tref=4°C)**	4.25	4.14	4.03	3.93	3.84	**3.75**	**3.66**	3.57	3.50	**3.42**	3.35	3.28	3.21	3.15	3.08	3.02	2.97
B	**weight F**	*1.00*	*0.94*	*0.88*	*0.81*	*0.75*	*0.69*	*0.63*	*0.56*	*0.50*	*0.44*	*0.38*	*0.31*	*0.25*	*0.19*	*0.13*	*0.06*	*0.00*
C	**lin. interpol.**	4.25	4.17	4.09	4.01	3.93	3.85	3.77	3.69	3.61	3.53	3.45	3.37	3.29	3.21	3.13	3.05	2.97
	refrigerator Tref=5°C																	
D	**COP(Tref=5°C)**	4.39	4.27	4.16	4.05	3.95	3.85	3.76	3.67	3.59	3.51	3.43	3.36	3.29	3.22	3.16	3.10	3.04
E	**lin. interpol.**	4.39	4.30	4.22	4.13	4.05	3.96	3.88	3.80	3.71	**3.63**	3.54	3.46	3.37	3.29	3.21	3.12	3.04

Row notes:

E	Assume the refrigerator has a COP of 3.63 in a direct test at 5/25 regime (Tref=5°C, Tambient=25°C),
D	If the COP of that same refrigerator would have been tested at 16 and 32 degrees and then, through linear interpolation, the calculated COP at 5/25 would have been 3.51 (3.4% lower).
C	Now we lower Tref to 4 deg and we find a COP of 3.53, that could be expected if a real test was done at 4/25 regime, instead of 3.63.
A	But the test is not done at a 4/25 regime, but calculated with linear interpolation from a test at 4/16 and 4/25 and thus COP is still some 3% lower at 3.42.
B	To obtain an F factor that equals the original 3.63 one would have to use F=0.6 (an interpolation temperature of 22.3 °C)

Overall 6-7% <u>more</u> energy can be expected from the lower COP at 4/25 regime interpolated test results (from real 4/16 and 4/32 tests) versus a real test at 5/25 regime.

[114] For Tref=4°C: $COP(T_a)=0.6\cdot[(4-15)+273.15]/[(T_a+10)-(4-15)]=157.29/(T_a+21)$. Likewise for Tref=5°C: $COP(T_a)= 0.6\cdot[(5-15)+273.15]/[(T_a+10)-(5-15)]=157.89/(T_a+20)$

Table . Calculation of COP shift for regime -19/25 (real test) to regime -18/25 (interpolated from 4/16 and 4/32)

Row	Ta→	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
	freezer Tref=-18°C																	
A	**COP(Tref=4°C)**	2.36	2.32	2.29	2.25	2.22	2.18	2.15	2.12	2.09	**2.06**	2.03	2.00	1.97	1.95	1.92	1.90	1.87
B	**weight F**	*1.00*	*0.94*	*0.88*	*0.81*	*0.75*	*0.69*	*0.63*	*0.56*	*0.50*	*0.44*	*0.38*	*0.31*	*0.25*	*0.19*	*0.13*	*0.06*	*0.00*
C	**lin. interpol.**	2.36	2.33	2.30	2.27	2.24	2.21	2.18	2.15	2.12	2.09	2.06	2.02	1.99	1.96	1.93	1.90	1.87
	freezerTref=-19°C																	
D	**COP(Tref=5°C)**	2.31	2.28	2.24	2.21	2.17	2.14	2.11	2.08	2.05	2.02	1.99	1.96	1.94	1.91	1.89	1.86	1.84
E	**lin. interpol.**	2.31	2.28	2.25	2.22	2.19	2.16	2.13	2.11	2.08	**2.05**	2.02	1.99	1.96	1.93	1.90	1.87	1.84

Based on:
freezer Tref=-18°C: $COP(T_a)=0.6\cdot[(-18-15)+273.15]/[(T_a+12)-(-18-15)]=144.09/(T_a+45)$
freezerTref=-19°C: $COP(T_a)=0.6\cdot[(-19-15)+273.15]/[(T_a+12)-(-19-15)]=143.40/(T_a+46)$

Overall 0.5% less energy (COP 2.05 versus 2.06) can be expected from the lower COP at -18/25 regime interpolated test results (from real 4/16 and 4/32 tests) versus a real test at -19/25 regime, whereby it is assumed that for a temperature of -18 °C inside the warmest package an air temperature of -19°C is required. The corrected F factor will be around 0.44.

For refrigerator-freezers the COP shift will depend very much on the proportion of the relative volumes, the temperature control (one or two thermostats) and possible defrosting. An overall increase of the energy of 2-7% from the COP shift, as indicated by CECED, is plausible.

Note that the above calculates the effect of the COP shift only, i.e. excluding the increase or decrease of the heat load.

ANNEX C: Bills of Material

Table . Household refrigeration appliances: Bills of Materials (BOM)

	COLD1	COLD7	COLD8	COLD9	
net volume (litres)	**223**	**277**	**178**	**254**	All without no-frost,
gross volume (litres)	**230**	**294**	**202**	**260**	Refrigerant R600a,
Noise(dB)	**38**	**40**	**40**	**42**	Blowing agent
categories	**1-6**	**7&10**	**8**	**9**	cyclopentane,
Material/component mass→	**g**	**g**	**g**	**g**	EcoReport Category
PRODUCT					**3-Ferro**
Iron	8956	16118	10529	15766	23-Cast iron
Mixed steel+plastic	57	7	613	170	22-St tube/profile
Stainless Steel	63	867	43	0	25-Stainless 18/8 coil
Steel other	2373	1385	1368	1859	22-St tube/profile
Steel strip	9944	12640	12807	9459	21-St sheet galv.
Total ferro	***21392***	***31017***	***25360***	***27254***	
					4-Non-ferro
Al	945	1355	721	3360	26-Al sheet/extrusion
Cu tube	1847	1910	1641	1242	30-Cu tube/sheet
Cu wiring 230V	275	275	275	275	29-Cu wire
Total non-ferro	***2792***	***3265***	***2362***	***4602***	
					1-BlkPlastics
ABS	775	848	1015	206	10-ABS
EPS - Insulation	3	39	2	0	6-EPS
HDPE	56	86	589	53	2-HDPE
PP	950	1563	1902	883	4-PP
PS	5837	8981	10485	2310	5-PS
PVC	352	355	537	2117	8-PVC
SAN	0	0	1252	0	9-SAN
Elastomers (NBR)	76	211	60	48	1-LDPE
Total bulk plastics	***8049***	***12083***	***15843***	***5617***	
					2-TecPlastics
PA	58	20	56	43	11-PA 6
PC & POM	26	10	21	10	12-PC
PU Foam - Insulation	3843	6280	6627	6081	15-Rigid PUR
PUR	2153	1728	2017	2285	15-Rigid PUR
Total tech. plastics	***6080***	***8038***	***8721***	***8419***	
					5-Coating
Coating	***65***	***200***	***144***	***100***	39-powder coating
					6-Electronics
Capacitor	2	20	11	8	44-big caps & coils
PWBs, switches, lamp	84	157	244	27	98-controller board
Thermostat	149	147	90	134	98-controller board
Total electronics	***235***	***324***	***345***	***169***	
					7-Misc.
Glass	5	6276	0	0	54-Glass for lamps
Paper	197	274	185	120	57-Office paper
Total misc.	***202***	***6550***	***185***	***120***	
					Other
Lubricating oil	140	190	170	250	
Refrigerant	33	49	65	83	
Other*					
Total other	***140***	***190***	***170***	***250***	
TOTAL PRODUCT	**38955**	**61667**	**53130**	**46531**	
Cardboard	1444	2673	1935	1472	57-Cardboard
EPS	1034	1257	1046	1729	6-EPS
LDPE foil	248	257	328	542	1-LDPE
PP	31	35	48	64	4-PP
TOTAL PACKAGING	**2757**	**4222**	**3357**	**3807**	
TOTAL PRODUCT & PACKAGING	**41712**	**65889**	**56487**	**50338**	

* e.g. Plastics not specified (60-80 g), Adhesive tape(10-14 g), Dessicant (2g), Glue (5 g), Magnet (46 g), Thermopaste , Others (3 g)

Source: VHK (revisit of ENEA/ ISIS, Preparatory Study Ecodesign Lot 13: Domestic Refrigerators & Freezers, Task 5 (rev.3) final report, October 2007.