Ecodesign & Labelling Review
Household Refrigeration

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

Task 1-6 report

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Acronyms, units and symbols

Acronyms

a	year (annum)
***(*)	3/4 star freezer. Stars relate to Tc (-6, -12, -18 °C= *, **, ****) and for a 3-star with specific freezing capacity 4 star ***(*)
A+, A++, A+++	current energy label class denominations
AC/DC	Alternating/Direct Current
AHAM	US Association of Home Appliance Manufacturers
ANSI	American National Standards Institute
AP	Acidification, kt SO2 equivalent
ARMINES	Mines ParisTech, Energy and Process Department, FR (author)
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
avg.	average
BAT	Best Available Technology
BAU, BaU	Business-as-Usual (baseline without measures)
BC	Base case (average for a category)
BEP	Break-Even Point (not to confuse with bep, best efficiency point, in reports and regulations for other Ecodesign products)
BI	Built-In
BNAT	Best Not Yet Available Technology
BOM	Bill-of-Materials
Cat.	category
CECED	European Committee of Domestic Equipment Manufacturers
CECOMAF	Eurovent Certification scheme
CFC-12	dichlorodifluoromethane (Freon-12, refrigerant with high ODP, now banned)
CIRCA	Communication and Information Resource Centre
CLC, Cenelec	European Committee for Electro-technical Standardization
COP	Coefficient of Performance
C_5H_{10}	cyclopentane, blowing agent for PUR foam
DG	Directorate-General (of the EC)
DoC	Document of Conformity
DoE	US Department of Energy
EC	European Commission
EEI	Energy Efficiency Index
EIA	Ecodesign Impact Accounting (Study for the EC, 2014)
EN	European Norm
EoL	End-of-Life
EU	European Union
FAO	Food and Agricultural Organisation (of the United Nations, UN)
FF	Frost-Free
GHG	Greenhouse Gases
GWP	Global Warming Potential, in Mt CO_2 equivalent
haz.	hazardous
HM	Heavy Metals
ICSMS	Information and Communication System on Market Surveillance
IEC	International Electro-technical Committee
ISO	International Standardisation Organisation

JIS	Japanese Industrial Standard
JRC	Joint Research Centre (of the EC)
LBP	Low Back Pressure
LCC	Life Cycle Costs, in euros
LLCC	(design option with) Least Life Cycle Costs
MEErP	Methodology for Ecodesign of Energy-related products
MEPS	Minimum Efficiency Performance Standard
msp	manufacturer selling price
NF, FF	No Frost, Frost-Free, auto-defrost, not 'static'
NGO	non-governmental organization
ODP	Ozone Depletion Potential
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter (fine dust)
POP	Persistent Organic Pollutants
PS	polystyrene (inner-liner, packaging)
PUR	poly-urethane (foam)
PWF	Present Worth Factor
R/RF/W/Fu/Fc	Category denomination proposed by CECED: Refrigerator, Refrigerator Freezer, Wine storage, Freezer upright, Freezer chest. With suffix 'b' it relates to built-in appliances.
R600a	iso-butane (no ODP, very low GWP refrigerant)
RAPEX	EU Rapid Alert System
Re/genT	Refrigeration expert, NL (consultant for CECED)
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals (Regulation)
RoHS	Restriction of Hazardous Substances (directive)
SME	Small and Medium-sized Enterprise
SPB	Simple Payback period, in years
TC	Technical Committee (in ISO, CEN, etc.)
TR	Technical Report
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
VAT	Value Added Tax
VHK	Van Holsteijn en Kemna, NL (author)
VIP	Vacuum Insulation Panel
VITO	Vlaams Instituut voor Technologisch Onderzoek, BE (contract-manager)
VM	Viegand Maagøe, DK (review)
VOC	Volatile Organic Compounds
WEEE	Waste of electrical and electronic equipment (directive)
WG	Working Group (of a TC)
WI	Wuppertal Institute, DE (review)
yr	year

Units

P-,T-,G-, M-,k-, d-, c-, m-, μ-, n-	Peta-, Tera-, Giga-, Mega-, kilo-, deci-, centi-, milli-, micro-, nano- : parameter prefixes to indicate 10^15, 10^12, 10^9, 10^6, 10^3, 10^-1, 10^-2, 10^-3, 10^-6
CO2, CO_2	Carbon dioxide (reference for GWP)
J	Joule, SI-unit of energy

g	gramme, SI-unit of weight
h	hour, unit of time (3600 s)
Hg	Mercury equivalent (reference for HM emissions to water)
i-Teq	reference for emissions of POP
K	(degree) Kelvin
kW	kilo Watt, 10^3 W
L, ltr	litres (volume in m^3)
m	meter, SI-unit of length
m^2	square meter, unit of surface
m^3	meter cube, unit of volume
Mt	MegaTonne (10^6 metric tonnes, 10^9 kg)
Ni	Nickel (reference for emissions of HM to air and PAHs)
PO4, PO_4	Phosphate (reference for Eutrophication)
s	second, SI-unit of time
t	metric tonne
TWh	Tera Watt hour 10^{12} Wh
W	Watt, SI-unit of power (1 W= 1 J/s)
Wh	Watt-hour, unit of energy (1 Wh=3600 J)

Symbol	**Parameter**
A	'Auto-defrost' compensation factor
A	Refrigerator envelope surface (m^2), usually with suffix
a	Air passage height below unit (m)
A_{cd}	Condenser area (m^2)
AE, AEC, E	Annual Energy consumption, in kwh/a
B	Built-in compensation factor
b	Height & depth compressor area (m)
c	Suffix for compartment-specific parameters
C	Combi-factor
COP	COP value with actual Tev and Tcd
COP_{cyc}	Avg. Cop actual tev and tcd & cycling loss
COP_{nom}	Nominal compressor COP at -23.3/54.4 °C, sub-cooling 32.2 °C
Cycling loss	Part load losses (in % COP)
D	Multidoor compensation factor
d	Depth (m)
E_{16}	Daily energy consumption, in kwh/d, at 16 °C ambient test
E_{32}	Daily energy consumption, in kwh/d, at 32 °C ambient test
E_{aux}	Electricity CPU and possible fan (kwhel/a)
E_{daily}	Daily (24h) energy consumption E_{daily}, in Wh
$E_{loss\ tot}$	Annual heat energy loss (kwh_{th}/a)
eq	Suffix, means 'equivalent' for compartment
F, f	Regional weighting factor between E_{16} and E_{32}, implicitly determines average ambient temperature

h	Height (m)
k	Heat conductivity (W/mk)
k	Heat conductivity, in W/mk
L_{dr}	Length of door perimeter
Load factor	Ratio of heat load to cool power
M, N	Correction parameters for equivalent volume
P	Power, in W
Pc	Cool power (W)
P_{door}	Door heat loss $L_{dr}*U_{door}$ (W)
P_{loss_tot}	Total heat power loss $P_{trans} + P_{door}$ (W)
P_{nom}	Nominal compressor cooling power (W)
P_{trans}	Transmission heat loss (W)
q	Specific electricity consumption, in kwh/litre net volume
R^2	R-square, measure for confidence level of a regression
r_c	Compartment temperature correction (for Veq)
SAE, SAEC	Standard Energy consumption, in kwh/a
T	Temperature
t	Parameter: wall thickness ; unit: metric tonne (1000 kg)
t	Average wall thickness (m)
T_a	Ambient temperature (°C)
T_a	Ambient temperature (during tests)
T_c	Compartment temperature (°C)
T_{cd}	Condenser temperature (°C)
T_{cold}	Evaporator temperature inside the compartment (°C)
T_{ev}	Evaporator temperature (°C)
T_{ref}, T_c	Reference or 'design' air temperature of the compartment
U_{door}	Heat transfer coefficient door gasket (W/mk)
U_{wall}	Heat transfer coefficient wall (W/m²K)
V	Volume
V	Refrigerated volume (m³ or litre)
Veq	Equivalent volume
Vgros	Gross inner volume, including technical spaces e.g. For evaporator, lighting, etc.
Vnet	Net inner volume, excluding technical spaces e.g. For evaporator, lighting, etc.
w	Width (m)
ΔE_{df}	Defrost and recovery energy, in Wh
$\Delta E_{processing}$	Load processing energy (not used in the EU)
ΔT_{cd}	Condenser temperature difference K
ΔT_{cold}, ΔT_{ev}	Temperature difference between the evaporator and the average air in the compartment
Δt_{df}	Defrost frequency/interval, in h, rounded to the 1st decimal
ΔT_{ev}	Evaporator temperature difference (K) [r/f]

ΔT_{hot} , ΔT_{cd}	Temperature difference between the ambient air temperature and the condenser
η	Efficiency

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Executive summary

This is the Task 1-6 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 the same year. Tasks 1 to 3 contain (minor) changes following the first stakeholder meeting 1 July 2015. Tasks 4 to 6 will be the main subject for the second stakeholder meeting 14 December 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 report deals, after introductory chapters 1 and 2, with Task 1 to 6 of the MEErP methodology as follows:

- 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, Chapters 8, 9, 10).
- Definition of Base Cases (Task 5, Chapter 11)
- Design options (Task 6, Chapter 12)

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 2015 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.

As regards opportunities for saving on non-energy resources, discussed in Chapter 7, this product group is a-typical. The study team signals important opportunities for fighting food waste, e.g. through optimized storage and logistics. However, confirmed by several studies, little or no overall positive impact is expected of prolonging product life, improving reparability or recycling as more often than not it stands in the way of realizing energy efficiency improvement potential, i.e. technically and/or in the market. In terms of refrigerants and blowing agents the transition to low-GWP (Global Warming Potential) substances like isobutane and cyclopentane is almost complete (98%)

The new chapters 8, on statistical analysis, and 9 on, technical analysis, work towards a preliminary proposal for new metrics at the end of chapter 9. The proposal aims to be simpler, legally robust than the current metrics and offers more flexibility and options for innovation. The proposal has the following characteristics:

- The concept of product categories, i.e. predefined and named configurations of compartments, is abandoned in favour of a single formula that sets a reference (now *EEI*=1) for any configuration of different compartment types.
- The 8 compartment types are defined strictly by their temperature characteristics during testing.

- The concept of equivalent volume calculation is implicitly maintained, but the correction factor and term (now characterized by *M* and *N*) are greatly simplified. Equivalent volume is based on a calculated ambient temperature of 24 instead of 25 °C, from real tests at 16 and 32 °C following the new IEC standard.
- When compartments with different design temperatures are combined, with synergy-effects in terms of lower heat load and higher compressor-capacity, a new combi-factor *C* is introduced to set a more ambitious reference.
- Climate correction and adder for chillers are eliminated. Compensation factors for no-frost (stays at 1.2) and built-in (1.05 or 1.1 instead of 1.2) are proposed. A new door compensation factor *D* is introduced in order not to give a disadvantage to combi-appliances with three or more doors.

Chapter 10 presents several inputs for the definition and analysis of the five Base Cases. These Base Cases are analysed in terms of environmental impacts and monetary Life Cycle Costs (LCC) in Chapter 11. The use phase is still by far the most important for environmental impacts and responsible for three-quarters of the most important impact categories, despite ~20% energy saving and the ~10% average product weight increase over the last decade.

The total electricity consumption of the installed stock of household refrigeration appliances in EU-2014 is 87 TWh/year, i.e. more than 3% of the EU-total electricity final consumption. Greenhouse gas emissions amount to 39 Mt CO2 equivalent (0.8% of EU total). This makes household refrigeration appliances the most important large electric household appliance in terms of environmental impact.

Total EU-2014 acquisition costs for 19.4 million new household refrigeration appliances are 10.3 billion euros (€528/unit), while consumers spend over 17.1 billion euros on the energy bill for 303 million household refrigeration appliances installed in 2014 (€878/unit). Total consumer expenditure is thus estimated at 27.4 billion euros (€1404/unit) in the EU 2014.

For new units the discounted electricity costs are lower, i.e. €714/unit, and their energy costs for the period 2014-2030, discounted to the year 2014, will be 13.9 billion euros, based on ~70 TWh electricity/year. Total LCC of new units sold in 2014 are 24.2 billion euros.

Chapter 12 identifies the design options to improve energy efficiency and calculates savings, costs, payback period and life cycle costs. Depending on the category, the Least Life Cycle Cost (LLCC) point gives savings from 30 to well over 40% with respect to the average new product. Benchmarks for Best Available Technology (BAT) show savings of 60-70% with respect to the average new product.

Comments on all issues in this report are welcome.

Task 7 on policy options and scenarios will be part of the final report, planned to be issued after the 2nd stakeholder meeting.

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 (quick-scan) is not needed because it is already covered by the Omnibus study.
- Task 1 should focus on discussion of the scope and standards (Task 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 preparatory 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 an interim report four weeks earlier, took place 1 July 2015. The current Task 1-6 Report will be discussed at a 2nd stakeholder meeting 14 December 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 preparatory study on Smart Appliances led by 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 mid-2015 (procedure with Council and Parliament ongoing). 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.
- '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 outcome is reported in Chapter 7 (Task 3) and 10 (Task 5).

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

[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.ecodesign-fridges.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 October 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),
- Commission study on durability of refrigerators (Ricardo-AEA for EC DG ENV),
- IEC 62552 and related standards,
- Re/genT reports on new standards 2013,
- manufacturer data on wine storage appliances,
- Intertek report on correction factors,
- Miscellaneous technical articles on refrigerators.

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 10 months. Stakeholder feedback on Tasks 1 to 3 was received at the first stakeholder meeting on the 1st of July and more feedback on Tasks 4 to 6 is expected during the 2nd stakeholder meeting on the 14th of December.

2.3 Positions

Topics mentioned by stakeholders before the outset of the study:

- 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.

More positions of stakeholders are given in the minutes of the first stakeholder meeting in **Annex E** and are mentioned at appropriate places in this report.

3 Scope (Task 1.1)

3.1 Article 1 (Scope)

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

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

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. The reaction of the environmental NGOs was that the non-household appliances should remain included (see Minutes in Annex E)

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 refrigerating appliance', 'absorption-type refrigerating appliance', '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 *'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 62552-1:2015 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.

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

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[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.*

- *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. The reaction of the stakeholders was positive.

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 Energy Efficieny Index) to give a volume correction factor for built-in appliances (Table 6of IV). 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 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:

[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 fastened to the sides, top or floor of the cabinetry and (3) to either be equipped with an integral factory-finished face or accept a custom front panel.

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

- **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];
- **wine storage appliances:** that has no compartment other than wine storage compartments;
- **multi-use appliances:** that has no compartment other than multi-use compartments;
- **cellar:** that 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 a definition for ‘*wine storage compartment’* is included, which **<u>is</u>** 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*’ (citation Article 2, sub 7) it is a *‘wine storage*

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[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 which the temperature is not warmer than -12 °C.

appliance' and thus <u>excluded</u> 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 (stakeholder comments are in general positive, see detailed reactions in Annex E):

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 62552:2015 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 the study 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 of the regulation 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 Tables 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.

In the stakeholder meeting, environmental NGOs doubted the necessity of glass doors and thus the need for compensation. Also they are negative on compensation factors in general. Industry answered that the necessity for glass doors came from wine coolers in commercial markets. Industry did not ask for a compensation factor but for a separate category. Member States considered the glass door a detail that should be discussed later. (See also Annex E)

As regards built-in compensation it was clarified by industry and the study team that purely based on the difference in test method between a product declared as ‘freestanding’ or ‘built-in’ there is an 8-10 % difference for technically identical products. Without correction this may mislead the consumer in thinking that the product declared as ‘freestanding’ is more energy efficient, whereas –when tested in the same way—it would yield exactly the same energy consumption. Industry mentioned that 60-70 % of the stand-alone fridges in the Spanish market are actually used as ‘built-in’ and, considering that stand-alone fridges are ill-prepared for that situation, they use actually more energy than a ‘built-in’ appliance that has a worse test result on the energy label.

Consumer associations mention that a compensation factor needs to have a strict explanation. Transparency is imperative to be trustworthy.

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 201418. 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].

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.

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[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.

[26] OJ L 339, 18.12.2008, p. 45–52

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.

On the second point there was a clear position from all stakeholders NOT to mix product-specific regulations for household refrigeration appliances with horizontal issues like 'smart appliances'. There is a separate ongoing study on 'smart appliances' that should deal with this (see Annex E).

On the third point, the industry clarified that measurement of humidity in wine storage appliance testing has been included in EN 62552. Testing of wine storage appliance as per EN 62552 has been proposed by European delegates to IEC 59M and has been largely accepted and integrated into IE C62552-1, 2 and 3 with the exception of the humidity test requirement. This was generally found to be a not well developed part of the standard with difficult to maintain requirements.

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

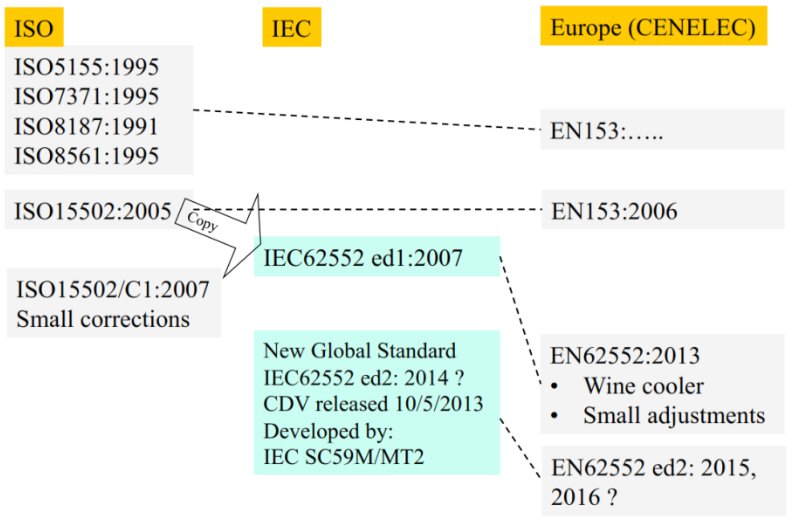


Figure 1. History of IEC 62552 (source: M. Janssen, 2013[27])

[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

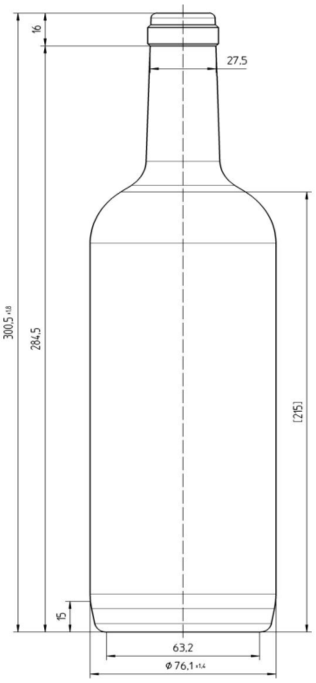
The IEC 62552:2015 standards and the draft EN 62552 are the most relevant for this study and will the subject of the rest of this section.

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)

1. 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;
2. The fresh food target temperature is changed from 5 to 4 °C;
3. 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;
4. 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 of IEC 62552-1 is dedicated to definitions for wine storage compartment tests and describes the narrow temperature ranges and the vibration reduction.

It does not, 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.

<u>Consideration (for stakeholder feedback)</u>: 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.

In <u>reaction</u> there was a clear position from all stakeholders NOT to mix product-specific regulations for household refrigeration appliances with horizontal issues like 'smart appliances'. E.g. in this case there are issues of food safety involved. Industry states explicitly that this test is intended to demonstrate how long food can be stored safely in a freezer in case of a serious, long time, power-cut. This test is not related to smart appliance control, where on a regular basis power would be cut for shorter durations which could impact food quality, hence requiring product adaptations.

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 <u>external</u> 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 (IEC 62552-3,Annex B);

- Defrost and recovery energy and temperature change in ΔE_{df} , in Wh (IEC 62552-3, Annex C);
- Defrost frequency/interval Δt_{df} in h rounded to the 1st decimal (IEC 62552-3,Annex D);
- Specified auxiliaries energy ΔE_{aux}, e.g. an ambient-controlled anti-condensation heater or an automatic ice-maker, in kWh/year (IEC 62552-3,Annex F).

Also, for certain regions a load processing energy $\Delta E_{processing}$ is defined in Annex G of IEC 62552-3.

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

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

<u>Consideration (for stakeholder feedback):</u>
An important change is in the <u>separate</u> assessment of defrost and recovery energy and interval, instead of it being <u>integrated</u> 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.

In the 1st stakeholder meeting there was <u>no reaction to the above</u>; probably this aspect will be judged in the context of a complete proposal.

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 obtaining the best possible temperature setting for the compartments. In order to achieve this, at some expense of the previously mentioned shorter testing time, the standard allows —within boundaries— a mathematical optimisation from 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 current standard only allows 1 or 2 tests (interpolation) per compartment and per ambient temperature.

Consideration (for stakeholder feedback): This leads to an 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 high. How to deal with that?

Industry reacted that the shorter test periods under the new IEC standard more than make up for the extra tests due to possible triangulation and testing at two ambient temperatures:

- Test periods are no longer a fixed 24 hours, but until stable conditions are reached;
- Elimination of the load packages in the freezer brings the stabilisation time of products from several days to less than 1 day.

Separate measurement of defrost and steady state part reduces the 'waiting time' considerably for no frost appliances. Confidential information from industry shows that for most products the duration of the tests under the new IEC standard can be almost half with respect to the current test standard.

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.

Consideration (for possible stakeholder comments):
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-standard) is to test including the extra energy consumption $\Delta E_{processing}$ with a load of PET-bottles filled with water at ambient temperature. 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].

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

There was no specific reaction from stakeholders on this issue and the study team assumes that most stakeholders agree to continue with current EU practice.

4.2.4 Circumvention clause

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.'*.

> 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.

The introduction of this circumvention clause is essential in avoiding manufacturers wilfully manipulating test results (compare: Volkswagen-scandal). In principle, in anticipation of the new IEC standard becoming harmonised, it may be advisable to include the above text directly into the regulation.

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 59X, WG 8 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].

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.

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): 19 % more energy[35]. 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.

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[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.

[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 $COP_{carnot} = (T_{cold} + 273.15)/(T_{hot} - T_{cold})$

[35] Note that the CECED reports mention 9%, but the Excel tool indicates a value of 19%. In a reaction CECED states that 9% is a typo and 19% is correct.

- Category 7 (fridge-freezer), frost free (two thermostats): 9 % more energy, reflecting new defrost-cycle being more stringent and the relatively high impact of defrosting on the very efficient products in this group.[36] 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 °C. 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:

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

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).[37]
- 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 T_{cold} from °C to Kelvin (K), as is required in the original Carnot formula.[38]

[36] 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.
[37] 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 T_{ref}, 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 °C and 32 °C (ceteris paribus[39]).

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.

, Appendix A of 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); which is more or less in line with a similar calculation in the standardisation platform by L. Harrington. The study team finds 0.44 (interpolated temperature 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 CECED report from 2013 finds F=0.55 (23.1 °C). The study team finds, see 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 will prove to be stimulating for design changes that lead to a better overall performance over the ambient temperature range.

<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.

[38] 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.

[39] Latin, meaning'other things being equal'. Abbreviation: cp or c.p.

In a preliminary reaction, most stakeholders in the 1st stakeholder meeting could agree to using F=0.5 (a calculated 24 °C ambient from 16 and 32 °C ambient test results). The study team will take that into account in the rest of its work.

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). [40]
- Japan is expecting new measures in 2016. The Japanese weighted average between the 16/32 °C tests is 25 °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.

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

- 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.

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[41], 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.

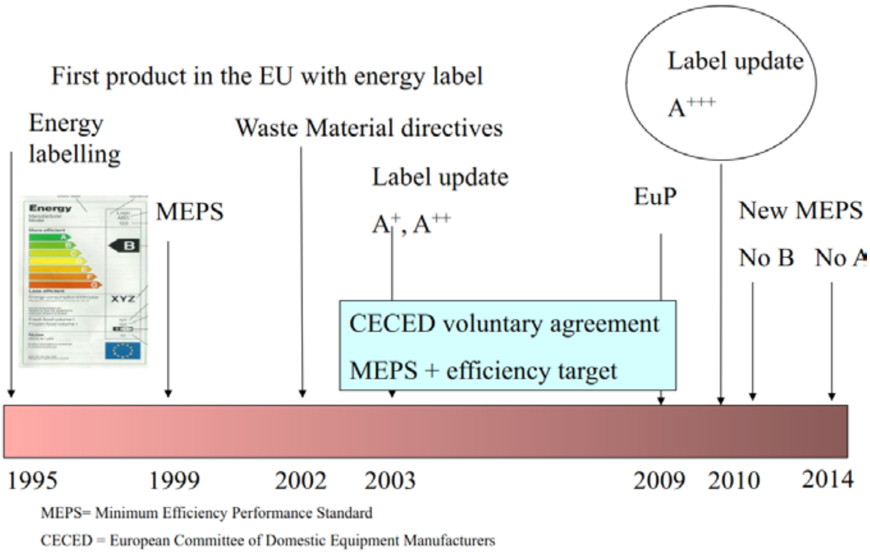

Figure 4. Short history of EU Energy Label and Ecodesign measures. (Source: M. Janssen, Refrigerator testing: IEC 62552 ed 2 development and AUS/NZ Round Robin testing, Presentation 13402 / RE24 / V2, Re/genT BV, 17/10/2013)

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

[41] Commission Decision 2003/66/EG

under the first Energy-using Products framework directive 2005/32/EC offered a more robust alternative.[42]

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 %. [43]

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 to 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, i.e. 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[44] 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 now these are also phased out, unless there is a justified claim for an exemption, under the new regulation EU No. 517/2004 [45]. 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 Waste of Electrical and Electronic Equipment (WEEE)-

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

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

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

[45] 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

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, WEEE-recast 2012[46]). This means that special treatment facilities were set up to recover the refrigerant and —without significant emissions to outside air— to shredder the foam (and cabinet).

From 2016 the minimum collection rate is set at 45 %[47] (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.
Article 10 of the WEEE Directive 2012/19/EU has laid down stringent rules to prevent the repair and re-use of appliances once they are classified as 'waste' (a.k.a. as the Basel convention). This prevents the (now illegal) export and subsequent re-use of old refrigeration appliances e.g. in Africa, which is considered as a negative environmental impact, i.e. it prevents the uptake of more efficient appliances and may lead to avoidable release of ozone-depleting or high-GWP refrigerants in the atmosphere at end-of-life.

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[48] and attention of the legislator to 'nanosilver' under the Biocide Regulation. [49]

As regards electrical safety household refrigerating appliances are subject to the Low Voltage Directive[50] and for electro-magnetic compatibility there is the EMC Directive[51]. Being a food-storage device the materials that come into contact with food should be safe to human health. This means that e.g. '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.

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

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[46] 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
[47] Or between 40 and 45% for several Eastern-European Member States
[48] 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.
[49] 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)
[50] 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
[51] Directive 2004/108/EC relating to electromagnetic compatibility and repealing Directive 89/336/EEC, OJ L 390 of 31 December 2004

aspects[52], 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'.[53]

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.[54] 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.

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[52] 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]
[53] http://ec.europa.eu/environment/consultations/closing_the_loop_en.htm (Consultation for all interested stakeholders from 28.5.2015 to 28.8.2015).
[54] European Commission Conference on Product Policy –Ecodesign & Energy Labelling, 20-21 Feb. 2014, misc. lectures.

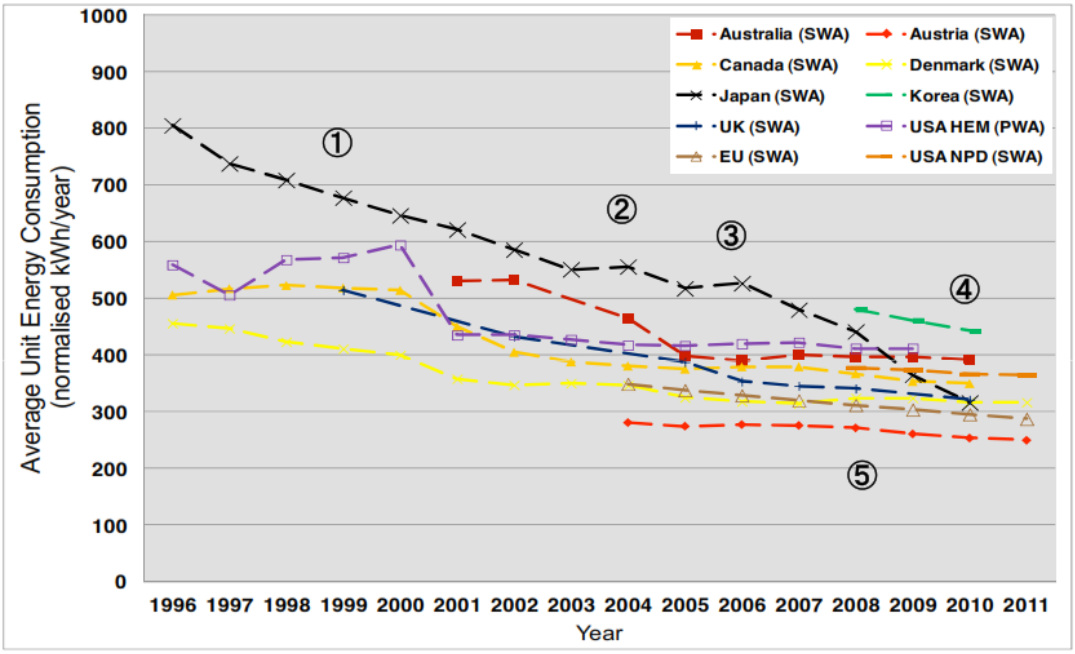

Figure 5. Average Unit Energy Consumption in selected countries and regions (Source: IEA 4E M&B, version 2014)

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 SAEC according to the calculation annexes of the EU regulations.[55]

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.

5.3 Ecodesign metrics

[55] 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.

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

The SAE is calculated by:

$SAE = V_{eq} \times M + N + CH$

with:

- 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.
- V_{eq} is the equivalent volume (in litres), with

$$Veq = \sum[V_c \times (25 - T_c)/20 \times FF_c] \times CC \times BI$$

where

  - V_c is the net volume of compartment C (suffix 'c' is the index of the compartment),
  - T_c is the nominal temperature of compartment c,
  - FF_c is the frost free correction factor 1.2, if the compartment c has automatic defrosting (otherwise FF_c =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-T_c)/20, is a technical parameter derived from the heat load of any compartment compared to the heat load of the fresh food compartment. If the ambient temperature is 25 °C and the fresh food compartment temperature is 5 °C, then the temperature difference inside-outside is 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 a nominal temperature of -18 °C, 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 N_{ch} and a variable part (depending on V_{eq}) M_{ch}, 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 V_{eq} 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 (msp) 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)[56].

[56] Eurostat data are given per 100 kg 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 data fields; : = 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[57], 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 penetration of around 1.4 refrigerating appliances per EU household[58] and —including secondary and vacant homes— 1.3 refrigerating appliances per EU dwelling. [59]

[57] Luxembourg, Cyprus, Malta, Bulgaria, Croatia
[58] Assuming around 210 million households in 2015
[59] 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)

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)[60]. 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[61]. The estimated 'equivalent volume' (*Veq)*, calculated according to the current regulations, 377 litres. The average 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

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[62].

[60] VHK, EIA-study, 2014.
[61] See Omnibus study, Figure 5-5 (source CECED), showing a compound aggregate growth in net volume of 15% over the 2001-2012 period.
[62] Including levies for recovery/recycling (F. 'recupel')

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.[63]

6.3 Actors, jobs and trends

6.3.1 Actors

Important manufacturers with EU production facilities are Electrolux[64], Bosch-Siemens, Whirlpool[65], Candy and Liebherr. Rapidly-growing importers are Arcelik/BEKO of Turkey, and Samsung and LG of South Korea. The latest development, in late 2014, is the acquisition of Indesit (IT)[66] by Whirlpool, a US based firm with its EU-headquarters in Italy. [67]

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[68], FRIO 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 (Media Markt), 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.

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[63] 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.'

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

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

[66] previously part of Merloni Elettrodomestici

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

[68] 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.

The European industry association is CECED[69]. 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[70]) 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[71], showing trends in energy efficiency related features.

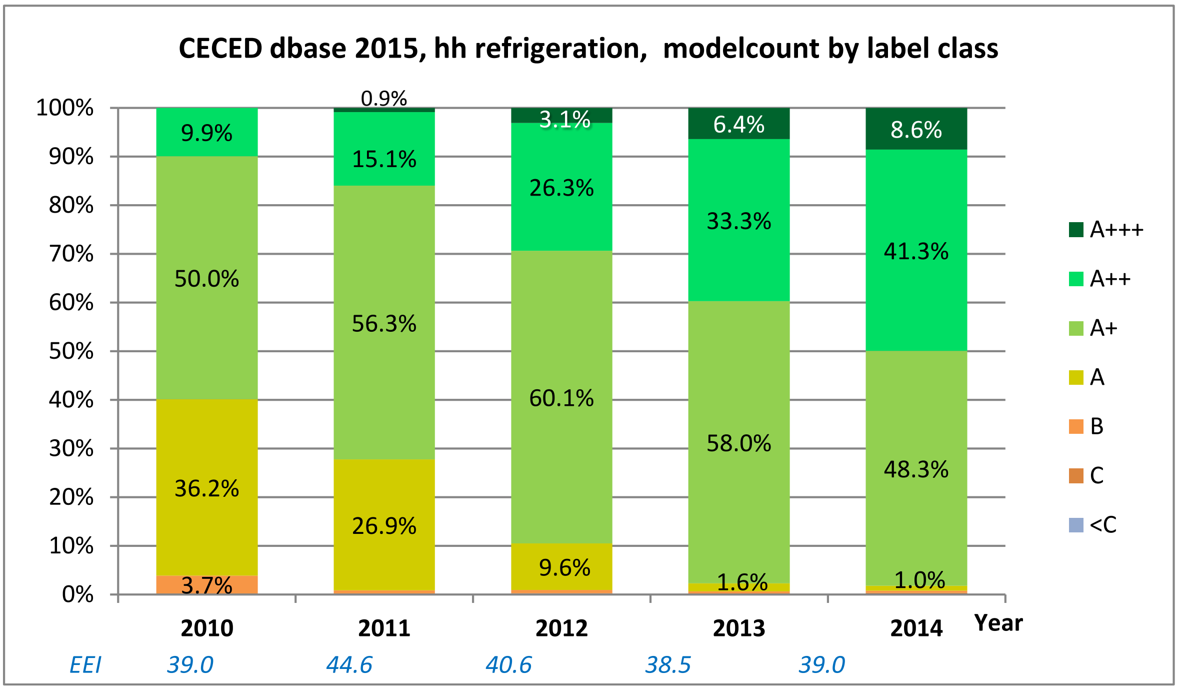


Figure 6. Counts by label class (source: VHK on basis of database CECED 2015)

[69] www.ceced.eu
[70] EC Impact Assessment 2009, SEC(2009)1021
[71] 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.

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.[72]

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.

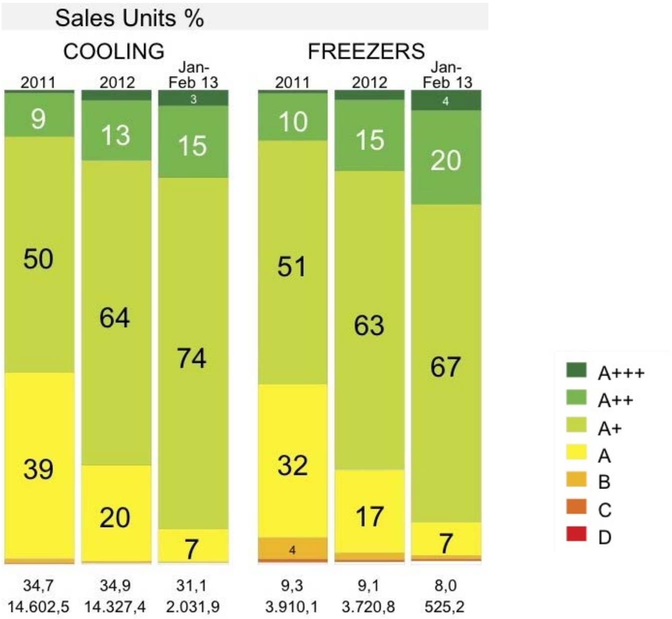


Figure 7. Sales data per label class (source: GfK for EU23, in TopTen 2013)

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**

[72] See Annex E for an explanation of the increase in model numbers

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.

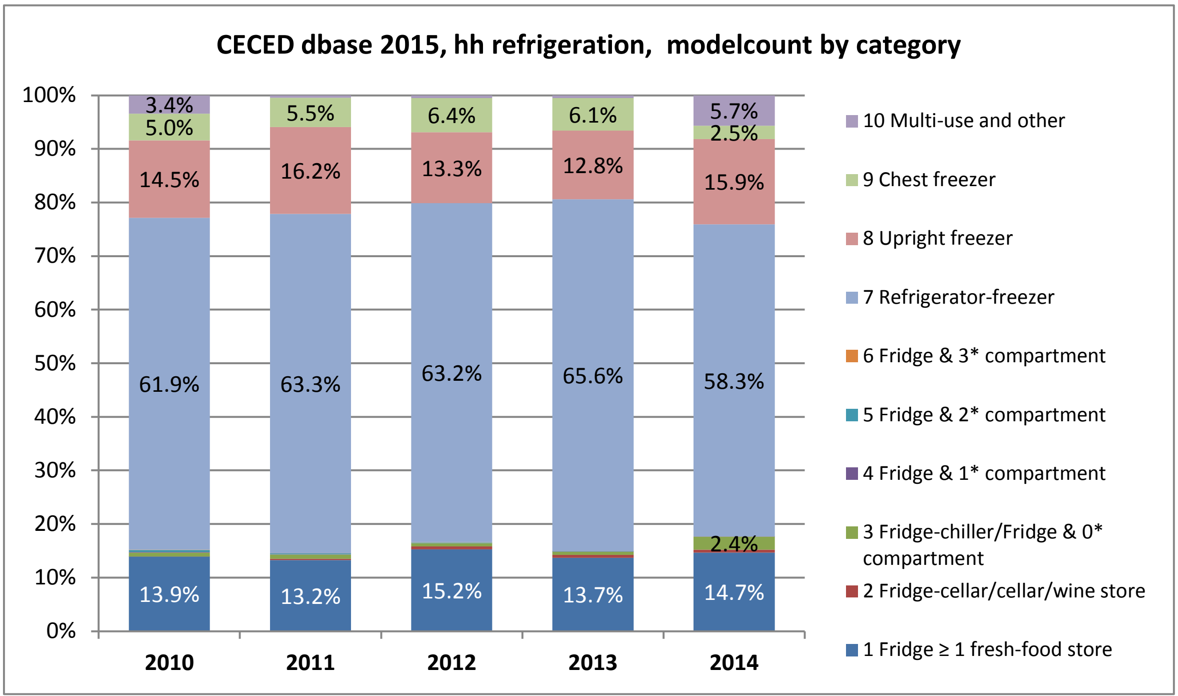


Figure 8. Counts by category (source: VHK on basis of database CECED 2015)

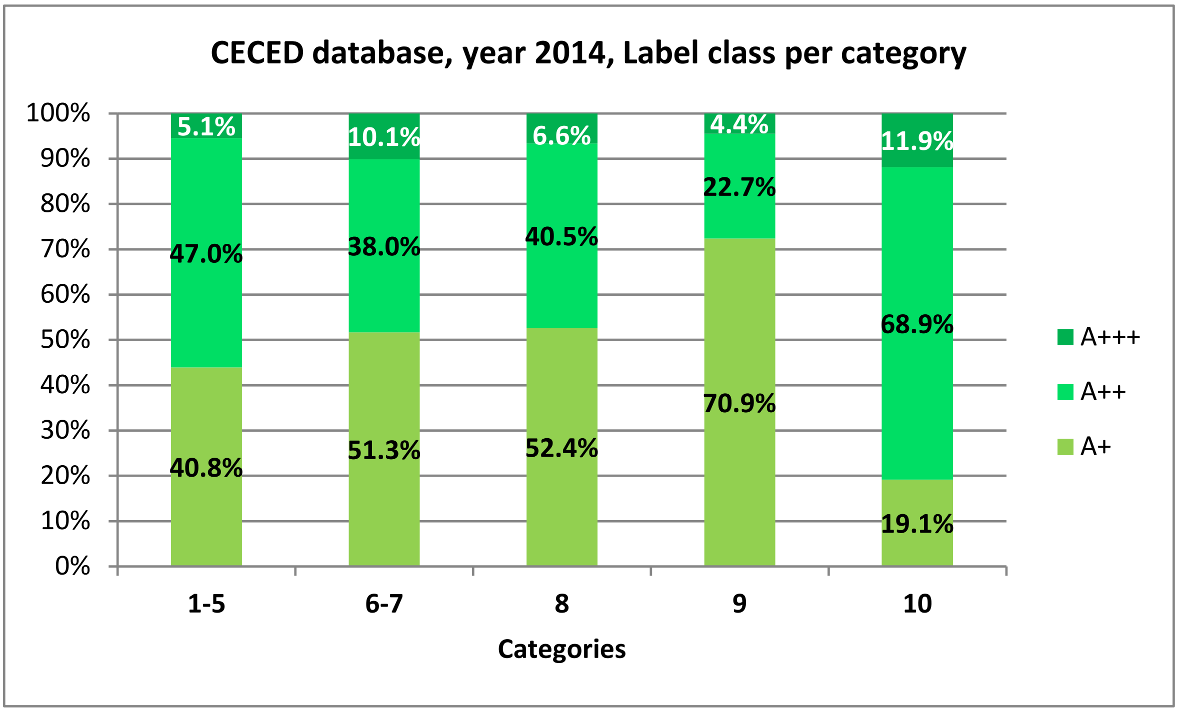


Figure 9. Counts by category and class (source: VHK on basis of database CECED 2015)

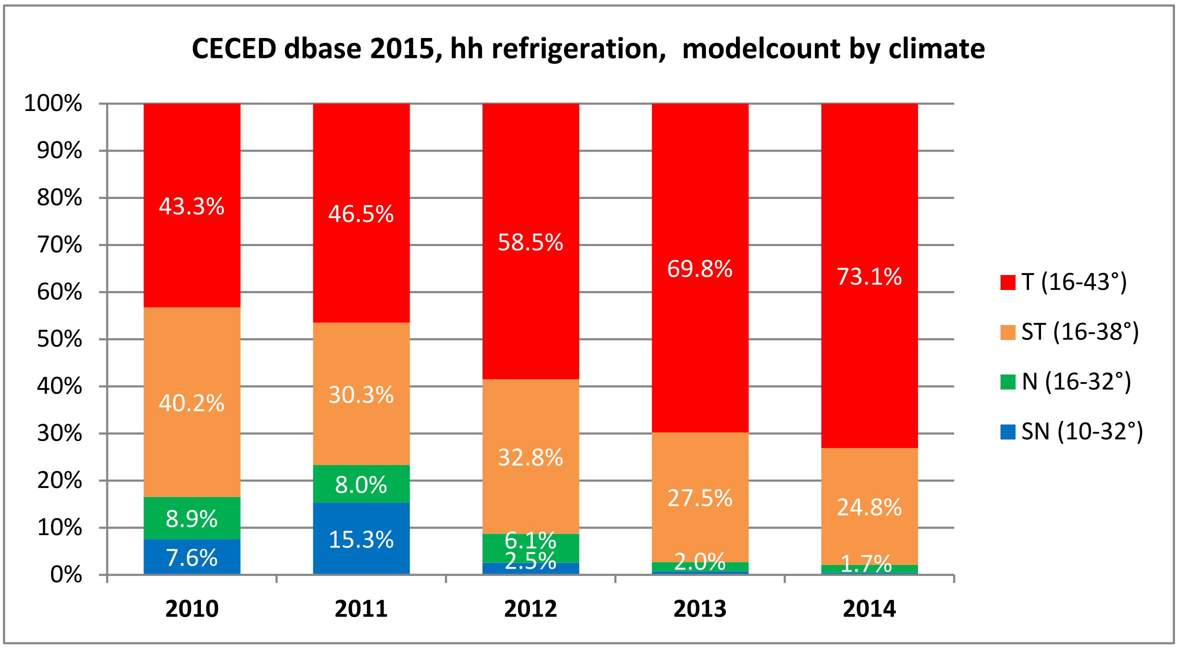


Figure 10. Count climate correction 2010-2014 (source: VHK on basis of database CECED 2015)

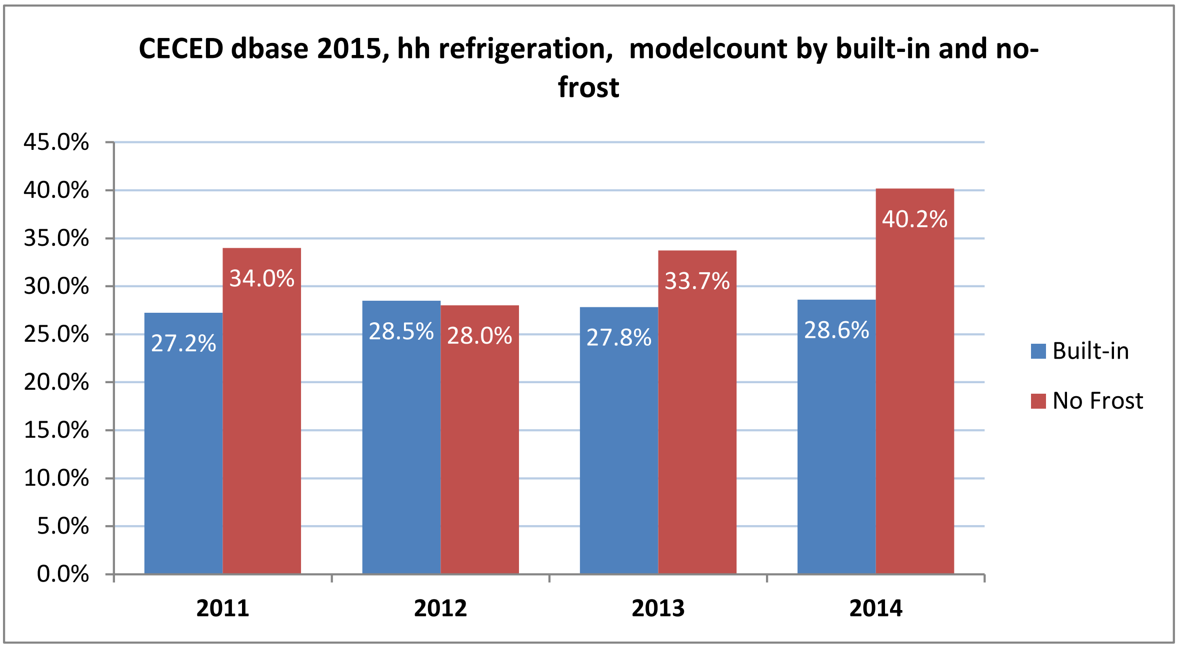


Figure 11. Count Built-In and No-frost appliances (source: VHK on basis of database CECED 2015)

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.

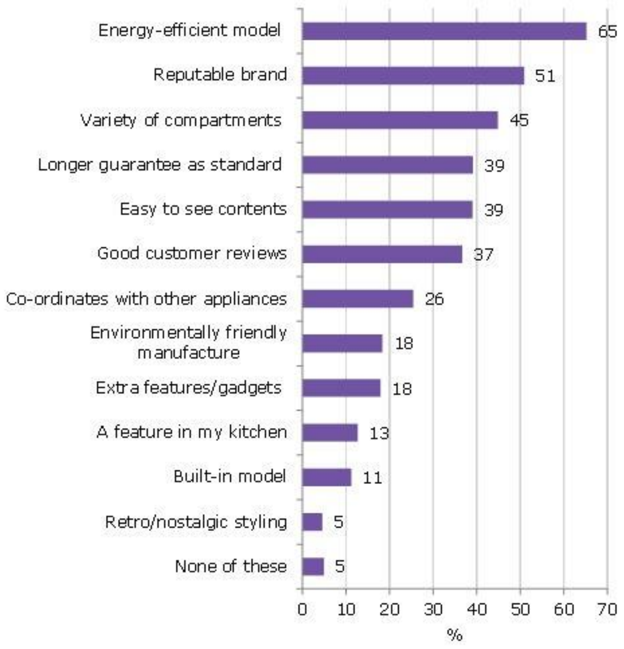


Figure 12. Factors influencing the choice of refrigeration appliances (source: GMI/Mintel "Fridges and freezers – UK", April 2014, in 'Energy efficient products – helping us cut energy use')

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 €522.

Table 10. Anchor points and PriceDec (source: 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 (source: 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.

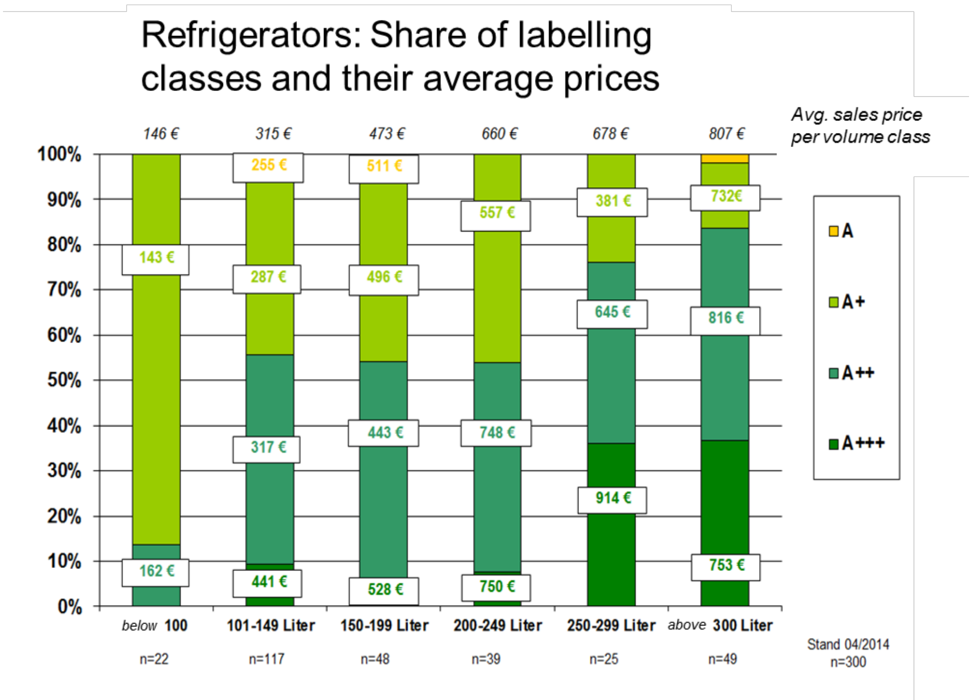


Figure 13. Refrigerator energy classification and prices, Germany 2014.
(source: Verbraucherzentrale Rheinland Pfalz, 2014)[73]

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.

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

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

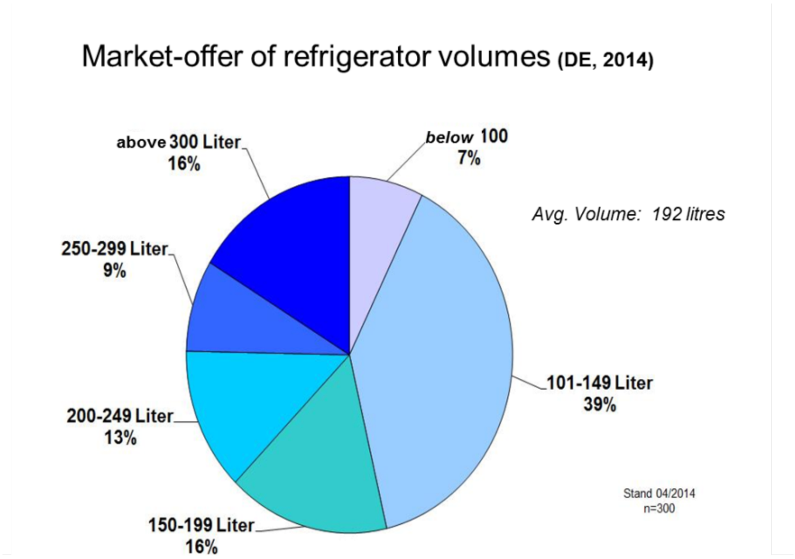


Figure 14. Refrigerator volumes on offer, Germany 2014.
(source: Verbraucherzentrale Rheinland Pfalz, 2014)

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.

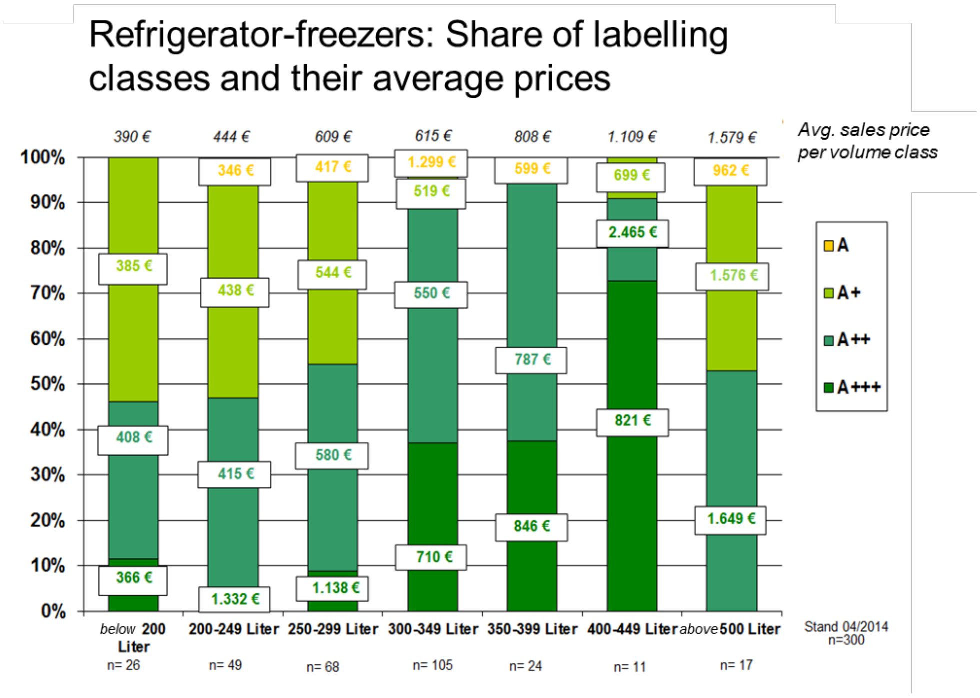


Figure 15. Refrigerator-freezers, energy classification and prices, Germany 2014. (source: Verbraucherzentrale Rheinland Pfalz, 2014)

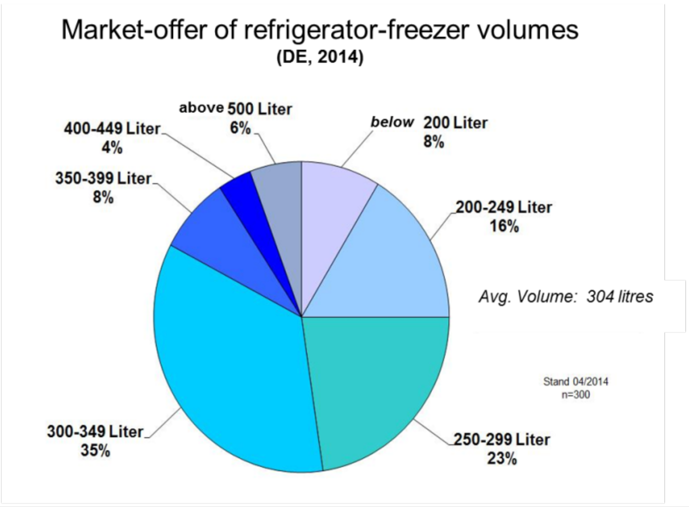


Figure 16. Refrigerator-freezer volumes on offer, Germany 2014.
(source: Verbraucherzentrale Rheinland Pfalz, 2014)

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

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

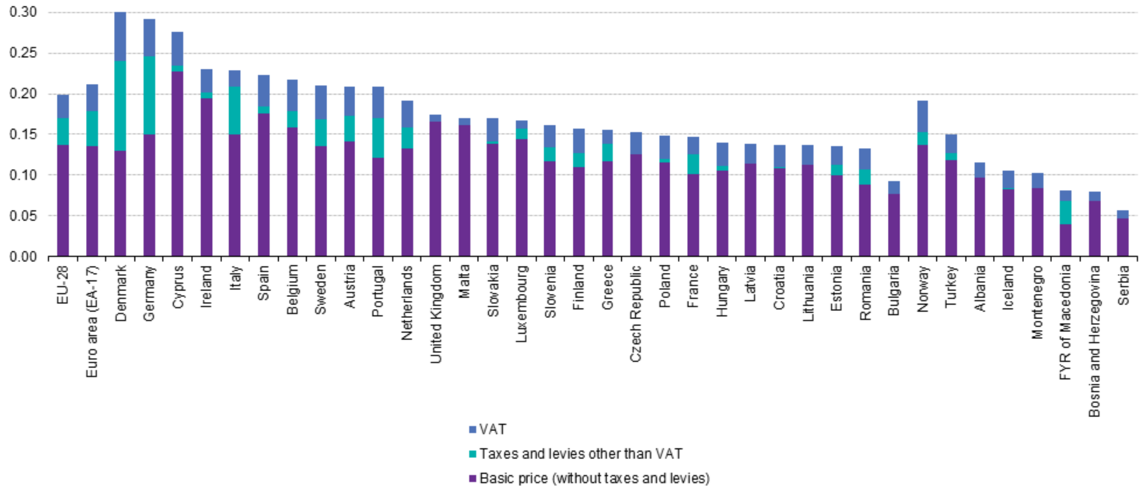
		1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013
Electricity rate	**€ / kwh elec**	0.12	0.13	0.13	0.14	0.15	0.16	0.16	0.16	0.17	0.18	0.19	0.20
Inflation	**inflation index (2010=1)**	0.67	0.74	0.82	0.91	0.92	0.94	0.96	0.98	**1.00**	1.02	1.04	1.06

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 infrastructure 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 for 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.

<u>A simple example:</u>
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 m^3/kg) 0.83 kJ/m^3/K. The appliance is a 300 litre fridge (200 litres net volume)-freezer (100 litres net volume). The ambient temperature in the kitchen is 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.

<u>*Door openings*</u>
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 m^3 of fridge air and 4 x 0.1 x 365= 146 m^3 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.

<u>*Warm load*</u>
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 fridge-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 of 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 space 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[74], 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 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.

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

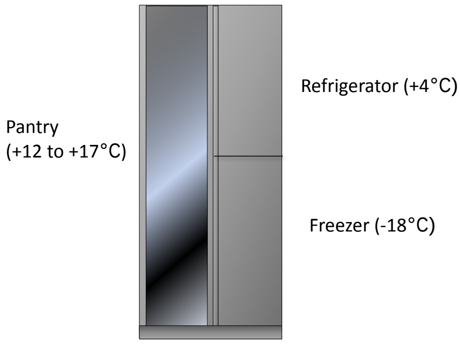


Figure 18. Illustration of a pantry / refrigerator / freezer
(source: VHK 2015)

Auxiliary food preservation techniques: Examples are humidity control or, e.g. in the chiller sub-compartment, creating an oxygen-poor environment (with CO_2).

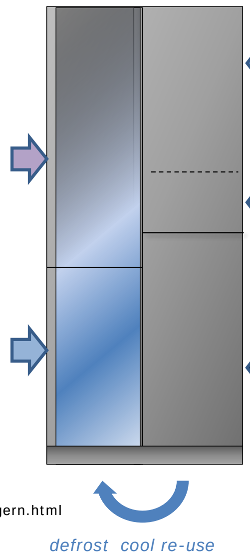
Food planning: Many people forget expiry dates, well-hidden left-overs, etc.. If the fridge had a scanner that could read bar- or QR codes of foodstuffs and a small display it could help to fight food waste. This might also help the fight against obesity or other eating disorders, both serving health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

BOX 1. Optimal food storage

PANTRY / CELLAR (16 °C, *humid or in containers, moderate ventilation)*
oranges, lemons, ripe tomatoes/ cucumbers/eggplant/melon/avocado/pineapple/ mango/papaya/bananas, grapes, peaches & plumbs, apples & pears (separate ventilation --> ethylene),
potatoes (dark), red wine (dark), unopened cheese.

DRINKS / WINE STORAGE (8-10 °C)
white wine, beer, fruit juice, soft-drinks, non-meat/fish leftovers, fruitcake , mayo/ketchup/salsa/honey (opened)



FRIDGE
Fresh food (4 °C): Diary products (milk, yoghurt, eggs, cut & fresh cheese, pudding), green vegetables (salad, broccoli) & herbs, carrots, cold cuts (ham, salami,bacon), ready-meals & leftovers

Chill sub-compartment (0 °C):
Fresh meat, poultry, fish, shellfish, etc.

FREEZER (-18°C):
frozen foodstuffs all types

VHK derived from e.g.
http://www.zentrum-der-gesundheit.de/obst-gemuese-lagern.html

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

7.3.1 Durability

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.

Figure 19, 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 %.

Note that the Japanese study is strictly based on the technological progress in energy efficiency of the refrigerators. It does not take into account the deterioration of the refrigerator over its product life due to wear and tear of e.g. door gaskets.

In the first stakeholder meeting for the underlying study in April 2015 Member States and NGOs requested more clarification on the above statements which apparently are counter-intuitive in the light of the current ‘circular economy’ concept.

This is given on the next page.

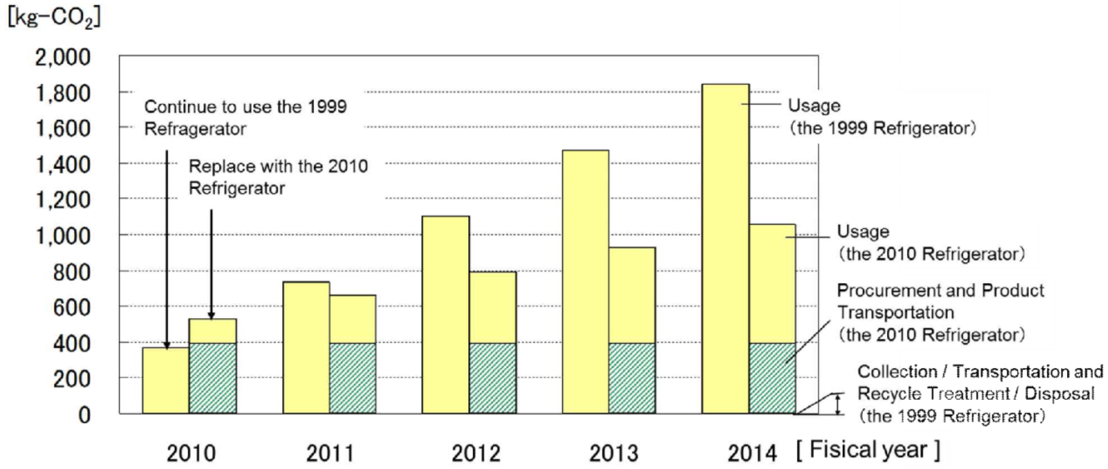


Figure 19. Greenhouse gas balance of life time extension: Continued use of 1999 refrigerator in 2010 versus replacement by 2010 refrigerator.
(source: JEMA, Report on Life Cycle Inventory (LCI)--Analyses of Refrigerators, The Japan Electrical Manufacturers' Association, The Environmental Technical Expert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

In the EU, durability and other EoL-aspects of household refrigerators were the subject of several case studies in the context of conservation of material resources and 'circular economy'.

Building on earlier work in 2011-2012[75], a 2014 article by Ardente and Mathieux from JRC-IES gives an overview of the current state-of-the-art in thinking about product durability[76]. In their methodology the evaluation if --and possibly by how much-- lifetime extension of an energy-using or energy-related product would contribute to resources conservation depends on technological progress and how much the product efficiency deteriorates during usage and over time. To that end they compare the total environmental life cycle costs in two scenarios: a 'business-as-usual' scenario and a scenario with an extended product life. In their own case study of refrigerators they could not conclude that life time extension of household refrigerators is useful in that respect.

In a recent study by Ricardo-AEA for DG ENV this is confirmed.[77] For refrigerators the following is concluded:

'....For the impact categories that result to a greater degree from the energy consumption during the use phase, extending the durability of the product does not lead to significant environmental benefits, and in fact a small improvement (less than 10%) in the energy efficiency of the replacing product can lead to a significant reduction of the life cycle environmental impacts of the standard scenario compared to the durable scenario.
For impact categories equally influenced by the three life cycle stages, the benefit of the life extension depends mainly on the energy efficiency of the replacing product. Sensitivity analysis revealed that a relatively small improvement (i.e. an average value of 15 %) in the energy efficiency of the replacing product can wipe out the benefits of the extended lifetime...'.

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[75] Ardente, F., Mathieux, F., Integration of resource efficiency and waste management criteria in European product policies – Second phase, JRC Technical Report, Report No. 1 (Analysis of Durability), Ispra, Sept. 2012
[76] 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.
[77] Ricardo-AEA, The Durability of Products -- Standard assessment for the circular economy under the Eco-Innovation Action Plan, report for the European Commission DG ENV, 17.8.2015.

Ardente and Mathieux also cite other sources, including the ISO 14000 series, that warn against the limits of lifetime extension and single out refrigerators in that respect. The technical report ISO/TR 14069 (2012) noticed that:

'for long-lived products, such as refrigerators with lifetimes of 10 or 20 years, technology development may be a factor that cannot be disregarded. One refrigerator with a lifetime of 20 years cannot simply be compared to two successive, present-day refrigerators with a lifetime of 10 years. The refrigerators available 10 years from now are certain to be more energy efficient (i.e. lower energy input per functional unit) than the present, the energy efficiency of the second refrigerator of the 10 + 10 option is determined by a trend projection, while the energy efficiency of the 20 years option is fixed'.

According to ISO/TR 14062 (2002) '*a balance is also necessary between extending a product's lifetime and applying the latest technological advances that may improve the environmental performance during use by taking into account possible upgrading during product development'.*

Dewulf and Duflou mention that '*However, for energy-using products (EuPs) and energy-related products (ErPs), lifetime extension is not necessarily the optimal strategy due to decreasing efficiency of worn-out products as well as due to technological progress'.* [78]

Furthermore, Article 10 of the WEEE Directive 2012/19/EU has laid down stringent rules to prevent the re-use of appliances that are classified as 'waste'. This is a reaction to the illegal export of discarded refrigerators to Africa. For instance, studies for Ghana revealed that in 2009, around 70 % of all imports were used EEE and 30 % of second-hand imports were estimated to be non-functioning (therefore e-waste): half of this amount was repaired locally and sold to consumers and the other half was unrepairable.[79]

7.3.2 Recycling and recovery

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 15 % (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. [80]

End-of-life PUR can be recycled chemically (costly and potentially polluting) or mechanically (crushed and compressed to form wood-like blocks). [81] Most end-of-life PUR

[78] W. Dewulf, J.R. Duflou, The environmentally optimised lifetime: a crucial concept in life cycle engineering, Proc. Global Conf. Sustain. Prod. Dev. Life Cycle Eng., 2004 (2004), pp. 59–62.
[79] Where are WEee in Africa? Findings From the Basel Convention, e-waste Africa Programme. Basel Convention, 2011.
[80] http://www.foam-tech.com/about_ft/environment.htm
[81] http://www.intcorecycling.com/How-to-recycle-pur.html

comes from dismantled flexible PUR-parts of furniture (sofas), 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.[82] 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 magnetic separation and incinerate (with heat recovery) the PUR-PS particles that remain.[83] 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 <u>increase</u> 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).

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 [84]

Annex D of IEC/TR 62635 technical report illustrates some examples for the calculation of the recyclability and recoverability of products, amongst which household refrigerators. The 'recyclability rate' of the refrigerator was found to be 75.3 % while the 'recoverability rate' was established at 81.9 %.

7.4 Infrastructure, smart appliances:

Household refrigeration appliances can possibly play a role as ‘smart appliance’, e.g. using the thermal storage capacity of the freezer to avoid electricity consumption during peak-hours. Currently the European Commission is engaged in a horizontal preparatory study on this subject.[85]

The message from the first stakeholder meeting was that this is a complex matter, with possible implications for e.g. food safety, and should be handled outside the scope of a review study on Ecodesign measures for a single product.

[82] 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.
[83] 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
[84] 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
[85] Project website: www.eco-**smartappliances**.eu Note that ARMINES/MINES ParisTech, co-author of this study, is also part of the smart appliances study team, thus optimal information transfer between the studies is ensured.

8 Statistical analysis of existing products (Task 4.1)

Since the first GEA preparatory study in 1992, statistical analysis of the industry (CECED) database has played a dominant role in shaping the energy labelling and Minimum Energy efficiency Performance Standards (MEPS).

In the MEErP, this subject is part of Task 4.1, which looks at the technical characteristics of the existing, improved and best available products (BAT). Given the importance of this subject for household refrigeration appliances, this part is treated in this separate Chapter 8. The technical aspects and current metrics, also part of Task 4.1 are discussed in Chapter 9.

The technical parameters of production, distribution and end-of-life aspects, Task 4.2 of the MEErP, are given in Chapter 10.

8.1 Categories and main MEPS parameters

The categorisation of household refrigeration is addressed in section 3.4. The frequency of the current categories in the 2014 CECED database is given in the figure below:

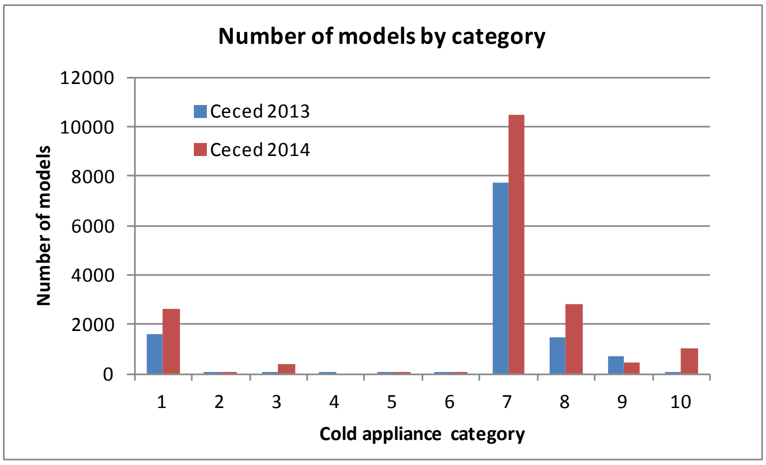


Figure 20. Toward base case definition

Section 3.4 also presents the industry proposal to:

1. combine most of the current refrigerator categories 1 to 5, as well as a part of category 10, in one category (hereafter 'COLD1' or 'RF'),
2. to single out from this combined category the 'wine storage appliances' ('COLD2' or 'W'), to combine fridge-freezer categories 6, 7 and another part of category 10 ('COLD7' or 'RF'), and
3. keep separate categories for upright ('COLD8' or 'Fu') and
4. chest freezers ('COLD9' or 'Fc').

This industry proposal was discussed in the first stakeholder meeting, 1st of July 2015, and the simplification was welcomed by all stakeholders with some reservations regarding COLD2. In any case, this chapter will investigate all 5 new categories and it can be decided at a later stage whether the separate COLD2 category is actually needed.

Industry also proposed to mirror the categories for 'built-in' versions of COLD1, COLd2, COLD7 and COLD8. Here the other stakeholders were not a priori in favour. This chapter will analyse 'built-in' and 'no frost' in the same way as in the current regulation, i.e. as features that may have a correction factor. If this correction factor is significant enough it may warrant a separate category, but that can be decided as one of the policy options.

Five base cases are then considered in this study:

- A single door refrigerator of category 1
- A fridge-freezer of category 7 (without no-frost or built-in option)
- An upright freezer of category 8
- A chest freezer of category 9
- A wine cooler of category 2

The main parameters for the base cases from the CECED database 2014 are net volume (litres), possibly split by compartment, equivalent volume (litres), annual energy consumption (kWh/a), energy efficiency index (EEI) and energy class (A-G).
Base Case correction factors for climate class, no-frost and built-in, as well as the presence of Vacuum Insulation Panels (VIP), average noise power and mass values are also given in Table 24.

Further details and discussion of average mass, dimensions, materials compositions, etc. are given in Chapter 9.

Given that A+ models represent 72 %[86] of the 2014 European market, it is considered that base cases are of class A+ except for the wine cooler category. In the case of wine coolers, according to 2014 CECED database: 41 % of the models have an energy class higher or equal to A and 28 % are B Class. It is considered that the base case of the category 2 is B Class.

[86] Topten.eu Energy efficiency of White Goods in Europe: monitoring the market with sales data. June 2015.

Table 14. Average parameters by category in CECED 2014 database

Category	Type	Total Count	Frozen (L)	Fresh (L)	Total Net Volume (L)	Eq. Volume (L)	Mass (kg)	Energy consumption (kWh/yr)	EEI (%)	Main Climate Class	Energy Efficiency Class	No-Frost	VIP	Built-in	Sound power dB(A)
1	Refrigerator (single)	2 506	11.8	250.9	247.5	313.5	49.9	118.7	36.1	SN-T	A+	N	N	N	38.4
2	Wine Cooler	100	0	187.1	187.1	139.6	52.4	237.0	87.0	N	B	N	N	N	43.7
7	Refrigerator-Freezer	10 437	93.9	215.6	309.6	515.1	70.4	258.0	36.3	SN	A+	N	N	N	38.6
8	Upright Freezer	2 760	203.0	0	203.0	602.8	66.6	231.8	36.7	SN	A+	N	N	N	39.5
9	Chest Freezer	445	260.7	0	260.7	674.0	47.3	235.9	39.0	SN-T	A+	N	N	N	41.8

According to Topten.eu, considering only the fridges and fridge-freezers (which is quite equivalent to models of categories 1 and 7), on average on the European market:

- the average energy consumption of refrigerator sales is 231 kWh/yr (and 247 kWh/yr for an A+ class);
- The average volume of freezer is 73 l (and 72 l for an A+ class);
- The average volume of refrigerator is 197 l (and 193 l for an A+ class).

These data are consistent (figure 25) with results obtained when weighting the characteristics of categories 1 and 7 products with the number of products by category in the CECED database.

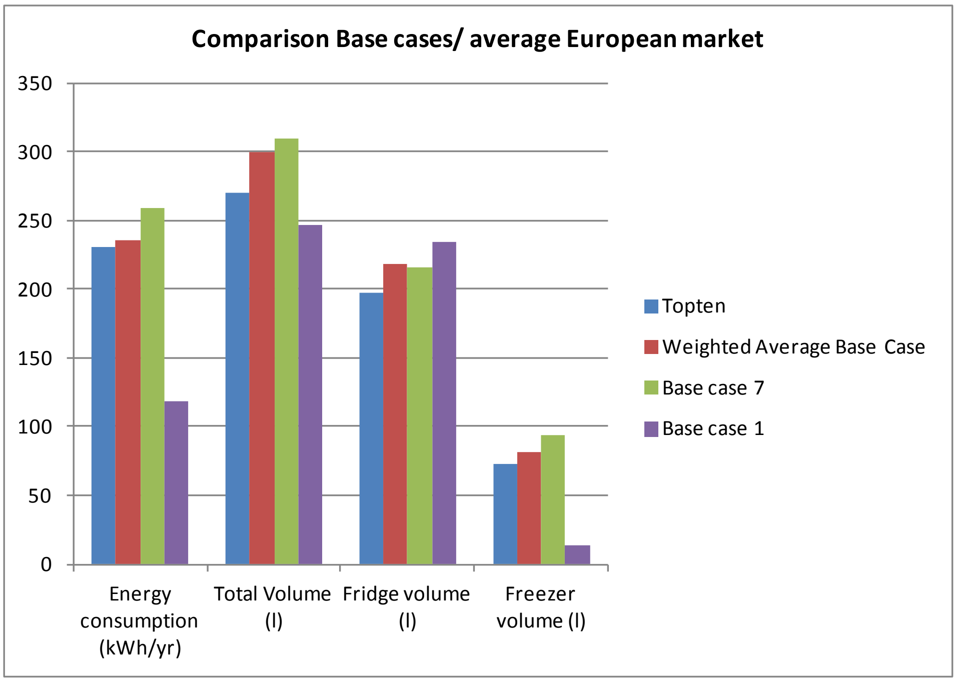


Figure 21. Comparison of base cases characteristics and average values on the European fridge market

The average characteristics by category are not representative of typical products. For instance, the EEI of real products stays close to the A+, A++ or A+++ lines, while average EEIs logically are situated between class A+ and A++.

8.2 Regression analysis from the database

8.2.1 Energy parameters

In 1992 the reference lines for label-class limits were derived from a linear regression of a database with household refrigeration appliances on the market at the time. For 2014 the industry association CECED has made a database available to the study team for the year 2014 with over 18 000 models that would allow repeating the linear regression after 22 years.

Naturally, the market data is biased. It has been influenced over the years by the energy label classification and there is a high density of data-points near the limit values. This means that the reliability in predicting the position of a single data-point from the regression formula, expressed e.g. by the R^2 parameter, will be very limited. Nonetheless, the linear equations can represent a hopefully meaningful average that can be compared to the results of the technical modelling and proposals made by the industry.

The data-base was first ‘cleaned up’, i.e. moving some wine storage products from Category 1 to 2 and eliminating incomplete entries. Then totals and averages were calculated per category and for 4 sub-categories with or without defrosting (FF) or built-in (BI): NoFF_NoBI, NoFF_BI, FF_NoBI and FF_BI. Some analysis was also done on appliances with chillers and a cellar compartment. All energy values, in kWh/a, are taken without correction factors. Despite the fact that the new standard uses a slightly more stringent definition, the comparison is still with the current <u>net</u> volume in litres as the new net volume is unknown and is believed to be only be slightly different.

The data-points per (sub)category are then introduced in XY-diagrams and linear regression 'trend-line' equations were produced in MS Excel. An average A+ line according to the current regulation was introduced for comparison. Because no correction factors are applied, a number of models end up above the A+ line. Especially for fridge-freezers (Cat. 7) this should be interpreted with caution, because per subcategory the r_c factor (correction for equivalent volume), on average 1.34 for all models and subcategories, may vary 10 % upwards (line more inclined upwards) or downwards (line inclined downwards). The results for categories 1, 7, 8 and 9 as well as for category 7 subcategories for type I and II are given in the figures on the next pages.

The regression equations were then corrected for the new standard, i.e. +9 % for the refrigerator, +6 % for the fridge (+10 % for type I, 3 % for type II), −5.7 % for the freezers. These corrections are based on the industry input and the technical modelling in the previous chapter. Subsequently, to calculate the new M and N factors, the correction for the new rc –based on Ta=24 °C—was taken into account.[87]

The resulting table, table 15, gives the M and N factors in the current database 2014 but with the new standard.

In the final stage a comparison is made between these curves from the linear regression, the current regulation and the technical modelling.

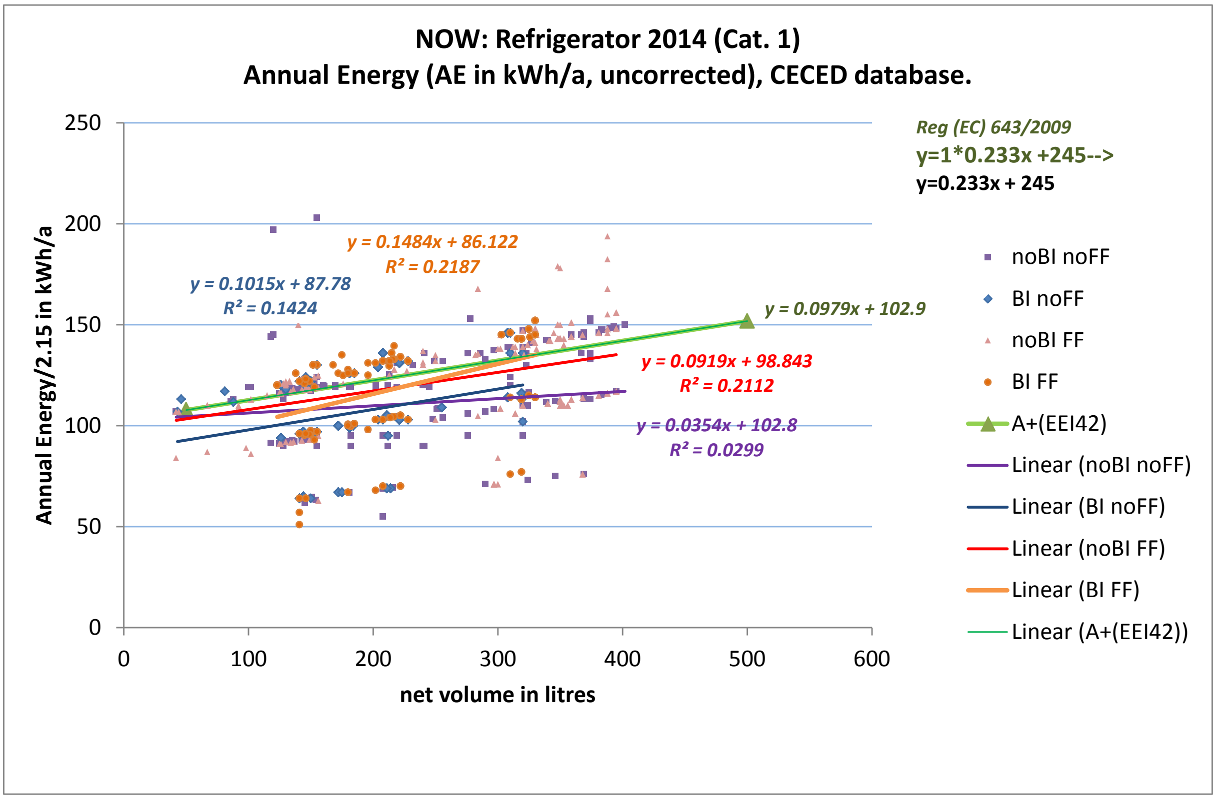


Figure 22. Refrigerator (category 1), regression of energy consumption in 2014 CECED database

[87] To ensure that $r_{c\_old}*M_{old}=r_{c\_new}*M_{new}$. With the new ambient temperature T_a =24°C the rc value of all non-fresh food compartments will change, e.g. for a freezer it becomes 2.1 instead of 2.15.

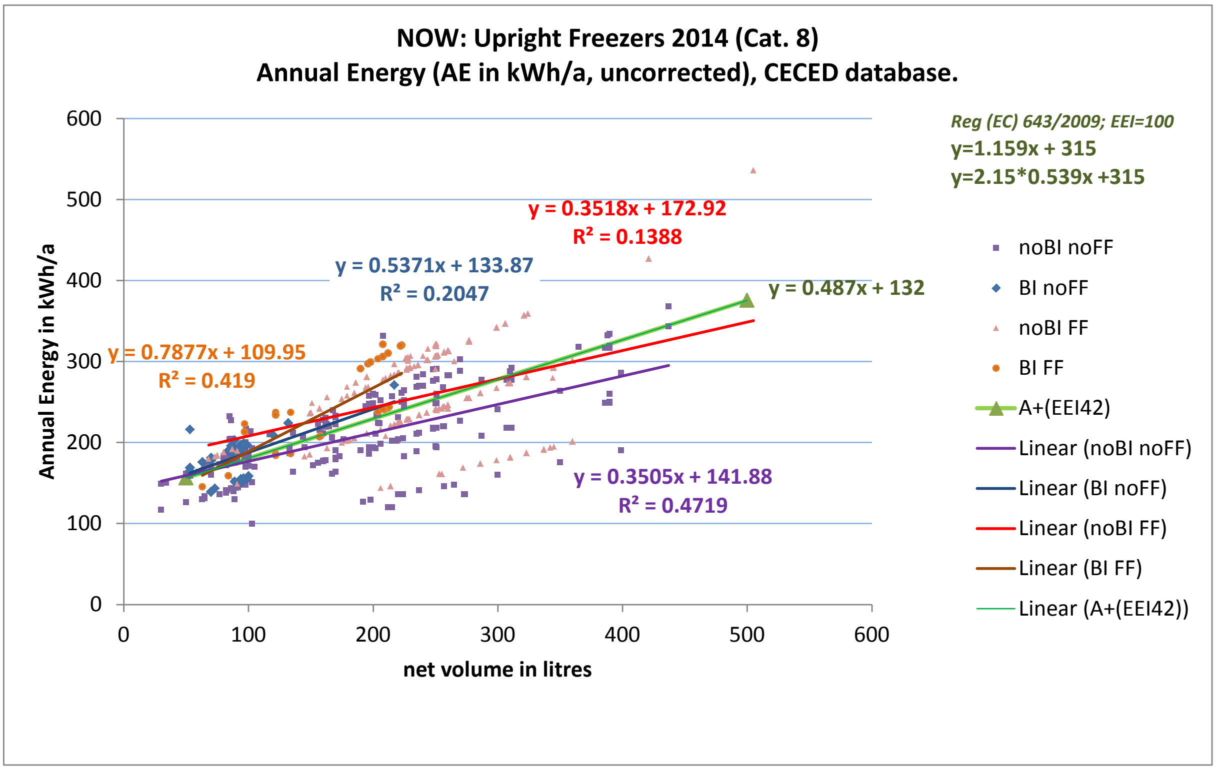


Figure 23. Upright freezer (category 8), regression of energy consumption in 2014 CECED database

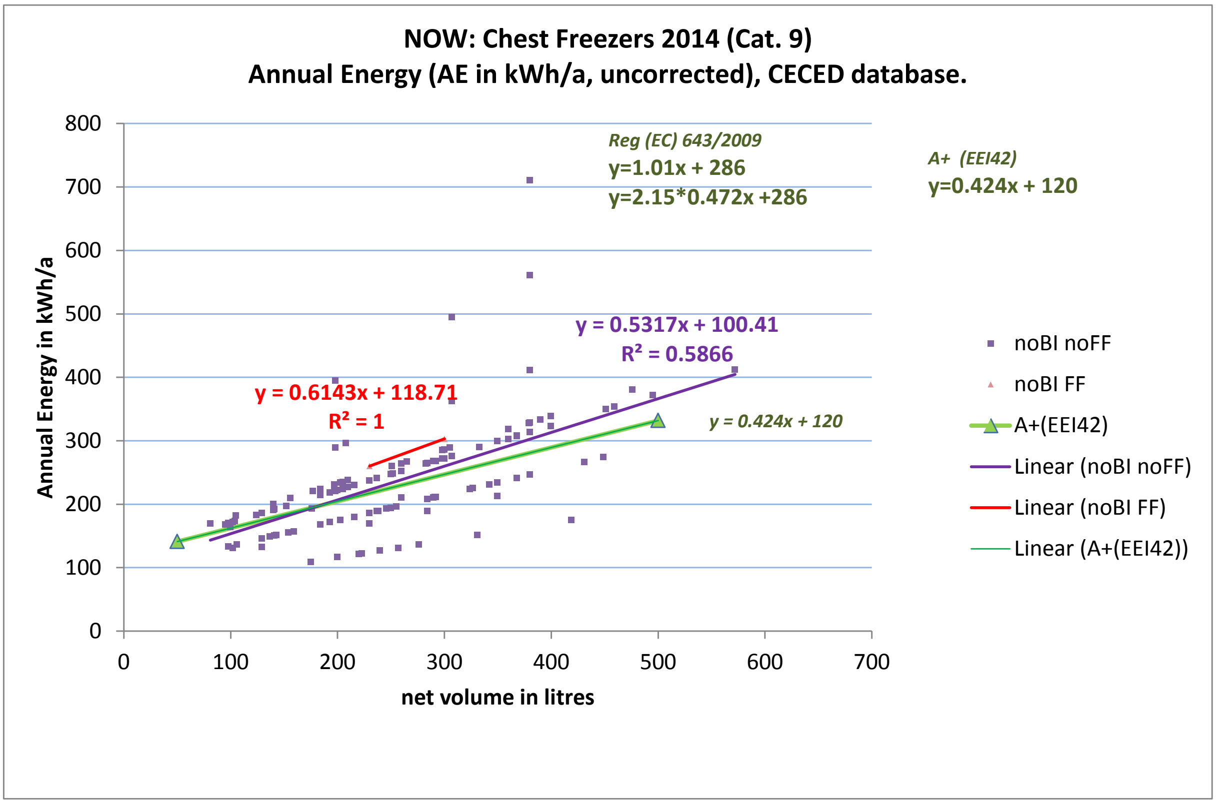


Figure 24. Chest freezer (category 9), regression of energy consumption in 2014 CECED database

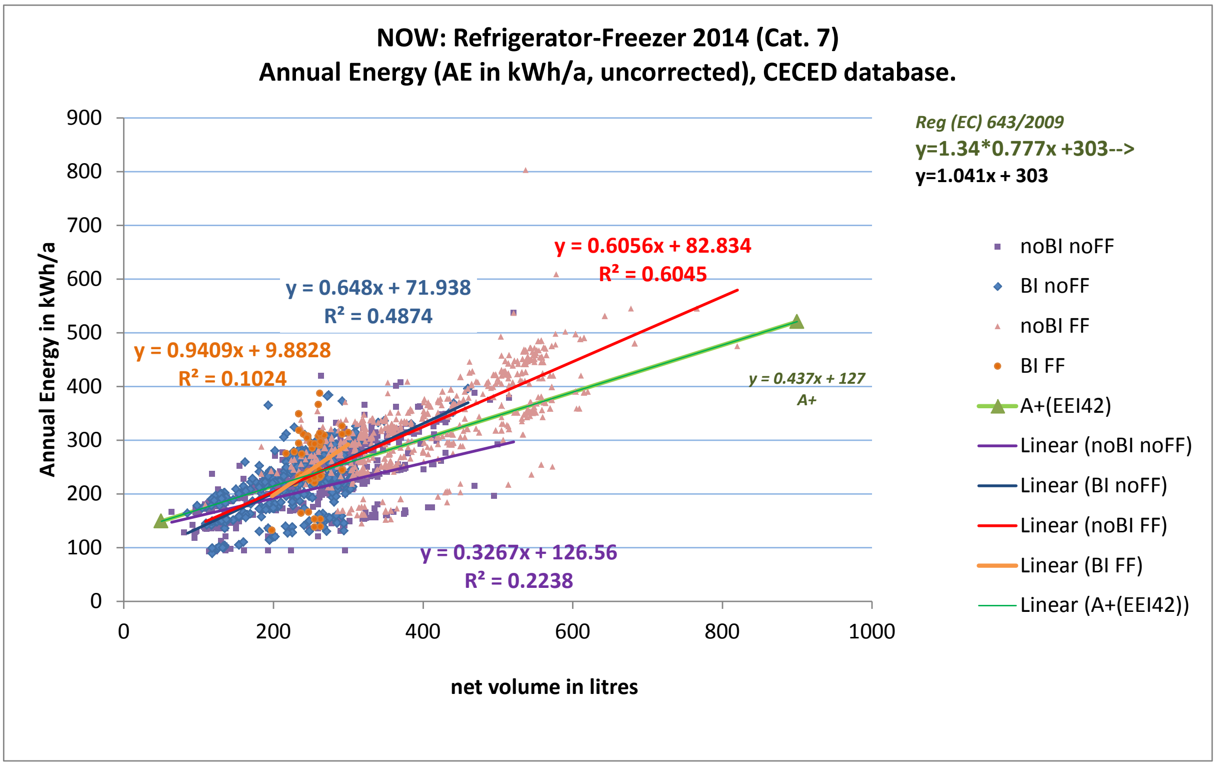


Figure 25. Refrigerator-freezer, all types (category 7), regression of energy consumption in 2014 CECED database

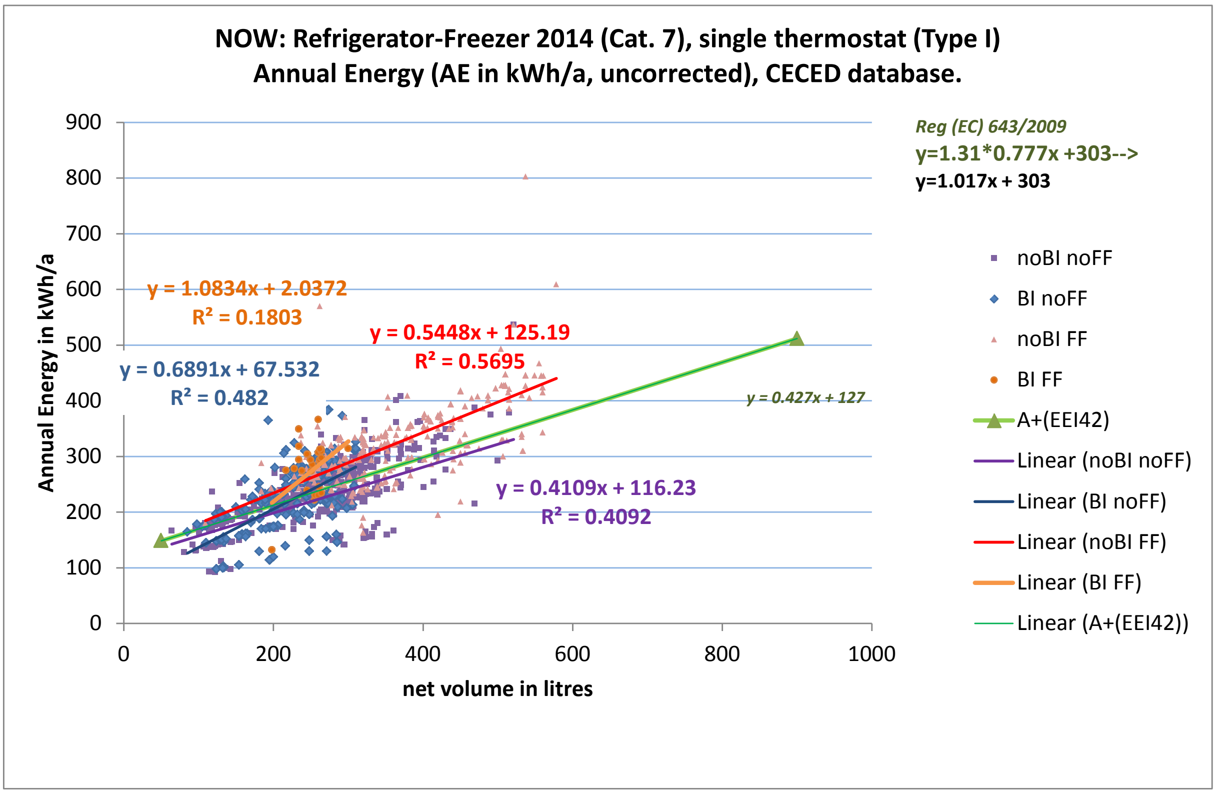


Figure 26. Refrigerator-freezer, all types (category 7), regression of energy consumption in 2014 CECED database

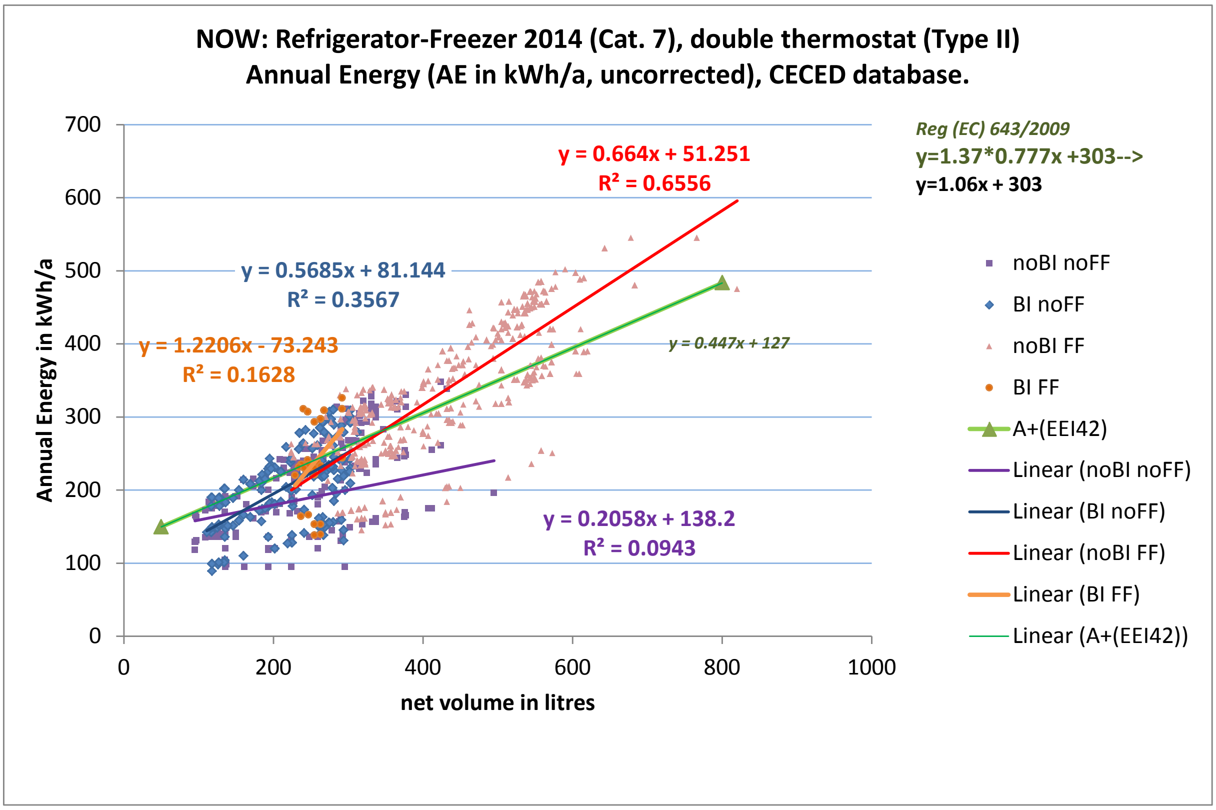


Figure 27. Refrigerator-freezer, Type II (category 7), regression of energy consumption in 2014 CECED database.

Table 15. Reference lines from linear regression of CECED database 2014

Category	No.	FF	BI	popul.	linear trend	r_c	Vgros	Vnet	Vfrz	Vother	Vfridg	AE	multi	factor	term	new r_c	new **M**	new **N**
				#	*y=*	*avg.*	*litres*	*litres*	*litres*	*litres*	*litres*	*kWh/a*						
1 Refrigerator	1	n	n	1024	0.035x+103	1	275	270			270	112	9%	0.038	112	1.00	0.038	112
	2	n	y	601	0.101x+88	1	208	204			204	108	9%	0.110	96	1.00	0.110	96
	3	y	n	610	0.092x+99	1	295	282			282	125	9%	0.100	108	1.00	0.100	108
	4	y	y	293	0.148x+86	1	218	216			216	118	9%	0.161	94	1.00	0.161	94
	5	A+=0.098x+103		2528	0.078x+96	1	257	251			251	115	9%	0.085	105	1.00	0.085	0.085
2 Wine storage	6	n	n	152	0.030x+179	0.65	238	207		207		237	8%	0.028	193	0.60	0.030	193
	7	A+=0.063+103		152	-0.127x+263	0.65	238	207		207	0	237	8%	0.028	193	0.60	0.046	0.030
7 Fridge-freezer	8	n	n	3726	0.326x+126	1.28	289	275	71	1	203	216	6%	0.346	134	1.28	0.344	134
(all)	9	n	y	2185	0.648x+72	1.21	242	230	44	3	183	221	6%	0.687	76	1.21	0.685	76
	10	y	n	4256	0.606x+83	1.45	423	385	108	6	270	316	6%	0.642	88	1.31	0.712	88
	11	y	y	339	0.941x+10	1.42	277	249	66	5	183	249	6%	0.997	11	1.32	1.077	11
	12	A+=0.411x+127		10506	0.526x+94	1.34	333	309	80	4	225	259	6%	0.558	99	1.29	0.436	0.581
7 Fridge-freezer (I)	13	n	n	2329	0.408x+112	1.29	288	276	73	2	202	229	10%	0.449	123	1.30	0.447	123
single thermostat	14	n	y	1352	0.677x+63	1.2	238	227	42	4	182	224	10%	0.745	69	1.21	0.738	69
	15	y	n	1214	0.480x+131	1.45	383	349	97	15	245	315	10%	0.528	144	1.34	0.573	144
	16	y	y	99	1.026x-3.7	1.42	270	252	60	9	184	274	10%	1.129	4	1.27	1.259	4
	17	A+=0.401x+127		4994	0.511x+101	1.31	297	280	70	6	207	249	10%	0.562	111	1.29	0.441	0.569
7 Fridge-freezer (II)	18	n	n	1398	0.214x+134	1.27	284	274	69	1	204	194	3%	0.220	138	1.28	0.219	138
double thermostat	19	n	y	834	0.547x+79	1.23	247	235	48	1	185	214	3%	0.563	81	1.22	0.567	81
	20	y	n	3040	0.573x+65	1.45	439	399	113	8	278	316	3%	0.590	67	1.32	0.651	67
	21	y	y	240	0.387x+130	1.43	280	256	69	6	181	239	3%	0.399	134	1.30	0.438	134
	22	A+=0.416x+127		5512	0.47x+87	1.37	364	336	90	5	241	266	3%	0.484	90	1.30	0.374	0.511
7(FF) no chiller	23	y	n	3217	0.514x+98	1.33	423	375	268	0	105	316	6%	0.545	104	1.78	0.407	104
	24	y	y	298	0.168x+206	1.31	277	256	67	0	189	252	6%	0.178	218	1.29	0.181	218
	25	A+=0.411x+127		3515	0.485x+107	1.33	411	365	251	0	112	311	6%	0.514	114	1.75	0.292	0.390
7(FF chiller)	26	y	n	1039	0.551x+84	1.32	467	415	120	24	272	341	6%	0.584	89	1.33	0.579	89
	27	y	y	41	0.458x+96	1.22	276	237	57	41	139	222	6%	0.485	102	1.30	0.456	102
	28	A+=0.428x+148		1080	0.547x+84	1.32	460	408	118	25	267	336	6%	0.580	90	1.33	0.436	0.574
7 (with cellar)	29	n	y	18	-0.404x+343	0.94	299	277	32	cllr 94	151	222	6%	-0.424	364	0.99	-0.402	364
	30	A+=0.307x+127		18	-0.404x+343	0.94	299	277	32	cllr 94	151	222	6%	-0.424	364	0.99	-0.428	-0.403
8 Upright freezer	31	n	n	1030	0.348x+137	2.15	191	176	176			204	-6%	0.328	129	2.10	0.336	129
	32	n	y	271	0.548x+127	2.15	98	86	86			180	-6%	0.517	120	2.10	0.529	120
	33	y	n	1351	0.325x+170	2.15	280	249	249			261	-6%	0.306	160	2.10	0.314	160
	34	y	y	263	0.704x+108	2.15	217	191	191			260	-6%	0.664	102	2.10	0.680	102
	35	A+=0.487x+132		2915	0.388x+149	2.15	226	203	203			233	-6%	0.366	140	2.10	0.174	0.375
9 Chest freezer	36	n	n	449	0.516x +101	2.15	268	261	261			240	-6%	0.487	95	2.10	0.498	95
	37	y	n	4	0.606x +118	2.15	270	265	265			282	-6%	0.571	111	2.10	0.585	111
	38	A+=0.424x +120		453	0.517x+101	2.15	268	261	261			240	-6%	0.487	95	2.10	0.232	0.499

8.2.2 Stand-alone and static

The categories of stand-alone (not built-in) and static (not frost-free) appliances are the basis for the analysis. As in the technical chapter 9, the figure 28 below gives the equations and curves for categories 1, 7, 8 and 9, in kWh/litre for the statistical regression. Figures 8, 9 and 10 give a comparison with curves from the present legislation (A+) and the technical modelling for categories 1, 7 and 8 (explained in Chapter 9).

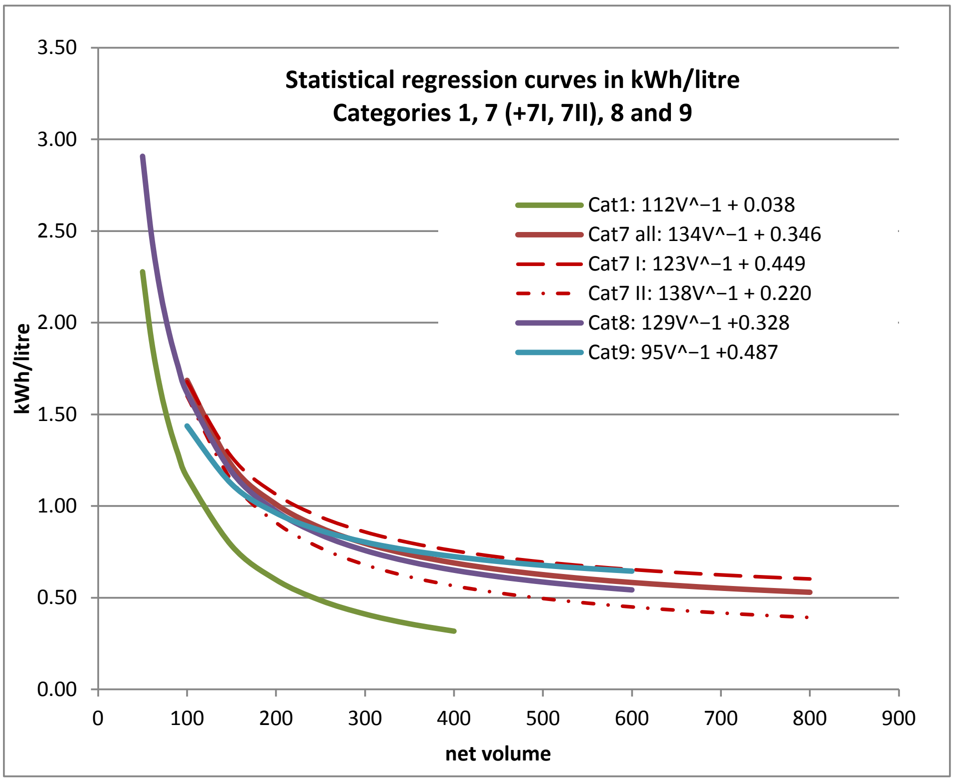


Figure 28. Statistical regression curves in kWh/litre for categories 1, 7, 8 and 9

The figure shows that the curves of categories 7, 8, 9 are very close together. Refrigerators in category 1 follow a steeper curve which is considerable lower than the rest, due mostly to the low M factor for fridges today. The fridge-freezer sub-category 7, Type I, is consuming the most per litre of volume, even more than freezer categories 8 and 9. Subcategory 7, Type II, is consuming less than the freezers and more than the refrigerators in category one.

The figure 29 below shows that the statistical regression curve for refrigerators, according to the new standard and without compensation factors, follows exactly the current A+ limit curve. The technical model, which will be explained in chapter 9, is more ambitious for the smallest models but close to the statistical regression curve for the largest models.

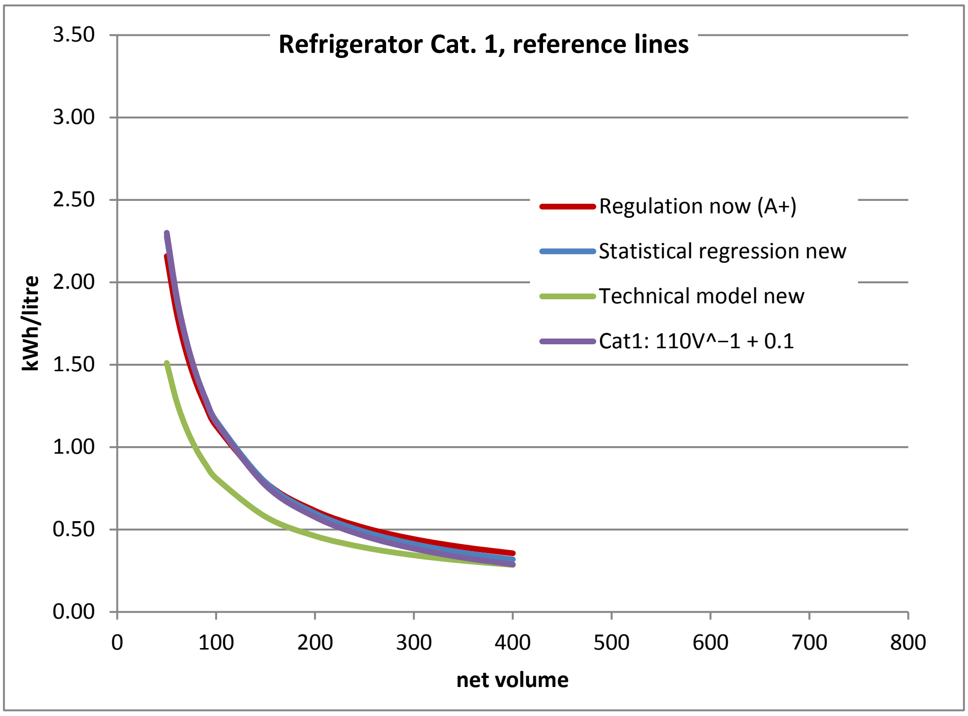


Figure 29. Refrigerator category 1, reference lines.

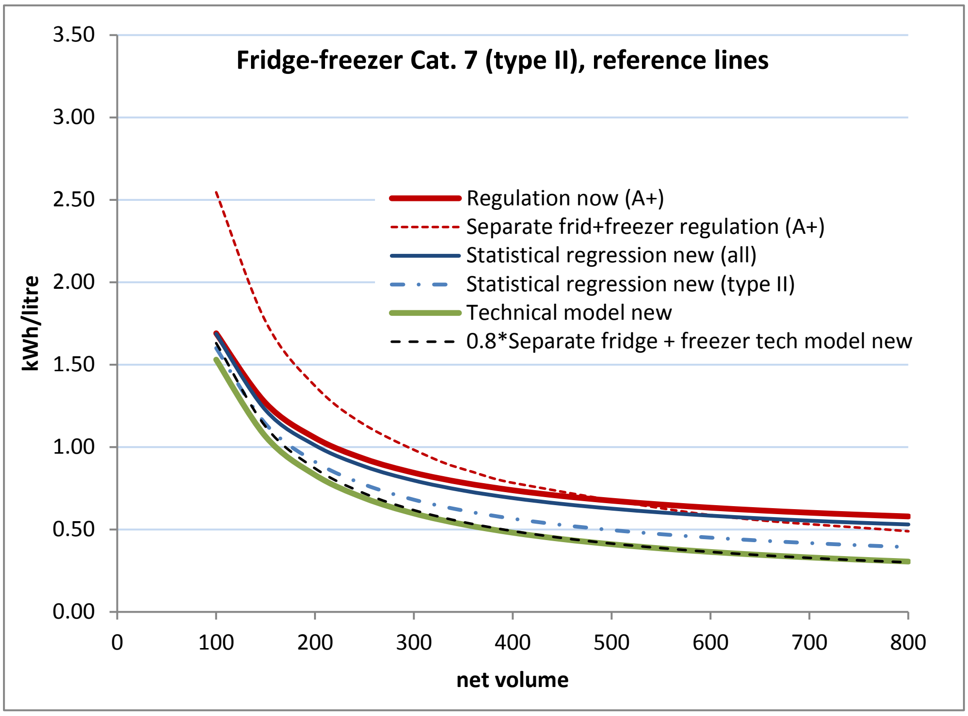


Figure 30. Refrigerator-freezer category 7, reference lines.

The fridge-freezer curves are shown in figure 30. It shows that the average regression curve for all types (blue solid line) is following the regulation curve at a constant distance of around 10 % lower. More interesting is the regression line of Type II (blue dash-dot line), which is very similar to 0.8 times the sum of the separate fridge and freezer (black dotted line).

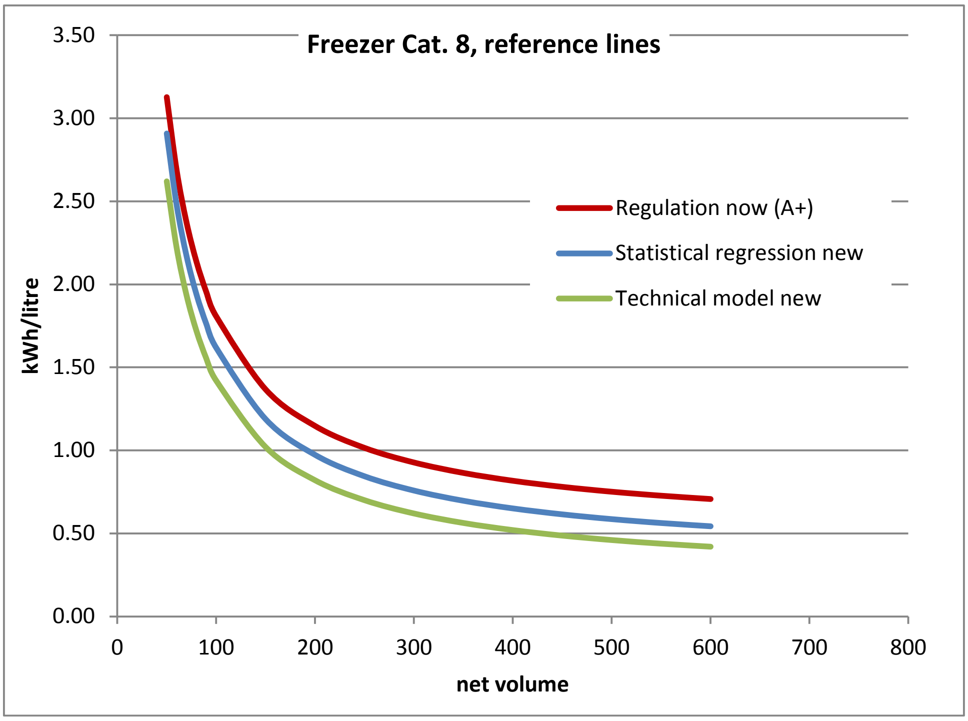


Figure 31. Upright Freezer category 8, reference lines.

The statistical regression curve for the upright freezers is close to the technical model (see Chapter 9). Both these curves follow the regulation-curve up until a net volume of 100 litres. After that they deviate slightly and reach a more ambitious level.

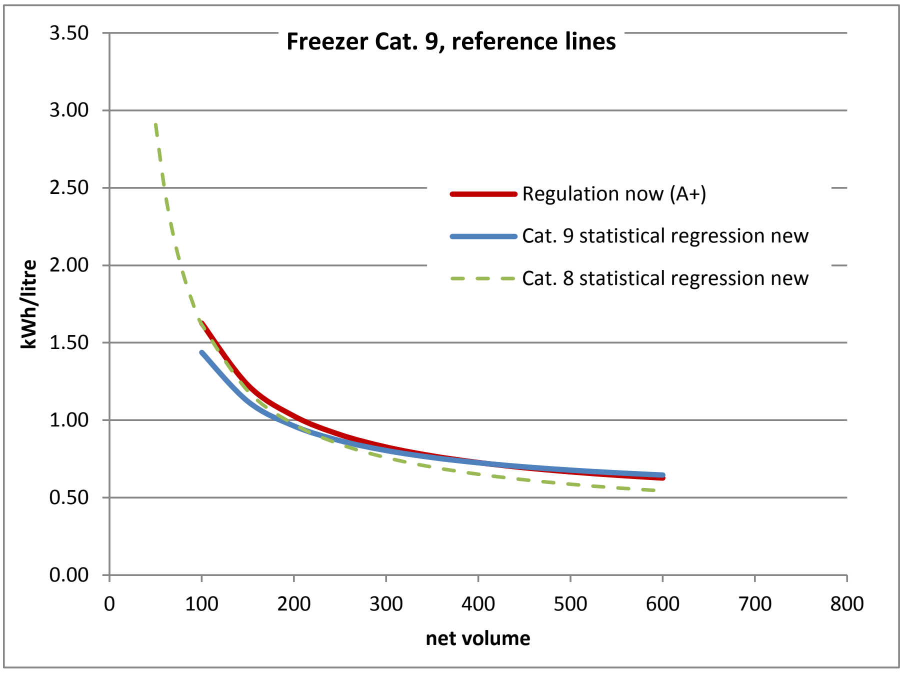


Figure 32. Chest Freezer category 9, reference lines.

8.2.3 No-Frost

The CECED database makes a distinction between 'no-frost' and normal refrigerators of category 1. This 'auto-defrost' feature is not compensated in the regulation (the FF applies only to frozen food compartments), but apparently the fan and smart control can raise the energy consumption by some 10-13 kWh or around 8-10 %. In the stand-alone upright freezer the defrosting costs 57 kWh or 28 % more, but the no-frost freezer is on average also bigger. The M-values are similar (defrost 0.02 lower), but the N-values suggests that —per litre volume— the extra energy use is 20-22 % (compare new N=129 versus new N=160 minus a small effect from the lower M). There are only 4 models of no-frost chest freezers in the database, but the little information that is available suggests a 16-17 % difference. In this case it affects both the M and N values.

Stand-alone no-frost fridge-freezers are completely different from stand-alone fridge-freezers, in size and features. Hence it is not possible to derive meaningful conclusions for a no-frost factor from the comparison. The built-in fridge-freezers with and without no-frost are similar. The difference in annual energy consumption (AE) is 28 kWh/a. For the appliance as a whole this is an increase of 12 %. Assuming that the freezer consumes less than half of the total energy, the increase relative to the freezer volume is around 25-30 %. The appliances have the same refrigerator volume (183 litres) but the freezer compartment of the no-frost appliance is 50 % larger (66 versus 44 litres). This indicates a correction factor of around 1.2 is appropriate when applied only to the freezer volume.

8.2.4 Built-in

Built-in refrigerators consume on average as much as stand-alone refrigerators in the CECED database, so there seems to be no apparent need for a 'built-in' compensation. With the stand-alone upright freezer we see that the M-value is 0.2 higher in the built-in appliance (57 % increase), while the N-value stays equal. Taking the stand-alone static freezer as a basis (176 litre) this means a 10-11 % increase per litre, i.e. from around 200 to over 220.

The static 'built-in' fridge-freezer is almost 20 % smaller in volume than its stand-alone counterpart (230 versus 275) but consumes slightly more (221 versus 216 kWh/a). As can be seen from the M and N values as well as the figures 1 to 6, the built-in fridge-freezers show a strong upwards inclination (high M) compared to the stand-alone. This is coherent with the fact that the BI-factor applies to the equivalent volume. It may also coherent with a possible design-strategy where the extra room provided by the factor 1.2 is optimally utilised for energy-using extra features that are not related to 'built-in'. Otherwise it is hard to explain, e.g. in comparison with the freezer that is in much more need of cooling air than a built-in fridge freezer.

In short, a 10-11 % built-in correction acceptable for a freezer-compartment, also when included in fridge-freezer, is consistent with the results and not necessarily contradicted by the factor 1.2 found for fridge-freezers. This also simplifies the calculations.

8.2.5 Wine storage

The wine storage appliances in the database contained models of all energy classes, i.e. from A to G and even a few A+. Even when eliminating the extreme 'G' appliances 152 data-points remain that show a huge spread. The only thing we might learn from the equation is that the line of kWh/a versus volume is almost flat, i.e. there is relatively large fixed energy consumption which hardly varies with volume. The reasons may be that a) consumers of these appliances hardly have an interest in the energy label and thus even 'G' labels are commercially unproblematic, and b) there is no Ecodesign minimum requirement.

8.3 Comparison of 2014 base cases to 2005 ones

In order to find the trends from the last nine years of average and maximum appliances for each category, the 2014 data are compared to data that found in 2005. Table 16 below gives the results of the 2005 data (EuP Lot 12 Preparatory study 2007) and compares them to data of the 2014 database. The 2014 category 1 is compared to the 2005 Category 1-6, 2014 category 7 to 2005 categories 7&10. Categories 8, 9 and 2 remain unchanged between studies.

Table 16. 2014 and 2005 data category data for all domestic refrigeration appliances

2014	Net Volume (L)			Energy Consumption (kWh/yr)			En. Cons. by vol.	Energy Efficiency Index (%)			Mandatory Noise (dbA)	
Category	Min	Max	Average	Min	Max	Average	Average	Min	Max	Average	Max	Average
1	42	402	247	51	261	119	0,48	17	95	36	45	38
7	64	820	310	89	609	258	0,83	16	89	36	52	39
8	30	505	203	100	536	232	1,14	20	55	37	50	40
9	81	572	261	109	710	236	0,90	22	95	39	55	42
2	20	625	187	102	676	237	1,27	33	258	87	63	44
2005	**Net Volume (L)**			**Energy Consumption (kWh/yr)**			**En. Cons. by vol.**	**Energy Efficiency Index (%)**			**Mandatory Noise (dbA)**	
Category	Min	Max	Average	Min	Max	Average	Average	Min	Max	Average	Max	Average
1	45	403	223	83	285	164	0,73	30	79	54	46	38
7	98	627	277	124	786	324	1,17	27	90	54	48	40
8	45	335	177	135	540	275	1,55	29	105	56	45	40
9	57	572	254	134	595	300	1,18	27	108	64	49	42
2	150	390	314	131	226	164	0,52	40	72	53	40	37

Table 16 shows that, except for the wine coolers (category 2), there is a 2.7 to 14.6 % (average 11%) increase in average net volume for these five categories from 2005 to 2014 while the minimums remain comparable. This means that in general domestic cooling appliances have grown in size over the past decade at a rate of ~1 % per year. Along with this increase in size there has been a large decrease in annual energy consumption, except for wine coolers. Taking both of these changes into account the Energy Efficiency Index would have to decrease unanimously just as it is shown in the tables. Here it has decreased around 20 % for all categories; this is a substantial decrease in just nine years.

The minimum and maximum values relate to the extremes in the database. As the 2014 database is considerably larger than the 2005 database, the differences in minimum and maximum values do not necessarily reflect actual trends in the market.

9 Technical analysis and metrics (Task 4.1)

9.1.1 Introduction

The minimum ecodesign efficiency limits and energy label class limits for household refrigeration use specific and unique metrics, with reference lines for the limits (mainly) determined by the equivalent volume V_{eq}, a factor M and a term N.[88] The equivalent volume V_{eq} is a technical correction for the design temperature of the compartment(s), taking the inside-outside temperature difference of the fresh food compartment (20 K) as a reference.[89] The parameters M and N are derived from a regression analysis from the database of commercially available models in 1992.
With the review and the new global IEC standard there is an opportunity to update and improve the reference lines to 2015. This means not only looking at parameter values but several stakeholders also call for a simpler approach and an approach that is based (also) in technology and not only abstract values from a commercial database.

This chapter aims to explore

- the effect of the current metrics and its alternatives; as well as
- the technical reasons behind the current and possibly the future reference lines.

Ultimately this is part of the effort to establish the definition of new reference lines for Ecodesign minimum efficiency values and energy label class limits.

9.1.2 Effect of M and N in the current regulation

The energy efficiency parameter of a household refrigeration appliance is currently defined as an energy index EEI which is calculated from the ratio between the actual annual electricity consumption of a model AE [in kWh/a] and a 'standard' annual energy consumption SAE [in kWh/a]: $EEI=AE/SAE$. Subsequently the value SAE is calculated from an equation with equivalent volume V_{eq} [in litres], which is the actual net volume V multiplied with the ratio of compartment-ambient temperature difference of the compartment and 20K. For a refrigerator, with compartment temperature +5 °C, ambient +25 °C and thus a temperature difference ΔT_{rf} of 20K, this ratio is 1. Subsequently, V_{eq} is multiplied by a factor M with the addition of the term N. For instance for single compartment appliance $SAE=V_{eq}\cdot M+N$. For an appliance with a number of n compartments (identified by an index c, with a specific compartment temperature T_c) the equivalent volume without correction factors is $V_{eq}=\sum_{c=1}^{c=n} V_c \times \frac{(25-T_c)}{20}$. Hereafter we use the notation $r_c=\frac{(25-T_c)}{20}$.

It is important to realise that the use of the index and the comparison with a standard reference use is a choice, which mathematically could also have been made differently. For instance, the above means that $EEI=AE/(V_{eq}\cdot \mathrm{M}+\mathrm{N})$. In case of a refrigerator, with $V_{eq}=r\cdot V$, the index $EEI=AE/(r\cdot V\cdot \mathrm{M}+\mathrm{N})$. If we split up the denominator in $AE=V\cdot q$, where q is the specific annual energy consumption in kWh/litre, the equation can be rewritten to $EEI=(V\cdot q)/(r\cdot V\cdot \mathrm{M}+\mathrm{N})$. For the baseline with $EEI=1$ the equation becomes $V\cdot q= r\cdot V\cdot \mathrm{M}+\mathrm{N}$ and thus $q=(r\cdot V\cdot \mathrm{M}+\mathrm{N})/V$. This can be rewritten as $q=r\cdot M+N/V$, expressed in kWh/litre, which is a unit comparable to the one used in other Ecodesign regulations to define limit values e.g. $\mathrm{lumen/W_{in}}$, $\mathrm{W_{out}/W_{in}}$, $\mathrm{Wh_{in}/cycle}$, etc.. More conventionally, given that the multiplier and variable V go first, the expression is $q=N/V+rM$ or $q=NV^{-1}+rM$.

[88] And a possible correction for the chiller CH.
[89] The approach does not want to abandon the equivalent volume approach itself, but takes a critical view at the correction factors M and N.

Note that it is much more apparent that the expression is non-linear (format $y=x^{-1}$) and sets, comparable to other Ecodesign regulations, more stringent requirements as the volume of the refrigerator increases. The figure below compares, for a refrigerator in the current regulation (M=0.233, N=245), the q and the SAE lines, both for EEI=1 (M=0.233, N=245) and EEI=0.42 (current A^{+} label and Ecodesign minimum; M=0.098, N=103).

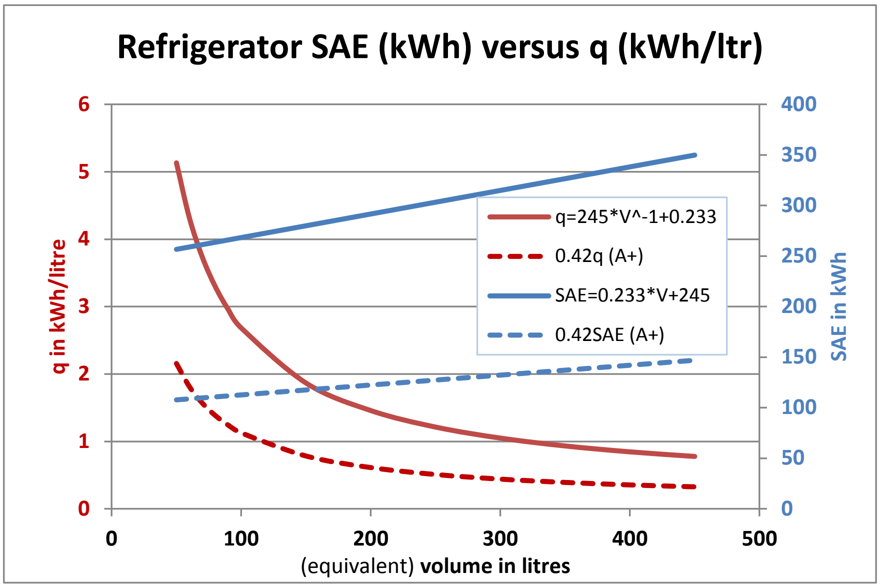


Figure 33. Standard Annual Energy (kWh) versus specific energy q (kWh/litre) for EEI =1 and EEI=0.42 (A+) in the current legislation.

The figure shows that, with the current A+ limit (EEI=0.42), a 50 litre refrigerator is allowed to consume 2.16 kWh/litre and a 400 litre refrigerator only 0.36 kWh/litre, i.e. a factor 6 less.

The current legislative text could thus have been more compact, stating e.g. that a refrigerator (fresh food compartment) shall have a specific energy consumption $q \le 103 \cdot V^{-1} + 0.098$ and using $EEI \cdot (245 \cdot V^{-1} + 0.233)$ for the class limits.

In case of a 3/4-star upright freezer (Category 8, T_c=-18°C; M=0.539, N=315) the equivalent volume is 2.15 times the actual net volume. In that case the reference line ($EEI=1$) would be $q= 315V^{-1} + 2.15 \cdot 0.539 = 315V^{-1} + 1.159$. The limit at A+ ($EEI$=0.42) is $q \le 132V^{-1} + 0.487$. For a similar chest freezer (Cat. 9; M=0.472, N=286) the limit at A+ is $q \le 120V^{-1} + 0.426$.

In case of a fridge-freezer (Category 7, M=0.777, N=303), assuming actual freezer volume to be 25% of the total[90] and thus $V_{eq}=0.25*2.15 + 0.75*1=1.29$, the reference line would be $q= 303 \cdot V^{-1} + 1.29 \cdot 0.777 = 303 \cdot V^{-1} + 1.002$ and the limit at A+ is $q \le 127 \cdot V^{-1} + 0.420$.

The figure below gives an overview of the A+ curves in kWh/litre for categories 1, 7, 8 and 9 (refrigerator, fridge-freezer, upright and chest freezer).

[90] Average of the 2014 CECED database is 25.8%.

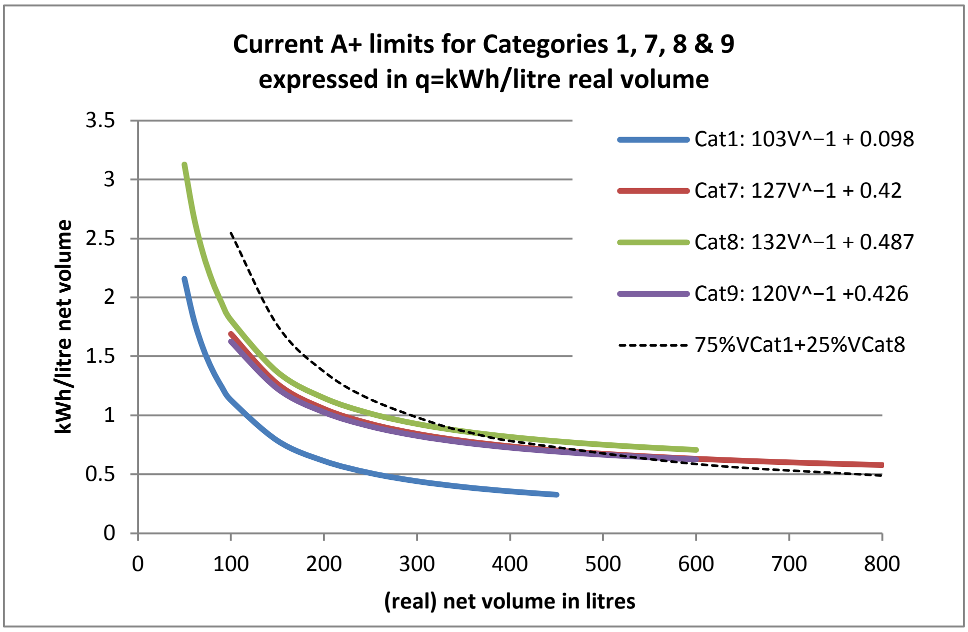


Figure 34. Overview of the A+ curves in kWh/litre for categories 1, 7, 8 and 9.

For comparison with the fridge-freezer category 7 a dotted curve was added for the case where the compartments for freezers and refrigerators would have been realised with a separate refrigerator (75 % of volume) and a separate freezer (25 % of total volume). It shows that above a net volume of 500 litres, at the limit A+ line, the combination of a separate 125 litre upright freezer (Cat. 8) and a 375 litre refrigerator saves energy with respect of a 500 litre fridge-freezer Category 7 with the same respective compartment volumes. Furthermore, it is remarkable that the limit in kWh/litre of a chest freezer (category 9, r=2.15, T_c=-18 °C) is lower than that of a fridge-freezer (category 7, r=1.29, T_c = +5 [75 %V] and -18°C [25 %V]).

In the technical paragraphs hereafter we will explore this further.

9.1.3 Simple heat demand model for a refrigerator

In the following it is attempted, through a simplified model with parameters that can be verified in the manufacturer's database, to explain the technical background of the equivalent volume correction.

The simplest representation of (the heat load of) a refrigerator is based on a closed box with outer width w, depth d, height h and wall thickness t, all dimensions are in m. The inner volume of the box, in m³ (1000 dm³), is:

$$V = (w-2t)\cdot(d-2t)\cdot(h-2t)$$

The compartment (inside) temperature T_c of the box is 5 °C and the ambient (outside) temperature T_a is 25 °C. The temperature difference ΔT is 20 K. The thermally neutral envelope runs exactly half way between outer and inner envelope. The surface of that envelope, in m² (100 dm²), is:

$$A = 2 \cdot [(w-t)\cdot(d-t) + (w-t)\cdot(h-t) + (d-t)\cdot(h-t)]$$

For the calculation of the transmission heat losses we need to know the thermal conductivity of the wall k, in W/mK (per m²), and the wall thickness t in m (10 dm). The transmission heat transfer coefficient U, in W/m²K, is:

$$U = k/t$$

The k-value of poly-urethane (PUR) is around 0.02 W/mK. For instance with a wall thickness t of 0.05 or 0.06 m (5 or 6 cm) this would result in a U value of 0.4 W/m²K.

Assuming that the box is fully closed, i.e. there are no convective heat losses, the (transmission) heat loss P, in W, is:

$$P = A \cdot U \cdot \Delta T$$

Now the annual heat losses in kWh can be calculated for a year with 365 days and 24 hours per day (conversion factor from W is 0.001).

$$AE_{load} = 0.001 \cdot 365 \cdot 24 \cdot P$$

The figure below shows examples of the dimensions of a typical small ('mini-bar') and large refrigerator. With a k-value of 0.02 W/mK for the insulation material it can be calculated that the annual heat loss of the small refrigerator is 117 kWh/a (P= 13 W) for a volume of 68 litres. The annual heat loss of the large refrigerator is 260 kWh/a (P= 30 W) for a volume of 403 litres.

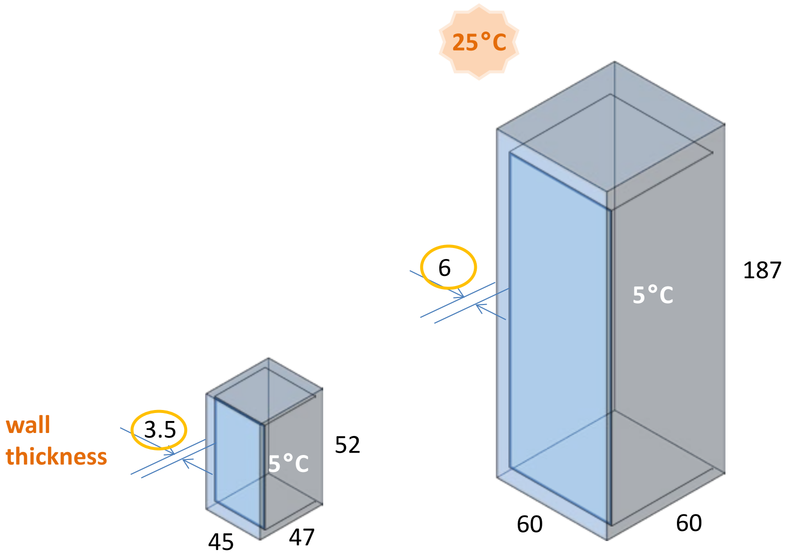


Figure 35. Smallest and largest refrigerators (Cat. 1) in CECED data base.

This means a specific heat loss per litre of volume of 1.7 kWh/litre for the smallest and 0.65 kWh/litre for the largest refrigerator. This is a factor 2.6 increase.
One cause is the relationship between the volume (functional parameter) and the envelope surface (heat loss determining parameter). In the construction sector, where the heat loss of houses is calculated in the same way, this is called the AV ratio (surface divided by volume). The AV ratio of the smallest refrigerator is 1.7 (1.7 dm² surface per 1 dm³ volume) and that of the largest refrigerator 1.1. This is a 55% increase.

Another cause is the difference in wall thickness. A wall of 6 cm instead of 3.5 cm gives a factor 1.7 increase. In combination with the AV ratio effect, the total increase in heat loss is 260 % (1.7*1.55=2.6).
One might argue that the wall thickness is not a pre-determined variable. However, in practice the designer has relatively little room for that because in a small refrigerator it is functionally not acceptable to have too little useful volume. In the CECED database, in as far as could be determined from the data, there seems to be a 'consensus' that the wall

thickness increases with volume in a fairly linear way (see statistical analysis in Chapter 10).

The illustrative figure below shows both influences in one graph.

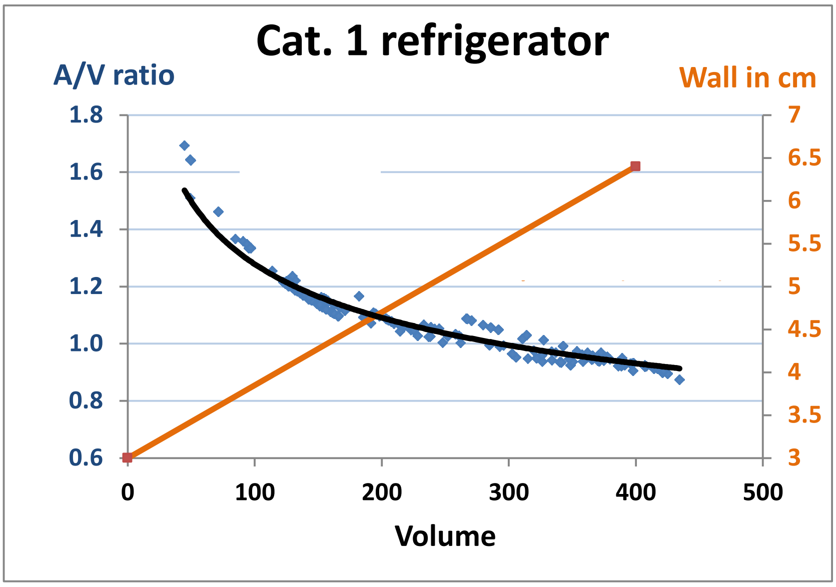


Figure 36. Calculated AV ratio and wall thickness versus net volume of a refrigerator (Category 1). Wall thickness is illustrative only (see Chapter 11)

When comparing these influences with the trend-line in the industry database for refrigerators (Category 1) a coherent picture appears (see fig.37).

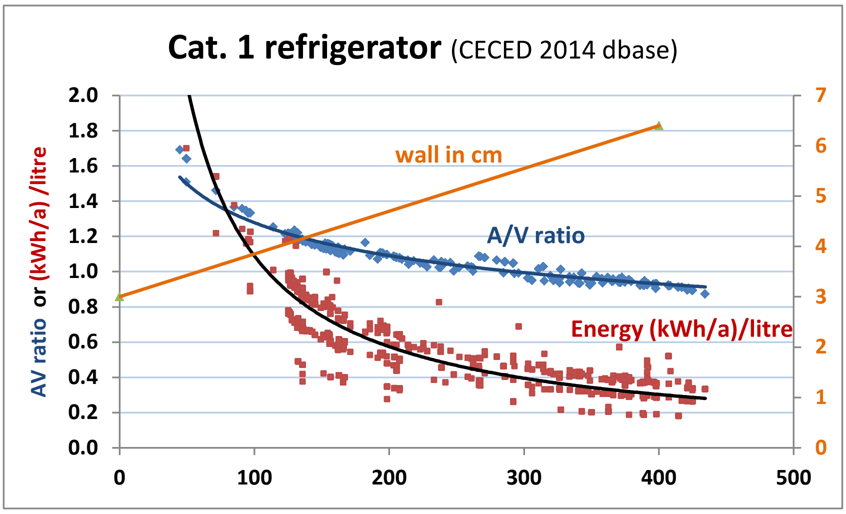


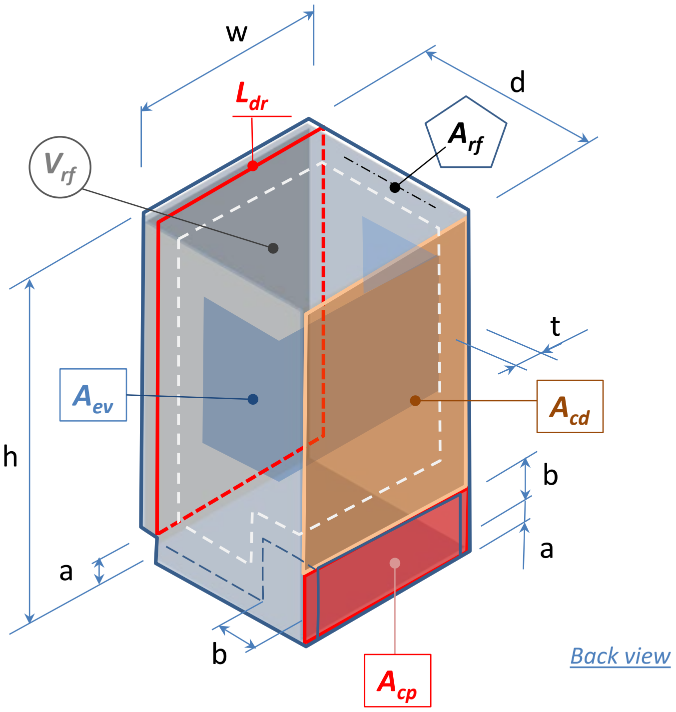
Figure 37. AV ratio, wall thickness (cm) and energy (kWh/a) per litre net volume

9.2 More detailed heat demand model for a refrigerator

In a more sophisticated model we can also take into account the influence of compressor area and the door heat leakage. Also the temperature model can be improved.

9.2.1 Compressor space

Some scale effect is expected from the compressor space, because –almost independently of the volume of the refrigerator—the dimensions of this space at the back of the product remain unaltered. This is illustrated in the figure below, where this space has the dimension b x b x w. At typical values b=0.2 m and w=0.6 m this means a volume of 24 dm^3 (litres) that is not available for the compartment or insulation. Furthermore, the space below the refrigerator, that is useful for the air passage from the front, is also not available. With dimensions a x w x d, where a=0.05 and d=0.6 m, this space takes up some 18 dm^3. For the larger refrigerator in figure 35, with an outer volume of 673 dm^3, the loss of 42 dm^3 is only 6 %; for the small minibar refrigerator, with an outer volume of 110 dm^3 and reduced width/depth, the space loss is up to 25 %.



Refrigerator geometry parameters

V_{rf}	refrigerated volume (m^3)
A_{rf}	refrigerator envelope surface (m^2)
A_{cd}	condensor area (m^2)
A_{cp}	compressor area (m^2)
A_{ev}	evaporator area (m^2)
L_{dr}	door perimeter length (m)
w	width (m)
d	depth (m)
h	height (m)
a	air passage height below unit (m)
b	height/depth compressor area (m)
t	average wall thickness (m)

Figure 38. Refrigerator dimensions and other relevant geometry parameters.

Also relevant for scale effects in efficiency is the fact that the fixed compressor space (surface A_{cp}) takes away space from the (variable) available space for realising the condenser. As will be discussed later, the condenser surface is an important parameter in the COP and the space/surface available for maximising the condenser surface (A_{cd} in the picture) is thus important. In the case of the small refrigerator the A_{cp} is almost 50 % of the total back-surface, which means that only 50 % (13 dm^2) of the back-surface of the refrigerator is available for the condenser space/surface A_{cd}. In the case of the large refrigerator only 13 % of the back-surface is taken by the compressor, which means that still 87 % (97 dm^2) remains for the condenser.

The reason why the available condenser and evaporator area are important for the energy efficiency is explained in the following paragraphs on temperature maps and cooling systems. Quantitatively the effect is demonstrated for several design options in Task 6 (Chapter 12). But, in short, a larger heat exchanger surface means —for a given capacity— lower heat exchanger temperatures, which means a better compressor/cooling system efficiency (COP).

9.2.2 Door gasket heat leakage

The door gasket heat leakage is another issue to take into account in a more sophisticated model. In inefficient models it is said to account for only 10-20 % of the total energy loss, but especially with well-insulated models it may run up to 30 % of the total. The most common accounting unit is W/mK, i.e. Watts heat loss per meter of door gasket per degree K of inside-outside temperature difference. In reality, the quality of the gasket (material & shape), wall thickness and the general geometry ('labyrinth) in the door area play an important role, as well as the presence of a possible 'anti-sweat' line running around the cabinet edges. In other words, 'door gasket losses' should be understood in the widest possible sense.

Industry sources report values of 0.08 W/mK for a refrigerator and 0.03 W/mK for freezers (including 30 % extra losses for fan-assisted evaporator). Academic studies by Huelsz et al. for freezers confirm this order of magnitude.[91] This suggests that the wider contact area that comes from the larger wall thickness compensates for the inside-outside temperature differences between refrigerator (20 K) and freezer (43 K).
The door gasket losses have a scale effect that is unfavourable for smaller appliances. For instance, the door perimeter length L_{dr} of the small refrigerator amounts to 1.84 m, which amounts to 3 W heat loss (1.84 m x 0.08 W/mK x 20 K) while for a large refrigerator it is 4.84 m amounting to 7.8 W. This is a factor 2.6 difference, but the difference in useful inner volume between the two is a factor 7.6. Per unit of inner volume the small fridge has thus almost 3 times more door heat leakage.

The equations for the aggregated parameters are straightforward and are given below:

$$V_{rf} = (w-2t)\cdot(d-2t)\cdot(h-a-2t) - b^2\cdot w$$

$$A_{rf} = 2\cdot(w-t)\cdot(d-t) + 2\cdot[(h-t-a)\cdot(d-t)-(b+0.5t)^2] + 2\cdot(w-t)\cdot(h-t-a)$$

$$A_{cd} = w\cdot(h-a-b)$$

$$A_{cp} = w\cdot(a+b)$$

$$L_{dr} = 2\cdot(w+(h-a))$$

For dimensions a and b fixed values of a=0.05 m and b=0.2 m can be assumed.

9.2.3 Temperature map

In a less simple model, a closer look at the temperature values shows that there is not just a single compartment temperature T_c of +5 °C and an ambient temperature T_a of 25 °C. The air temperature in the middle of compartment may be 5 °C, but according to industry a roll-bond evaporator that is integrated in the wall of the compartment may have a temperature that is 15 °C lower (-10 °C) and this influences the transmission losses. In fact, inside a refrigerator with only a plate heat exchanger there is a considerable temperature gradient, from cold to less cold, from back to front and from bottom to top.

Also outside the cabinet the ambient air temperature varies, even in a test room of nominally 25 °C. At the back of the refrigerator it is considerably higher than 25 °C. The condenser is 35 °C and is placed only 3.5 cm from the backside insulation. The same goes for the compressor that might emit 30-40 °C heat. Therefore the outer back-wall including compressor space, which makes up some 20 % of the total envelope surface

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[91] Guadalupe Huelsz et al., Evaluation of refrigerator/freezer gaskets thermal loads, HVAC&R Research, 17(2):133–143, 2011.

will be subject to a temperature of at least 30-32 °C. The temperature difference with the evaporator that is placed also on the back-wall from the inside is thus easily 40 K. At the same time, the rest of the outside of the envelope surface is colder than 25 °C. According to conservation laws, the temperature of the system should be in balance, except for the input of waste heat of the compressor which is subsequently extracted in the test-room. It is difficult to say whether a more realistic temperature map has a scale effect, but it might be of influence.

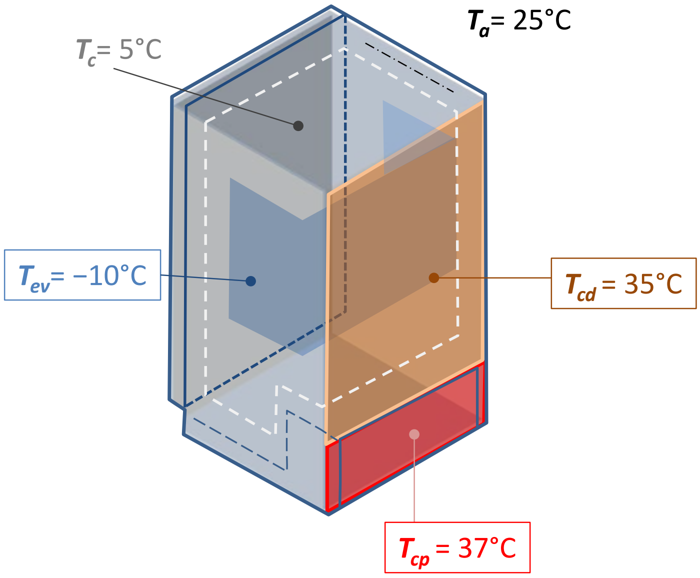

Figure 39. Basic refrigerator temperature map (illustrative)

9.2.4 Insulation values

Apart from PUR, vacuum insulation panels (VIPs) are more and more part of the top-range appliances. Typically, VIP panels of 2 cm thickness are used, embedded in PUR for structural strength. In that sense, despite the fact that the k-value is at least 4 times better than PUR, the U value of such a PUR/VIP panel is 'only' 33 % better. The panels are not used all-around, but only in (some of) the walls where they have most effect, i.e. bottom, back and front (door), and only in the larger and more expensive models. It can be estimated that in those models the sides with VIP panels make up 30-40 % of the envelope surface area and can bring about a 15% reduction in the transmission heat losses (12 % in total electricity consumption).
The table below gives k-values of refrigerator insulation and —anticipating the discussion on wine storage appliances— the U-values of a number of window-types (from Ecodesign Windows study 2015).

Table 18. U-values (source: Ecodesign Windows study 2015)

Glass door U-values glass+frame (70/30% of area)	**W/(m².K)**	
double glazing simple	2.8	
double glazing E-coating, argon fill	**1.7**	reference (economical, normal, etc.)
double glazing E-coating, krypton fill	**1.3**	for premium models
triple glazing E-coating, argon fill	1.1	very heavy door (hinge needs mechanical help)
triple glazing as above but middle 'glass' is film	1	estimate (door is lighter)
triple glazing E-coating, krypton fill	0.8	very heavy door (BAT)
vacuum glazing (double glass with studs)	0.8	Experimental; door would be lighter (BNAT)
quadruple glazing, E-coating, krypton fill	0.6	impossibly heavy for fridge door (BAT for fixed windows)
Refrigerator insulation	**W/mK**	Watts per meter thickness and K
PUR + cyclopentane	0.020	for average size, i.e. 270 litre, 6cm is normal
VIP	0.005	
Combined 40% VIP (2 cm), 60% PUR (3 cm)	0.015	

9.3 A simple cooling system model

9.3.1 Overview

To balance the heat loss and keep the inside temperature constant a cooling system is needed to cool the interior, in this case a Carnot-cycle heat pump. This heat pump consists of a heat exchanger (the 'evaporator') to cool the inside of the box, a heat exchanger outside the box to dissipate the process heat (the 'condenser'), a compressor and a throttling valve.

The 'efficiency' or rather the *COP* (Coefficient of Performance) of the cooling system depends on

- the *COP* of the compressor, depending on type (scroll/piston/other), materials used, production tolerances, etc.,
- the evaporator ('cold'[92]) temperature T_{ev} and condenser ('hot') temperature T_{cd}, depending on
    - compartment temperature T_c and ambient temperature T_a,
    - the temperature difference between compartment air and evaporator ΔT_{ev} respectively between ambient air and condenser ΔT_{cd} to bring about the heat transfer process. This is largely determined by the efficiency and design of the heat exchangers and auxiliary provisions (convection fans, multi-flow, etc.). The relevant equations are $\Delta T_{ev} = T_c - T_{ev}$ and $\Delta T_{cd} = T_{cd} - T_a$.
- Control features, such as variable versus fixed speed, single thermostats versus thermostats per compartment, smart electronic versus electro-mechanical control, etc..

[92] Regent uses the notation T_{cold} for the evaporator temperature and T_{hot} for the condenser temperature. For our purposes we prefer T_{ev} and T_{cd} because it allows also to refer to other 'cold' and 'hot' temperatures.

9.3.2 Compressor COP

'*The COP*' of a hermetic compressor for household refrigeration usually means the COP at ASHRAE[93] LBP[94] standard conditions T_{ev} -23.3 °C and T_{cd} +54.4 °C (at ambient temperature and sub cooling 32.2 °C) or the COP at EN 12900/CECOMAF[95] standard conditions at -25 °C and +55 °C. Also there are COP test conditions from AHAM[96] and Chinese standards that typically use a temperature pair of T_{ev} -23.3 °C and T_{cd} around 40 °C.

These temperatures are typical for application in e.g. a two-star freezer; for a refrigerator T_{ev} is higher and T_{cd} is lower, resulting in a higher COP. This principle is evident from the theoretical COP of an ideal Carnot process COP_{Carnot}.

$$COP_{Carnot} = \frac{T_{ev} + 273.15}{T_{cd} - T_{ev}}$$

With this formula the real system efficiency (COP) can be calculated for every T_{ev} and T_{cd}, if at least the COP is known at one specific combination of T_{ev} and T_{cd} using the ratio η_{Carnot} between the real and theoretical *COP.*

$$COP_{real} = \eta_{Carnot} \cdot COP_{Carnot}$$

Regent uses a value $\eta_{Carnot} = 0.6$ for its calculations, which applies to very efficient compressors.
The compartment temperature T_c and ambient temperature T_a are given so the main design-challenge in optimising the efficiency is in decreasing the temperature difference, in K, between compartment air and evaporator ΔT_{ev} with

$$\Delta T_{ev} = T_c - T_{ev}$$

as well as the temperature difference between ambient air and condenser ΔT_{cd} with

$$\Delta T_{cd} = T_{cd} - T_a \,.$$

Industry mentions typical ΔT_{ev} values of 15, 8 and 10 K for categories 1 (refrigerators), 7 (fridge-freezers) and 8&9 (freezers) respectively. The ΔT_{cd} values are 10, 10 and 12 K respectively for the same categories.

With ambient temperature T_a 25 °C and average compartment temperatures T_c of +5 (Cat. 1) , -1 (Cat. 7[97]) and -18 °C (Cat.8+9), this means typical evaporator temperatures T_{ev} are -10, -9, -28 °C for the respective categories and typical condenser temperatures T_{cd} are 35, 35 and 37 °C respectively.

[93] ANSI/ASHRAE Standard 23-2005 'Methods of Testing for Rating Positive Displacement Refrigerant Compressors and Condensing Units'. (US standard)
[94] LBP=Low Back Pressure
[95] EN 12900:2013 Refrigerant compressors. Rating conditions, tolerances and presentation of manufacturer's performance data. 'CECOMAF' is a short denomination of a Eurovent/CECOMAF certification scheme. Main difference with ASHRAE is in the sub cooling temperature (CECOMAF 55 °C).
[96] AHAM=Association of Home Appliance Manufacturers (US).
[97] Average compartment temperature based on temperature differences for 75% refrigerator volume (20K) and 25% four-star freezer volume (43K), resulting in 26K difference with a 25°C ambient.

9.3.3 More detailed cooling system model

Most compressor-manufacturers give several exact COP-values, with different temperature pairs, for their products. The figure below shows a compressor with a COP of approximately 1.5 at -25/+55 °C ($T_{ev}/\ T_{cd}$, CECOMAF) that can reach a COP of almost 3.4 at -10/+35 °C, which is a temperature pair typical of a refrigerator.[98]

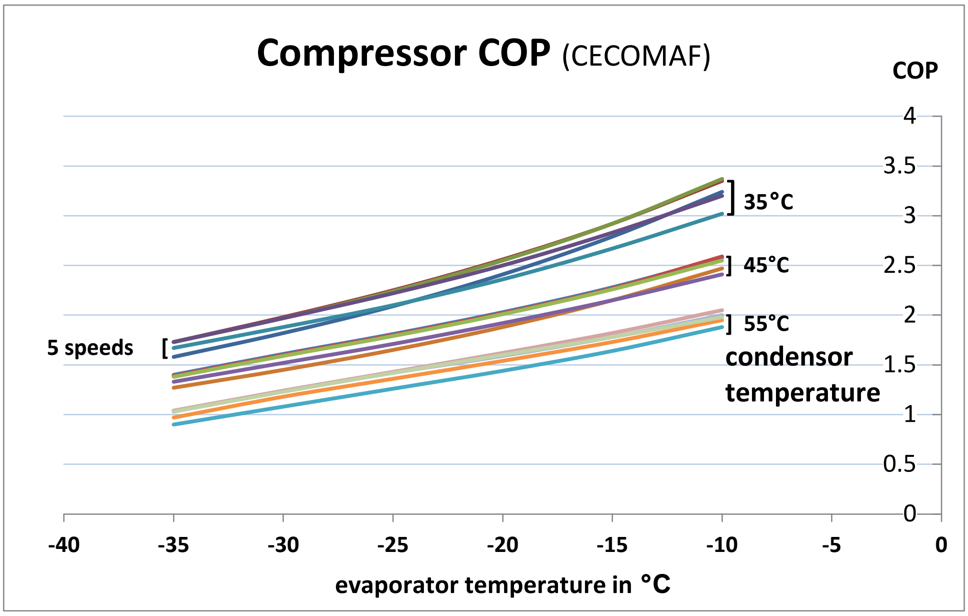

Figure 40. COP curves of low back pressure hermetic compressor EMBRACO VEM X7C at different speeds (1200/1600/2000/3000/4500 rpm), evaporator and condenser temperatures.

Note: COP ranges from 0.9 at 1200 rpm, -35/+55 °C (cooling power 15 W) to 3.4 at 2000 rpm, -10/+35 °C (cooling power 168 W). Maximum cooling power is 377 W at 4500 rpm, -10/+35 °C and an electric power consumption of 147 W. Note that the VEM is an efficient compressor but not the latest generation.[99]

The figure indicates that the previous Carnot formula gives a good estimate but is still an approximation, which only takes into account the two main process variables but not any other conditions or design optimisations[100]. For instance, the COP_{Carnot} at -25/+55 °C is 3.21 and the COP_{Carnot} at -10/+35 °C is 5.85. This is a factor 1.81 difference, while the actual manufacturer data in the figure 8 indicate a difference of slightly more than a factor 2. [101]

In addition, there are differences between the ASHRAE standard rating conditions and the real operating cycle.

In the ASHRAE standard conditions, the temperature inlet to the expansion valve is fixed to 32.2 °C, which gives a large sub-cooling for standard conditions (54.4-32.2=22.2 K). This sub-cooling temperature difference decreases when the condensing temperature decreases, down to 0 when the condensation temperature reaches 32.2 °C. In the real cycle, most of the sub-cooling is done in the liquid / vapor heat exchanger (IHX - Intermediate Heat eXchanger). The larger the temperature difference between T_{cd} and T_{ev}, the larger the sub-cooling.

[98] M. Janssen, Impact of the new IEC 62552-1,2,3:2015 global standard to cold appliance energy consumption, Report no. 15127/CE40/V1, Re/genT for CECED, 13 April 2015.
[99] E.g. the EMBRACO EMD32 has a claimed COP above 2 at ASHRAE conditions.
[100] E.g. ambient and suction temperatures, capacity setting (mass/volume flow rate), etc.
[101] Nonetheless, the approximation is broadly accepted and for the purpose for which it used in the industry report, to estimate the impact of the new global standard, it is certainly a valid tool.

In addition, in the ASHRAE standard conditions, the compressor inlet temperature is fixed to 32,2 °C, which means that the superheat increases with decreasing evaporating temperature. And this superheat is accounted in the capacity rating, although it is not useful in a real cycle as the superheat develops in the IHX and not in the evaporator (in which superheat is close to zero).

Because of these differences, it was decided to use compressor data and a simple cycle model in order to estimate the capacity and COP of a compressor for varying operating conditions. Only Embraco gives performance data over a large set of different evaporating and condensing temperature conditions so their data was used to derive COP and capacity curves of typical compressors. Both capacity and COP were modelled, as capacity is required to compute the degradation of performance due to cycling.

In order to model the capacity and COP variation with T_{cd} and T_{ev}, the following approach was adopted:

- regression of the volumetric and isentropic efficiency for ASHRAE conditions with varying T_{cd} and T_{ev},
- integration of the IHX,
- cycle calculation for varying Tev and Tcd and realistic cycle conditions (subcooling and superheating is supposed to be zero in the condenser and evaporator resp. and to fully develop in the IHX),
- Fitting of the cooling capacity (without accounting for the superheat enthalpy change) and of the COP using compressor-like polynomials of T_{cd} and T_{ev}.

These curves have been dimensioned so that the nominal capacity and COP may be changed and adapted to varying cooling loads and COP levels. Two different compressors were investigated, one optimized for refrigerators operating conditions and the other one for freezers operating conditions. However, the COP and capacity differences are relatively small and only the compressor optimized for refrigerator operating conditions is used.

In the figure 41 below, we represent the capacity and COP curves for this compressor. The COP curve is compared with the relative Carnot approach described before; the difference in % is shown on the graph.

The differences in COP between the cycle model and the Carnot approach lie between 5 and 10 % under operating conditions of typical refrigerators (T_{ev} = -10 °C / T_{cd} = + 35 °C) and freezer (T_{ev} = - 30 °C / T_{cd} = + 35 °C).

As a fridge may operate at much higher temperature than 25 °C (until between 32 and 43 °C depending on the class), the compressor capacity for a given couple of T_{ev} and T_{cd} is much higher than the cooling load required from the compressor. The compressor then cycles on and off to maintain the required temperature set-point in the cold volume. Typically, the run-time fraction (ratio of compressor on time to the sum of compressor on time and compressor off time) is 40 % at 25 °C.

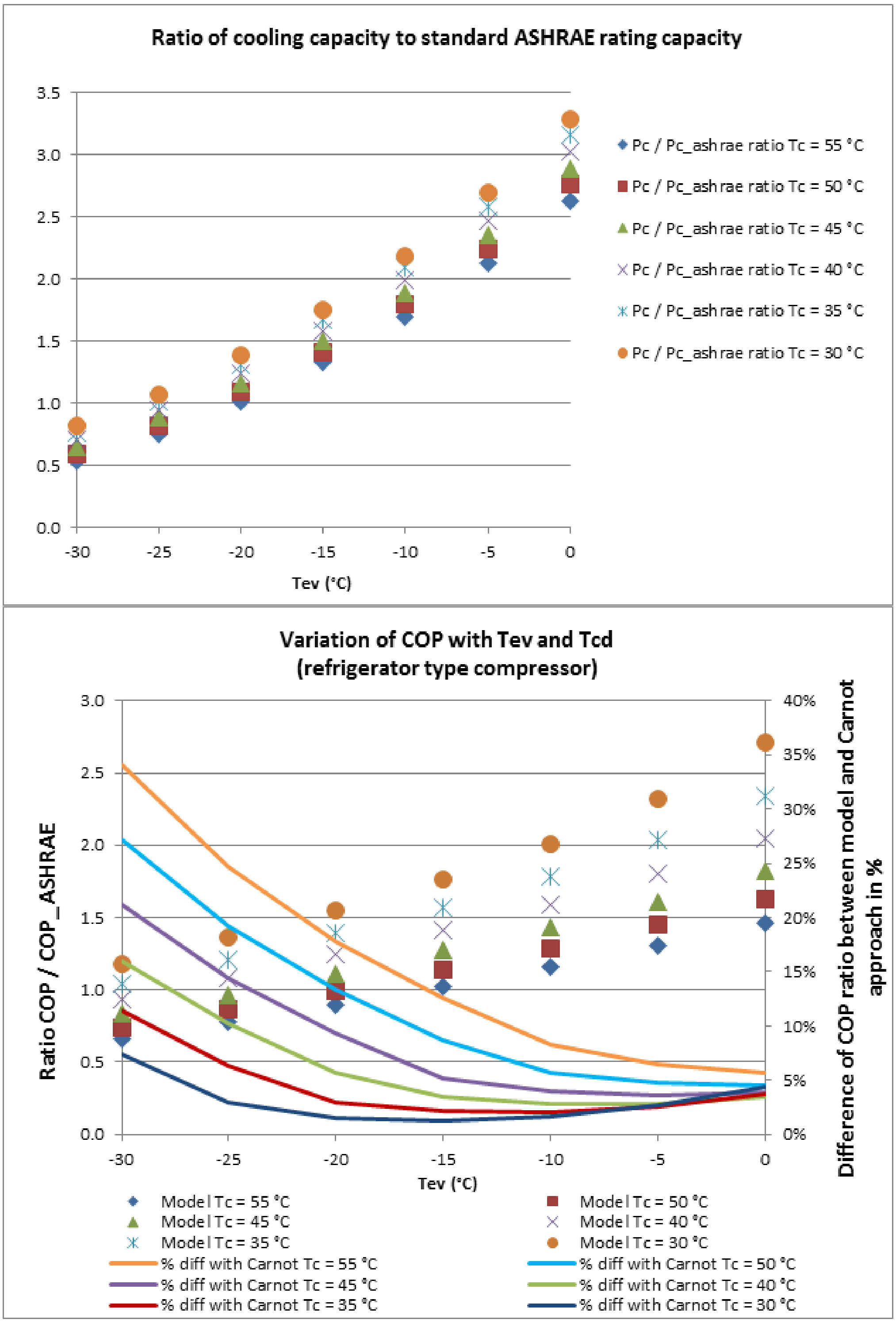

Figure 41. Model of relative capacity (a) and COP (b) as compared to ASHRAE standard rating conditions with varying Tev and Tcd and comparison with Carnot COP.

For cyclic operating conditions as compared to standardized operation, there is a performance degradation which is conversely proportional to the ratio between the cooling load and the compressor capacity for the T_{ev} and T_{cd} conditions. It can be expressed as follows:

$COP / COP_{ss} = 1 - Cd \cdot (1 - Load / Pc)$

with

- COP is average COP over an on/off cycle
- COP_{ss} is COP in steady state operating conditions (without cyclic operation)
- Cd is cycling losses degradation coefficient
- $Load$ is thermal load to be extracted from the fridge by the compressor (in W)
- Pc is cooling capacity at given Tev and Tcd (in W)

The reference cycling study for refrigerators[102] suggests that a Cd coefficient of 0.25 is a good estimate of cycling losses. This corresponds to about 15 % loss at 25 °C. However, more recent findings[103] show that with simple modifications of the refrigeration cycle components, it is possible to reach about half this value. In absence of more information, a Cd value of 0.125 is kept in the study.

As regards the scale effects, both physical effects and production/design aspects are relevant. In both respects, refrigerant R600a (isobutane) has been a significant improvement over its predecessors like R134a, with vapour pressure levels almost half as low, a good volumetric capacity and overall a better COP. At the moment this substitution is now almost complete at 98 % of household models currently sold using R600a, but it has been a source of considerable efficiency-improvement in the recent past. With increasing efficiency improvements over the years, swept volumes of household refrigeration compressors have become significantly smaller over the years. This means that it has become more challenging to keep the same relative production tolerances for smaller as for larger compressors. There are no empirical data available that would allow a real quantification and theoretical modelling is beyond the scope of this study, but the comparison with e.g. the efficiency curve for standard air piston compressors from the Ecodesign preparatory study on standard air compressors indicates a scale effect for compressors, i.e. smaller compressors being less efficient.[104]

[102] Coulter, W. H. and Bullard, C. W., An Experimental Analysis of Cycling Losses in Domestic Refrigerator-Freezers, ACRC TR-77, June 1995.

[103] Björk, E., Energy Efficiency Improvements in Household Refrigeration Cooling Systems, Doctoral Thesis, 2012.

[104] VHK, Preparatory ecodesign study standard air compressors (2014): The isentropic efficiency η_{isen} of a standard air compressor can be expressed as $\eta_{isen} = 0.35\ V_1\ (p_2^{0.2857}-1)\ /\ P_{real}$, where V_1 is the flow rate (in l/s), p_2 is pressure (in bar) and P_{real} is electric input power (in kW).

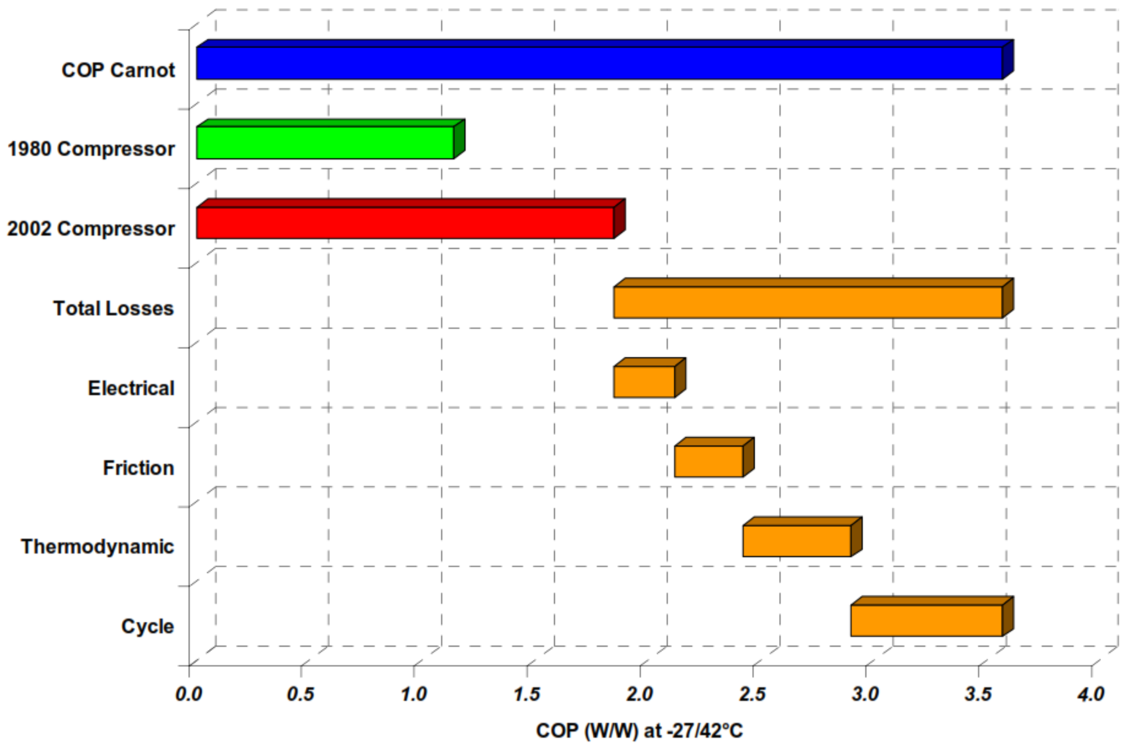

Figure 42. Efficiency of hermetic compressors (source: Possamai et al.[105])

9.3.4 Evaporator and condenser temperature difference

From the above it is clear that, once T_c and T_a are given, the minimisation of the temperature differences ΔT_{ev} and ΔT_{cd} is an important task in modern refrigerator design.

As mentioned before, industry reports typical natural convection ΔT_{ev} values of 15, 8 and 10 K for categories 1 (refrigerators), 7 (fridge-freezers) and 8+9 (freezers) respectively. The ΔT_{cd} values are 10, 10 and 12 K respectively for the same categories.

The values of ΔT_{ev} and ΔT_{cd} , hereafter ΔT_{HE} (ΔT_{ev} or ΔT_{cd} as appropriate), depend on the heat exchanger duty [P_{HE} in W], heat exchanging surface A_{HE} [in m²] and heat transfer coefficient of the heat exchanger U_{HE} [in W/m²K] as given in the expression:

$$P_{HE} = \Delta T_{HE} \cdot A_{HE} \cdot U_{HE}$$

Apart from the specific design of the heat exchanger (plate, tube or finned tub, fin spacing, etc.), it depends also on the space (surface) that is available to realise an optimal heat exchanging surface A_{HE}. In that sense, the differences in useful back-panel surface between small and large appliances is relevant.

For the value of U_{HE} the first design question is whether the heat transfer should depend wholly on natural convection or whether there is (also) forced convection with a fan.

In the case of natural convection the aim is to create a laminar flow that ensures that enough air passes through/alongside the heat exchanger. This 'chimney effect' is best achieved by creating smooth surfaces, no obstacles to the main flow and creating long

[105] Fabricio C. Possamai, Marcio L. Todescat (both Embraco), A Review of Household Compressor Energy Performance, International Compressor Engineering Conference, Purdue University, 2004.

‘chimney’ trajectories. The capability of creating a steady (laminar) flow also depends on the temperature difference ΔT_{HE}; larger temperature differences increase the buoyancy effect.

In the case of a natural convection evaporator, the U_{HE} is dominated by the radiative heat exchange between the cold surface of the evaporator and the hotter walls and doors. U_{HE} for refrigerator operating conditions lies between 6.5 and 7.5 $W/m^2.K$ [103,106] and decreases with increasing evaporating temperature. For freezer operating conditions, this value lies between 5 and 6 $W/m^2.K$ (the square meters relate to the heat exchanger plate surface). These values have been used to check the feasibility of particular ΔT_{ev} designs. In the case of natural convection wire-and-tube condenser, the heat that can be extracted is proportional to the temperature difference between the refrigerant and the air temperature. A correlation[107] and optimal design parameters[108] have been used to assess the maximum heat exchange coefficient. U_{CD} is estimated to vary between 23 $W/m^2.K$ and 29 $W/m^2.K$ for ΔT_{CD} varying from 5 to 20 K respectively. These values have been used to check the feasibility of particular ΔT_{CD} designs.

In the case of forced convection, the fan will take care that enough air passes the heat exchanger and the main concern is to create as much interaction as possible between air and heat exchanger surface through turbulence, denser fin spacing, etc.. The heat exchanger capacity with forced convection can easily be more than twice as high as with natural convection, especially when using tightly-spaced finned tube heat exchangers. The problem is the fan which, if it uses more than a few Watts, may ruin the efficiency improvement. Longevity and reparability of the fan, especially a condenser fan at the back of the appliance is a problem: either the fan matches the longevity of the compressor and/or it is easily accessible and repairable e.g. from the front. Finally, the sound level of the fans may be a (minor) problem and there is of course the extra cost of the fan. At the moment, evaporator fans are almost a standard feature in larger refrigerator-compartment; for frost-free freezers the forced convection comes from the evaporator fan that is anyway needed for the finned tube evaporator. Condenser fans are rare in European household appliances.

In the 2007 preparatory study, electric power values of 5W for an evaporator fan and 6-10 W for a frost-free fan in ‘A’ appliances were mentioned. At the moment condenser fans of 2 W (at 60-70 m^3/h) can be found in experimental settings and for evaporators multiple long-life computer-fans (0.5 W per fan) are an option. For small appliances with a consumption as low as 20-30 W (e.g. fridges below 100 litres net volume) this is still too much to be effective, but for larger appliances and built-in appliances the fans are definitely a realistic option. For forced convection finned-tube, possibly in combination with plate (roll-bond) evaporators, ΔT_{ev} values of 4 K (instead of 15 K) can be possible, leading to refrigerator evaporator temperatures around 0 °C instead of -10 °C with natural convection only (note that for so high evaporating temperature, the capacity of the compressor is very high. To limit the condensing temperatures and maintain the efficiency gains, a forced convection condenser would probably be mandatory). With a high-efficiency compressor, COP-values can then be higher than 4 (instead of 3 to 3.2 at -10/+35 °C), but at the expense of, say, 3-4 W in extra fan electricity (1 to 1.5 Wh/h with fan controlled to work only when the compressor is working). Net electricity savings are in the range of 0-10 %, depending on the size of appliances.

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[106] Fantini, M., Innovative techniques to reduce energy consumption of household refrigerators, M. Sc. Thesis, 2013.
[107] Cláudio Melo, Christian J.L. Hermes, A heat transfer correlation for natural draft wire-and-tube condensers, International Journal of Refrigeration, Volume 32, Issue 3, May 2009, Pages 546-555.
[108] P.K. Bansal, T.C. Chin, Modelling and optimisation of wire-and-tube condenser, International Journal of Refrigeration, Volume 26, Issue 5, August 2003, Pages 601-613, ISSN 0140-7007.

In combination with convection fans (including frost free) fans, multiple ducts ('multi-flow' systems) may help to bring the cold air at exactly the right location (see figure below).
Finally, in order to improve temperature control, the use of Phase Change Material (usually water in this context) may help to avoid temperature fluctuations and take care of peak capacity demands.

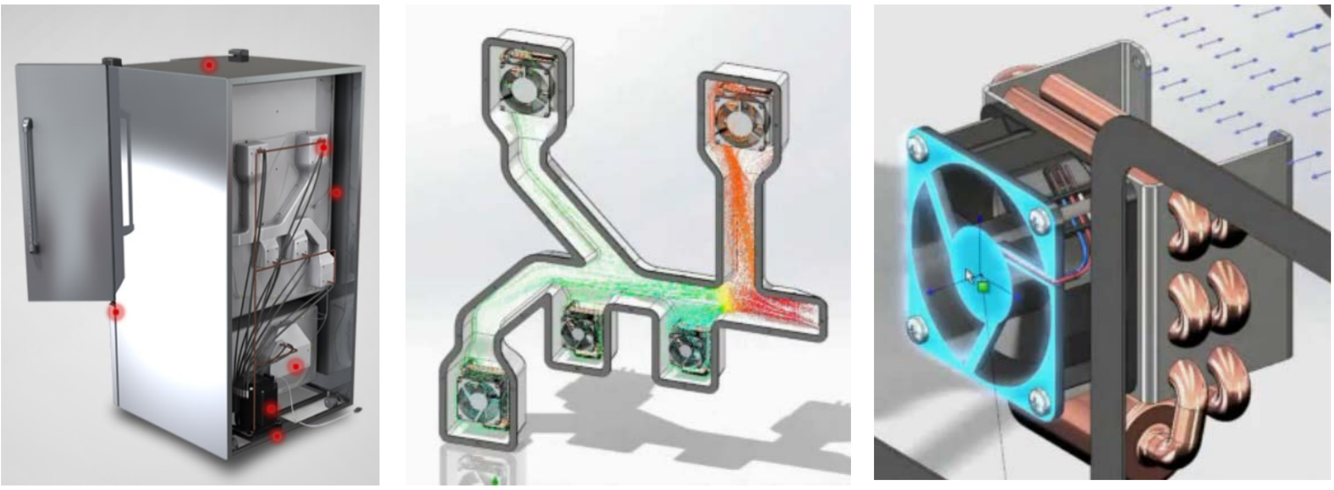


Figure 43. Frost free multi-duct fridge-freezer, using 5 fans and local finned coil evaporator heat exchangers (demonstration computer-model Solidworks[109]).

Control features

In the current test at only one ambient temperature of 25 °C the control features play only a modest role in the efficiency of a single-compartment refrigerator. The variable speed compressor will reduce the start-up losses and possible temperature overshoot with respect to a fixed-speed on-off compressor and this may give savings in the order of a few per cent. However, in the new global standard testing takes place at two temperatures, 16 and 32 °C, and the test standard allows testing of smart (variable) defrosting. There a variable speed control can play a more significant role with savings up to 10 %.

Rather than in single refrigerators or freezers, control features can play an important role in refrigerator-freezers (Cat. 7) or other multi-compartment appliances (Cat. 10).

In principle, there is an important and positive synergy-effect when combining compartments with low and high design temperatures (T_c):

- The compartments have a common wall, which —for 15-20 % of their envelope surface— decreases the temperature difference with the 'ambient' and thus lowers heat losses significantly;
- The compartments can share a common compressor/cooling system. Larger compressors have a higher COP ('efficiency'), which is especially important when individual compartment volumes are relatively small and would –as an individual appliance—require inefficient small compressors.
- The total available surface area for the condenser at the back of the combi-appliance is relatively larger, because the compressor space takes up less height

[109] Note that this not necessary an illustration of an energy efficient lay-out, only of the possible use of ductwork and fans.

than in single compartment appliances. Also the designer has more flexibility in optimising heat exchanger surface between e.g. the freezer (T_c = -18 °C and small volume) and the refrigerator space (T_c = +4 °C and large volume).

- In practice, although it may not show up in the separate auto-defrost test of the new IEC standard, there is the possibility to utilise the 'waste heat' from the auto-defrost for freezer compartments for high-temperature compartments.
- Economically, the shared costs would allow to employ better components e.g. a more efficient and/or variable speed compressor, electronic instead of electro-mechanical controls, etc. than would be possible for single appliances in certain low-cost market segments.

However, the degree to which the synergy-effect of a combi-appliance is realised depends on the specific (control) solution applied.

For instance, in the CECED database the difference in energy efficiency between the single (Type I) and double thermostat (Type II) fridge freezers is quite significant —up to 20 to 25 % (see Chapter 8).

Type I models rely on a fixed partitioning between fridge and freezer capacity regulated only by one thermostat in the refrigerator compartment. As described in Annex D of the 2015 Re/genT report, these Type I models may show considerable extra energy consumption because they have to use an auxiliary heater (or lamp) in the refrigerator compartment or have colder-than-required freezer temperatures. The main quality of single thermostat fridge-freezers is their low price.

A double thermostat is much more efficient, but also requires a cooling system that allows a good independent and separate regulation of the temperatures in the freezer and fresh food compartment. The most effective temperature control solution, but not necessarily always the most efficient solution, is to use two compressors and thus two independent cooling loops. This solution does not profit from the synergy-effect of the compressor size and is relatively expensive; currently it is employed mainly in large (>300 litre) fridge-freezers.

Less expensive and possibly more efficient for smaller combi-appliances is the regulation with a single compressor and solenoid valves that allow consecutive regulation of the loops. In order to operate efficiently a variable speed compressor would be required because the pressures/temperatures required for the freezer cooling are different from those of the refrigerator cooling.

An alternative way of controlling, typical for e.g. larger frost free appliances, is the use of a single central compressor, duct-work and multiple small fans that supply cold air to all different types of compartments (see Fig. 43). If this way of controlling is more efficient than the two other double-thermostat ('Type II') solutions above will depend on the extra auxiliary electricity use of the fans and the heat loss of the ductwork. In any case —relevant for scale effects— mainly for reasons of space (and costs) the designers will have less possibilities to use the more elaborate solutions involving fans and internal air-ducts in smaller appliances.

Overall, as was shown in Chapter 8, the average Type II fridge-freezer (Cat. 7) is consuming 20 % (factor 0.8) less energy than the sum of an individual refrigerator and an individual freezer with the same compartment sizes.

9.3.5 Overall technical model

As illustrated by the 'more detailed' discussions in the previous paragraphs, it is not easy to construct a comprehensive and accurate overall model of refrigeration appliances. However, at the very least one can conclude that the current reference lines (M and N factors) are not —or not only— a consequence of random design solutions in a database, but that for refrigeration appliances —purely on physical grounds— the size really matters.

In this paragraph it will be attempted to integrate the basic equations of the heat demand and cooling systems in order to make an estimate how the reference lines work out for a technology-based approach, instead of the current approach based on statistical regression.

For that, a number of appliances were modelled with similar, more or less average technology but mainly different in size (net volume).

The technology entails efficient isobutane compressor(s), poly-urethane insulation with generous thickness. Values of ΔT_{ev} and ΔT_{cd} start out at levels indicated by industry, but available condenser/evaporator surface —in proportion to the overall envelope surface— is taken into account. The most difficult to model is the fridge-freezer. Because of the shared wall and single compressor, a single compartment configuration is assumed, but with compartment temperature (-1 °C), insulation thickness, ΔT_{ev} and ΔT_{cd} values[110], etc. based on a 25/75 partitioning between freezer and refrigerator volume. The extra length of door gaskets, the loss of volume due to the shared wall, and the extra transmission heat loss of the shared wall were taken into account.[111]

For fridge-freezers a double thermostat e.g. with variable speed compressor and solenoid valve, was assumed as it reflects most closely the physical constraints and not the technical solution. Actual modelling of the different technical solutions is more complicated because many systems will run with evaporator temperatures below freezer temperatures (even frost free products with air distribution).

Alternatively, we can also take the energy consumption of separate fridge and freezer and multiply with a factor 0.8. This would be a saving of 20 %, i.e. 10 % from the reduced heat loss of the shared wall (lower average ambient temperature) and 10 % from improved COP (scale effect). Both options will be given.

Overall, the efficiency should be between A+ and A++ level, but not A+++: VIP panels are not considered, nor the effect of smart control features.

Figure 44 below gives the main results. The modelling data is given in Table 19 on the page after the figure.

[110] Ignoring specific industry values in this case.
[111] Extra length of door perimeter is 2*w. Volume lost is (w-2t)*(d-2t)*t. Extra heat loss from freezer to fridge (ΔT=23) through the shared wall is modelled as extra envelope surface (w-t)*(d-t) , implicitly at Tc=-1°C.

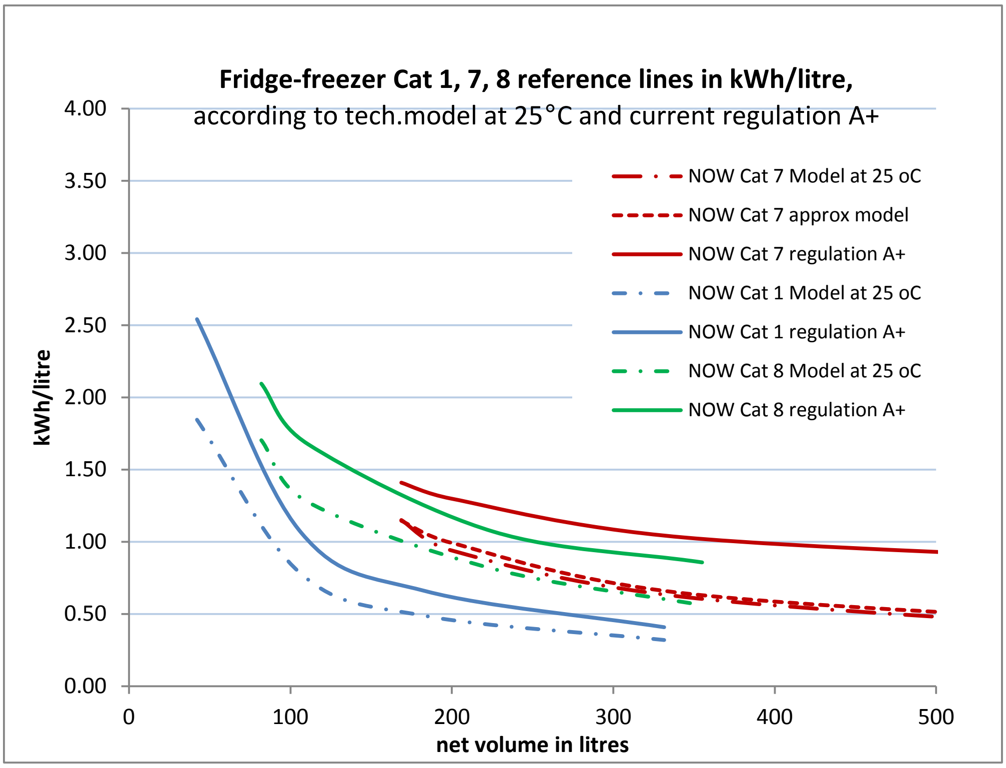


Figure 44. Reference lines from technical modelling (dot-dash line) versus the reference lines at A+ (EEI=0.42) according to the current regulation. [112]

[112] Note that the curves are built from 4 datapoints which explains some less than smooth transitions

Table 19. Basic technical model of refrigeration appliances

	Categories-->	Refrigerator (Cat. 1)				Freezer (Cat. 8)				Fridge-freezer (Cat. 7, Vr/Vf=0.73/0.27)			
Symbol	***Parameters (unit)***	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
V	refrigerated volume (m^3)	0.042	0.107	0.184	0.331	0.082	0.111	0.226	0.355	0.169	0.199	0.344	0.661
	refrigerated volume (litres dm^3)	42	107	184	331	82	111	226	355	169	199	344	661
A	refrigerator envelope surface (m^2)	1.002	1.717	2.574	4.161	1.716	2.254	3.957	5.015	3.045	3.520	4.999	7.404
A_{cd}	condenser area (m^2)	0.122	0.286	0.523	0.972	0.330	0.523	1.050	1.295	0.523	0.688	1.050	1.440
L_{dr}	door perimeter length (m)	1.84	2.54	3.4	4.84	2.7	3.4	5.1	5.5	4.5	5.1	6.3	7.2
w	width (m)	0.45	0.52	0.55	0.6	0.55	0.55	0.6	0.7	0.55	0.55	0.60	0.80
d	depth (m)	0.47	0.52	0.55	0.6	0.55	0.55	0.6	0.7	0.55	0.55	0.60	0.80
h	height (m)	0.52	0.8	1.2	1.87	0.85	1.2	2	2.1	1.20	1.50	2.00	2.05
a	air passage height below unit (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
b	height & depth compressor area (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
t	average wall thickness (m)	0.036	0.041	0.053	0.070	0.075	0.09	0.11	0.12	0.055	0.065	0.070	0.085
T_c	compartment temperature (°C)	5	5	5	5	-20	-20	-20	-20	-2.5	-2.5	-2.5	-2.5
T_a	ambient temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25
k	heat conductivity (W/mK)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
U_{wall}	heat transfer coefficient wall (W/m^2K)	0.56	0.48	0.38	0.29	0.27	0.22	0.18	0.17	0.36	0.31	0.29	0.24
P_{trans}	transmission heat loss (W)	11	17	19	24	21	23	32	38	30	30	39	48
U_{door}	heat transfer coefficient door gasket (W/mK)	0.08	0.08	0.08	0.08	0.03	0.03	0.03	0.03	0.07	0.0675	0.0675	0.0675
P_{door}	door heat loss $L_{dr}*U_{door}$ (W)	3	4	5	8	4	5	7	7	8	9	12	13
P_{loss_tot}	total heat power loss $P_{trans} + P_{door}$ (W)	14	21	25	32	24	27	39	45	39	39	51	61
$E_{loss\ tot}$	**annual heat energy loss** (kWh_{th}/a)	**124**	**181**	**218**	**276**	**212**	**238**	**344**	**395**	**340**	**344**	**446**	**537**
ΔT_{ev}	evaporator temperature difference (K) [r/f]	25	19	16	14	12	9	8	8	22 / 10	21 / 10	18 / 8	16 / 6
ΔT_{cd}	condenser temperature difference K	21	13	10	9	11	9	7	6	19 / 10	17 / 10	14 / 10	13 / 8
T_{ev}	evaporator temperature (°C)	-20	-14	-11	-9	-32	-29	-28	-28	-17 / -30	-16 / -30	-13 / -28	-11 / -26
T_{cd}	condenser temperature °C	46	38	35	34	36	34	32	31	44 / 35	42 / 35	39 / 35	38 / 33
P_{nom}	Nominal compressor cooling power (W)	45	45	45	45	80	100	120	140	100	100	120	120
COP_{nom}	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1.7	1.7	1.7	1.7	1.7	1.7	1.8	1.9	1.7	1.7	1.8	1.8
P	Cool power (W)	52	76	90	99	53	82	107	126	138 / 76	148 / 76	211 / 103	233 / 118
Load factor	Ratio of heat load to cool power	27%	27%	28%	32%	46%	33%	37%	36%	40%	39%	37%	39%
Cycling loss	Part load losses (in % COP)	9%	9%	9%	9%	7%	8%	8%	8%	8%	8%	8%	8%
COP	COP value with actual Tev and Tcd	**1.9**	**2.5**	**2.9**	**3.2**	**1.7**	**1.9**	**2.1**	**2.3**	2.08 / 1.79	2.21 / 1.79	2.69 / 2.00	2.90 / 2.21
COPcyc	avg. COP actual Tev and Tcd & cycling loss	1.7	2.3	2.7	2.9	1.6	1.7	2.0	2.1	1.83	1.91	2.27	2.46
Eaux	electricity CPU and possible fan (kWhel/a)	4	4	8	11	4	4	8	12	8	8	16	23
AE	annual electricity consumption (kWhel/a)	**78**	**83**	**89**	**106**	**140**	**141**	**183**	**199**	**194**	**188**	**213**	**241**

q-model	MODEL at Ta=25 °C (kWh/litre)	1.85	0.78	0.49	0.32	1.70	1.28	0.81	0.56	1.15	0.94	0.62	0.36
	approximate equation q-Model (V in litre)	70/V + 0.11				106/V + 2.15*0.157				176/V + 1.35*0.081			
q-A+	A+level in kWh/litre REGULATION (Cat. 1)	2.54	1.06	0.66	0.41	2.10	1.68	1.07	0.86	1.18	1.06	0.80	0.62
	A+ equation	103/V+0.098				132/V+2.15*0.226				127/V+(0.27*2.15+0.73)*0.326			
	difference *q-model* vs *q-A+* (%)	-27%	-27%	-26%	-22%	-19%	-24%	-24%	-35%	-2%	-11%	-22%	-41%

The results indicate that for refrigerators (Cat. 1) the specific energy use is 22-27% % better than the current A+. This is expressed mainly by a lower M-value. The third line from the bottom of the table gives an approximation of the curve pertaining to the model. In this case $q\text{-}model = 70/V + 0.11$ instead of $q\text{-}A\text{+} = 103/V + 0.098$.

The technical model for upright freezers (cat. 8), with the specific input values used, is 19-24% better than the current regulation at A+ level for the smallest 3 sizes. The largest 355 litre model is even 35% better. Here the equations are $q\text{-}model = 106/V + 2.15*0.157$ instead of $q\text{-}A\text{+} = 132/V + 2.15*0.487$. (note: 2.15=$r_c$)

For fridge-freezers (Cat. 7) the technical model has a steeper volume-dependent slope than the current A+ level. When the technical model is built from the sum of individual fridge and freezers multiplied by a correction factor the formula is very similar to that of the technical model. It must be mentioned again that the uncertainties in modelling this product group are considerable and that a plausible explanation must certainly also be sought in the commercial data analysis. Anyway, the preliminary equation is $q\text{-}model = 176/V + 1.35*0.081$ for the technical model, with 1.35 being volume-weighted average r_c.

For a model built from a separate technical model of fridge (here Vc=73%, rc=1) and freezer (Vc=27%, rc=2.15) energy use we have to find a combi correction factor C in the equation $q\text{-}model = C*[176/V + (0.098*0.27+2.15*0.487*0.73)] = C*(176/V+1.35*0.126)$. Also this correction factor should be flexible enough to accommodate different volumes and compartment types.

For comparison: the regulation uses $q\text{-}A\text{+} = 127/V + 0.42$ for fridge-freezers (with 25/75% partitioning between freezer and fridge compartments).

9.3.6 Correction for new global standard

With the same technical model it is possible to establish the impact of the new regulation. Following the first stakeholder meeting there seems to be a consensus that a calculated ambient temperature of 24°C (f=0.5) is the solution that is closest to the current real test at 25°C ambient. The calculated temperature is derived from a real test at 16°C and a real test at 32°C ambient. The fresh food temperature is lowered from +5°C to +4°C. The freezer compartment temperature is the air temperature and no longer the temperature measured inside test packages; it is assumed that this leads to an increase of the air temperature from -20 to -18 °C.

The model was recalculated with these changes. For refrigerators (Cat. 1) the technical model for the new standard showed an energy use that is 7% higher than in the current regulation/standard. For fridge-freezers (Cat. 7) the average energy use is 6.1% higher with a peak at 7%. For upright freezers the energy use is 5.7% lower throughout.[113]
When the above equations for the model at 25°C are corrected for these impacts, the equations for q-model would be $75/V + 0.12$ (refrigerator, Cat. 1) and $100/V + 2.15*0.15$ (upright freezer Cat. 8).

[113] For the calculation of individual M and N values the rc value of freezers becomes 2.1 instead of 2.15 (2% lower). This, however, does not influence the rc*M factor discussed here.

9.3.7 Compensation for no-frost

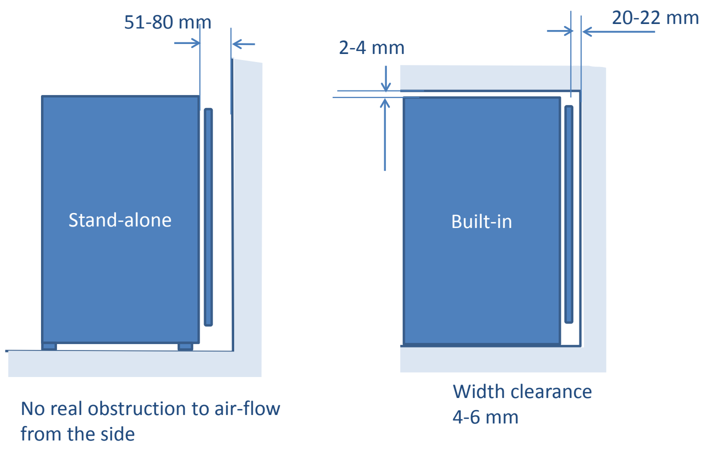
In the current regulation the no-frost is a multiplier of the equivalent volume, which ultimately means that it is a multiplier of the current M value when calculating in kWh/litre or rather a fixed amount per litre of net volume is added.
In the latest industry paper by Regent it is proposed to no longer correct just the equivalent volume but the whole reference line (both M and N).
In the Australian and US standards there is a different tradition: a fixed kWh amount is added as a compensation. The latest Australian proposals speak of one defrost cycle of 0.1 kWh per 24h at 32 °C (taking into account the new global standard) which means a compensation of 36.5 kWh/year. For the 16 °C test it is assumed one defrost per 40 hours, which comes down to a compensation of 21.9 kWh/year. In case of a variable ('smart') defrosting, the period between defrosting at 16 °C test is extended to 48 hours, which results in a compensation of 18.25 kWh/year. In Australia the currently proposed f-factor is 0.73, which means that overall the compensation for fixed defrosting is ca. 25 kWh/year and for variable defrosting ca. 22 kWh/year.
Out of these three alternatives, the industry proposal to correct the whole reference line makes technically the most sense. When the appliance is larger, also the evaporator is larger and it will take longer or it will take more power for an auxiliary heater to de-ice. And afterwards it will take more power, proportional to the steady-state power, to cool down the evaporator and the appliance.
The problem is that there are no data available for frost-free energy use. It is measured and reported separately in the new standard, but the test-data are not available. Considering the Australian fixed values and average sizes of around 200-300 litres, one could expect a factor between 1.1 and 1.15. The statistical analysis in Chapter 8 suggests that a factor 1.2 would be more appropriate.

9.3.8 Compensation for built-in

When an appliance is tested as 'built-in' it is placed in an enclosed space that limits the air flow to the condenser. As a result, the temperature difference ΔT_{cd} might increase by a few degrees (say +2 °C). In the technical model this then results in an increase of energy consumption of 5 % for refrigerator and fridge-freezer. For the freezer (Cat. 8) the increase is closer to 3 %. For the fridge-freezer and refrigerator it makes sense to compensate for a 10% (side-)wall thickness reduction and there a maximum compensation of 8 % might be in order. We expect the analysis of the commercial database to come up with numbers in that order of magnitude.

BOX 2. Comparison test for freestanding and built-in

8-10% difference in energy for the same appliance from testing stand-alone or built-in.
[SIDE VIEW below]



9.3.9 Compensation for chiller

Thus far, no plausible technical explanation for the chill compensation of 50 kWh/year (currently 21 kWh/year at A+ level) could be found. Also the industry report by Regent does not supply this information ('…beyond the scope of this note'). The chiller is usually a sub-compartment in the refrigerator compartment or a separate compartment with its own door between refrigerator and freezer. As such it is amply compensated for possible control issues through the equivalent volume calculation where a factor r_c=1.25 is used, because the average ambient temperature is much lower than the 25 °C that is used for the calculation of r_c.

9.3.10 Multi-compartment

Every extra compartment/door, above the two for the fridge and the freezer, adds twice the width of the appliance to the door length. If this extra compartment is a chiller (Tc=0 °C), the extra door losses add 3% to the total energy use of a large appliance[114], for which –as mentioned—the chiller is partly compensated in the equivalent volume equation. In case the extra compartment is a cellar or wine storage compartment (Tc=12 °C) the extra door gasket heat losses are about half, i.e. 1.5 % (after the equivalent volume correction). This could also be perceived to be compensated by the shared wall (lower average ambient) with e.g. the refrigerator, but —especially in the case of wine storage appliances with a very narrow prescribed temperature bandwidth— a shared wall can also be a disadvantage if no specific control measures are taken. Without that --in extremis-- it might even be necessary to install a small auxiliary heater to fine-tune the temperature to avoid that the wine storage compartment becomes too cold.

Industry proposes a generic compensation of 3 % (3 doors), 5 % (4 doors), 6 % (>4 doors) but only on the M factor. For the other compensations the industry targets both the M and N factors and we would propose to do the same here and apply a generic compensation of 2, 3.5 and 4% for respectively 3-, 4-, >4- door appliances.

9.3.11 Wine storage compartments

Wine storage and cellar appliances <u>with a solid door</u> behave like a normal refrigerator, but with a T_c=12 °C instead of T_c=4 (new standard). This means that the temperature ratio is r_c=0.45 instead of r_c =1. The A+-limit in the current legislation follows the equation $q=103/V+0.044$.

In the technical model we change the T_c to 12°C and –given the very low heat load— decrease COP_{nom} efficiency by roughly 20 % (series 1.2, 1.4, 1.5, 1.6). The COP calculation follows the simple Carnot-formula (par. 9.3.2). The figure below gives the result.

[114] At constant external volume

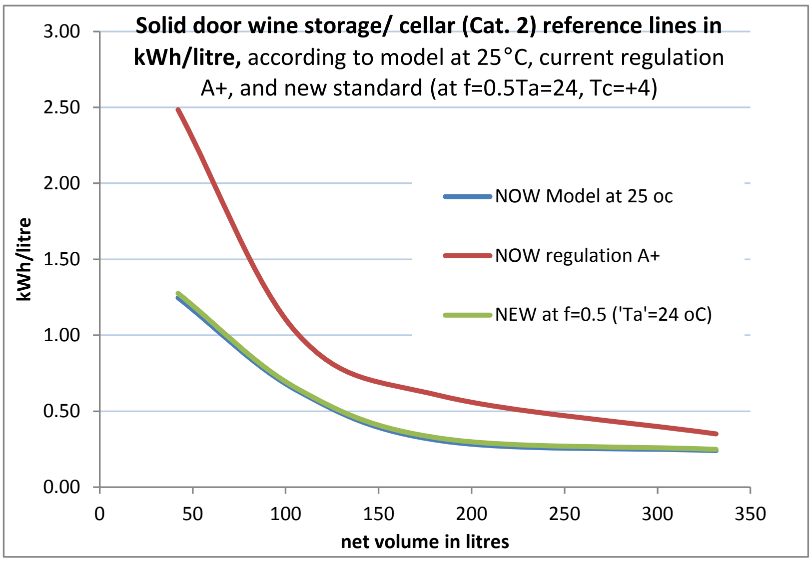


Figure 45. Solid door category 2 reference lines according to the technical model at 25 °C, current regulation A+ and the new standard at T_a=24 °C.

The energy consumption in the new standard is on average 3 % higher. There is a 50 % (smallest size) to 30 % (largest size) difference between the technical model and the current regulation.

In the case of a wine storage compartment with a glass door the U-value of the appliance changes. If we assume a glass door with double glazing and E-coating (argon fill), the U-value of the door becomes 1.7 W/m²K instead of on average 0.6 W/m²K for PUR. Values are given in Table 18. This applies to the door-surface, i.e. around 20 % of the total envelope, and it leads to ~40 % increase of the U-value and thus total heat transmission losses. The figure below shows the impact, with —for comparison— the curve from the technical model for the normal curve.

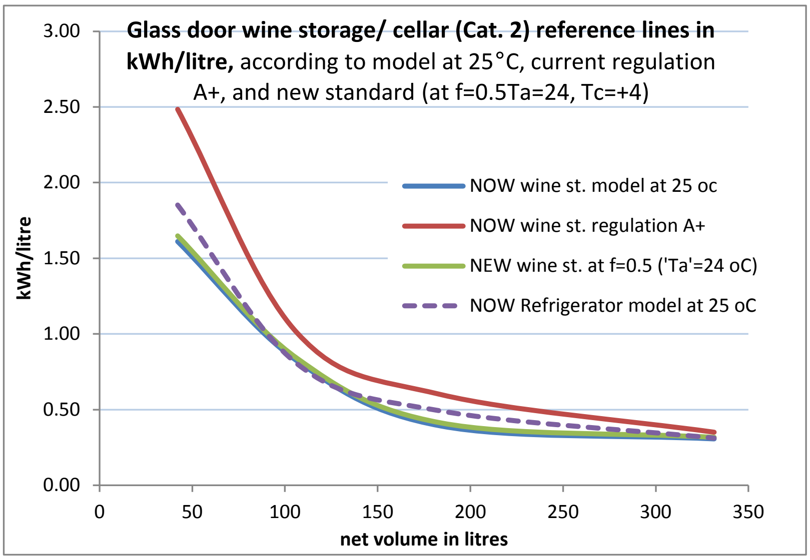


Figure 46. Glass door category 2 glass door reference lines according to the technical model at 25 °C, current regulation A+ and the new standard at T_a=24 °C.

The first impression is that, if manufacturers use the same quality level for wine coolers as for normal refrigerators there is no urgent necessity for a compensation with respect of the current A+ level or even a more ambitious future level. This means that a wine storage compartment integrated in a combi-appliance should have no problem in meeting the current ambition level, even with its own glass door.

If the legislator considers a compensation factor, it will be because stand-alone wine storage appliances —similar to e.g. commercial refrigeration appliances— are often produced in smaller series by small- and medium-sized enterprises (SMEs) that have problems to meet the limit. The value of a possible glass door compensation factor should not exceed 1.2, i.e. similar to what is used in California since 2007 for commercial refrigerators.

9.4 Preliminary proposal for the metric

From both technical analysis and regression analysis in the previous chapter some preliminary proposals can be made for at least the reference lines. These would then need to be discussed with the stakeholders. These reference lines give the metrics for possible measures, the ambition level is for Ecodesign or energy class limits is another matter.

In that sense, we propose the following:

A single equation for the reference specific energy use q_{ref} in kWh/litre per year (the new 'EEI=100')

$$q_{ref} = D \cdot \sum_{c=1}^{n} A_c \cdot B_c \cdot C_c \cdot \left(\frac{N_c}{V} + r_c \cdot M_c\right)$$ in kWh/litre per year,

where

- q_{ref} is reference electricity consumption in kWh/litre volume (V_c) annually,
- A_c is auto-defrost compensation factor (1.2 for frozen food compartments),
- B_c is built-in compensation factor (1.1 for compartments with T_c < 0°C, 1.04 for compartments with $T_c \geq$ 0°C),
- C_c is combi-factor, expressing synergy effect when different compartment types are combined in one appliance, with formula C_c= 0.7·$(r_c \cdot V_c/V)$ for multi-compartment 'combi' appliances[115] and C_c= 1 for single-compartment appliances,
- D is door heat loss compensation in combi-appliances with more than 2 doors (1.02/1.035/1.05 for appliances with 3/4/>4 doors); if so decided this factor could also give a glass-door compensation of e.g. 1.2 [116],
- n is number of compartments,
- c is compartment index suffix,
- N_c, M_c are constants specific for a compartment c (for 0 to 4 star frozen food compartments including ice-making N_c =100, M_c= 0.15, for all other compartment types including chillers N_c =75, M_c = 0.12; see also table),
- V is total net volume of the appliance,
- V_c is compartment net volume,
- r_c is temperature correction, with

  $r_c = (T_a - T_c)/20$

[115] Note that the inclusion of C_c in the summation and the part $(r_c \cdot V_c/V)$ only serve to get a compartment volume weighted average of r_c for the appliance as a whole; instead we could have placed the combi-factor and that calculation also outside the equation but this seemed more compact.

[116] This is roughly the compensation factor also used in e.g. California efficiency regulation for commercial refrigerators with glass door.

where

- T_a is ambient temperature 24°C and
- T_c is compartment design temperature (see table)

Table 20. Compartment types, test- and calculation parameters

Compartment type	T_{min}	T_{max}	T_c	r_c	N_c	M_c	B_c
Name	*°C*	*°C*	*°C*				
Pantry	+14	+20	+17	0.35			
Wine storage [1]	+5	+20	+12	0.60			
Cellar	+8	+14	+12	0.60	75	0.12	1.04
Fresh food	+4	+8	+4	1.00			
Chill	−2	+3	0	1.20			
0-star & ice-making	*n.a.*	0	0	1.20			
1-star	*n.a.*	−6	-6	1.50	100	0.21	1.1
2-star	*n.a.*	−12	-12	1.80			
Food freezer & 3-star	*n.a.*	−18	-18	2.10			

n.a.=not applicable; [1]= with humidity control and maximum deviation 0.5 K from set temperature.
Auto-defrost maximum temperature deviation X, etc. (to take from new standard)

For comparison: If the current metrics were used, the equation for SAE becomes

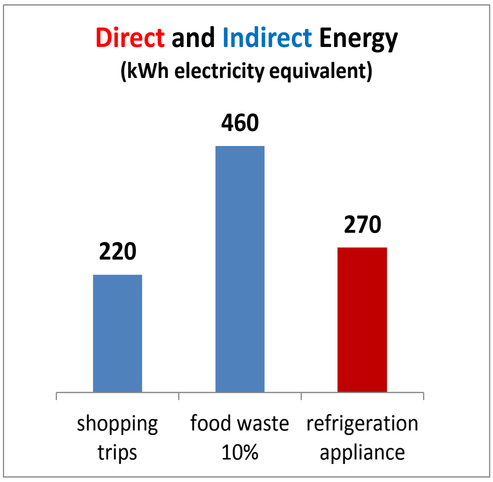
$$SAE = D \cdot \sum_{c=1}^{n} A_c \cdot B_c \cdot C_c \cdot (r_c \cdot M_c + N_c) \qquad \text{in kWh/a.}$$

The energy efficiency index then remains $EEI=AE/SAE$.

The proposal is simpler and legally more robust than the current metrics. It offers more flexibility and options for innovation. It will now be possible to combine fridge-freezers with chillers and higher temperature compartments (pantry, cellar). This will offer a more optimised environment for each type of food and beverage, thus help avoiding food waste and contributing to better health.

Also, apart from technically making sure that high-temperature cooling is no longer at a disadvantage for ecodesign and energy label rating through the above proposal, it is necessary to actively supply information to consumers how to best store their foodstuffs.
As mentioned in paragraph 7.1.4, avoiding food waste is probably the most important contribution that the household refrigeration appliances can make to realising the ‘circular economy’. BOX 3 hereafter gives an illustration of the impact of food waste and shopping trips versus direct electricity use, in terms of energy impacts. BOX 4 gives an example of benefits. A more comprehensive follow-up study on the issue is recommended.

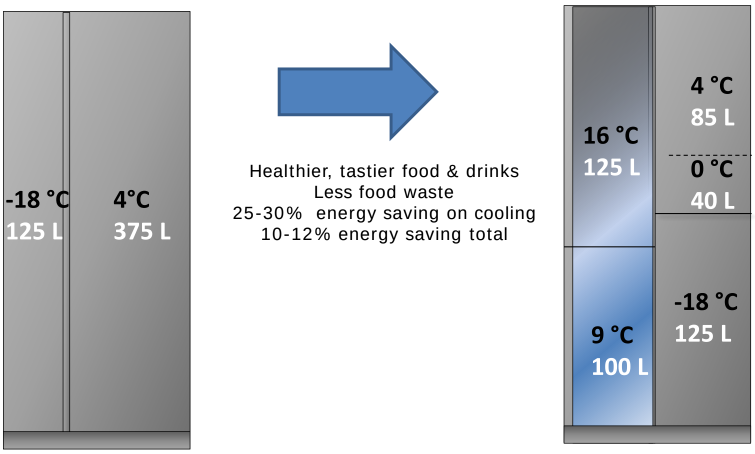
From a business perspective, Task 2 (Chapter 2, Figure 12) shows that ‘variety in compartments’ is the most important functional feature that consumers seek in a refrigeration appliance. This implies that consumers recognise the added value of the feature and should be prepared to pay, which means a higher business revenue for industry and trade.



BOX 3. Comparing direct and indirect energy (illustrative)

- Grocery shopping by car: Average 1-2 trips, 5-10 km per week → 500 km/year → city traffic 1 litre per 10 km→ 50 litre petrol/diesel → 2000 MJ primary/year → power generation 40%→ 220 kWh electricity/year equivalent
- Food 650 kg/yr/pp, 1500 kg/refrigeration appliance. Food life cycle energy content 25 MJ/kg* → 37500 MJ/refrigeration appliance → 4160 kWh electricity equivalent. Avoidable food waste in households (cooking failure, leftovers) 10%→ 416 kWh electricity equivalent.
- Compare: average refrigeration appliance 270 kWh electricity equivalent

BOX 4. Smart multi-compartment benefits (illustrative)



10 Production, distribution and end-of-life (Task 4.2)

10.1.1 Product weight and Bills-of-Materials (BOMs)

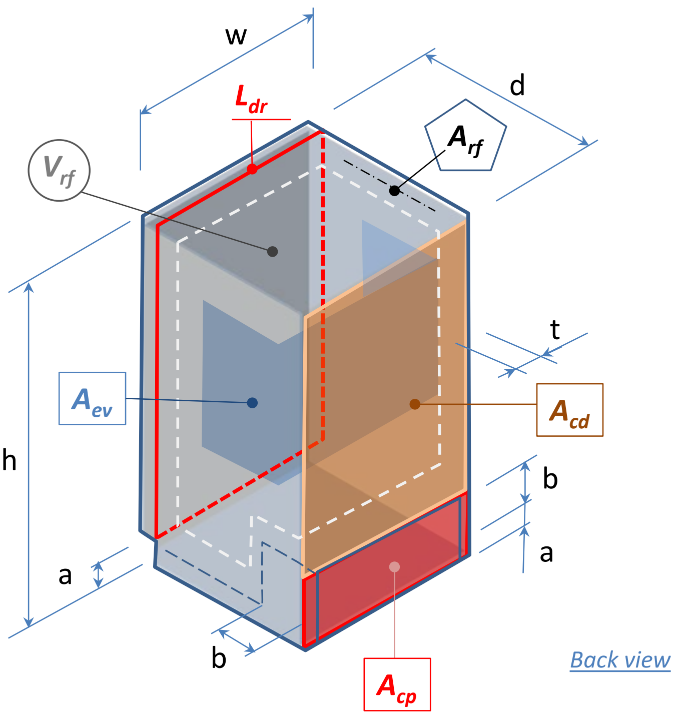
For the Bill-of-Materials the available data from the CECED 2014 database are used to update the findings of the 2007 preparatory study.

Table 28 gives the average product weight and dimensions for each of the base cases, from the CECED 2014 database.

Table 28. Average dimensions from CECED 2014 data and estimated packaged volume

Nr.	Category	product weight	net internal volume (***Vnet***)	gross internal volume (***Vgross***)	external height ***h***	external width ***w***	external depth ***d***	external volume (***Vext***)	packaged volume (+8 cm overall)	rounded packaged volume (***Vpack***)
	unit	*kg*	*dm³*	*dm³*	*cm*	*cm*	*cm*	*dm³*	*dm³*	*m³*
1	**Refrigerator**	50	247	254	135	57	59	454	827	0.9
2	**Wine cooler**	52.4	187	210	109	55	61	366	683	0.7
7	**Fridge-freezer**	70	294	334	170	62	63	664	1146	1.2
8	**Upright freezer**	66.5	205	230	148	63	63	587	1024	1.1
9	**Chest freezer**	47	261	268	86	106	69	629	1058	1.1

Figure 32 gives an overview of other dimensions, surfaces and volumes that can be estimated from the above dimensions in the CECED 2014 database.



Refrigerator geometry parameters

V_{rf}	refrigerated volume (m³)
A_{rf}	refrigerator envelope surface (m²)
A_{cd}	condensor area (m²)
A_{cp}	compressor area (m²)
A_{ev}	evaporator area (m²)
L_{dr}	door perimeter length (m)
w	width (m)
d	depth (m)
h	height (m)
a	air passage height below unit (m)
b	height/depth compressor area (m)
t	average wall thickness (m)

Figure 32. Refrigerator dimensions and other relevant geometry parameters. (VHK 2015)

Table 29 gives the dimensions that were established using the equations mentioned in the notes with the table.

Table 29. Derived dimensions from CECED 2014 data (base cases except wine cooler)

	Category	average wall thick-ness *t*	ext volume (V_{ext})	ext. volume minus wall ($V_{gross'}$)	external compo-nent space (V_{extcmp})	In-sulation volume (V_{ins})	internal component space (V_{intcmp})	Net volume (V_{net})	net freezer volume (V_{net_frz})	net non-freezer volume (V_{net_rf})
	Unit	cm	*dm³*	*dm³*	*dm³*	*dm³*	*dm³*	*dm³*	*dm³*	*dm³*
	Note	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	**Refrigerator**	4.7	454	244	53	157	7	247	0	247
7	**Fridge-freezer**	5.9	664	342	65	257	40	294	79	215
8	**Upright freezer**	8.5	587	222	55	310	40	205	205	0
9	**Chest freezer**	8.1	629	257	74	298	7	261	261	0

Notes:

1. Approximated by finding the value of *t* where $(w-2t)\cdot(d-2t)\cdot(h-a-2t) - b^2\cdot w - V_{gross}=0$, with V_{gross} is gross (internal) volume, *t* is wall thickness (result), *a* is bottom&backside clearance (default a=0.5 dm), *b* is height and depth of compressor space (default b=2 dm), *w* is external width, *d* is external depth, *h* is external height. For cat. 7 the found value for t is corrected with a factor 0.85 to account for the common wall; For cat. 9 the correction is 1.12 to account for the fact that the compressor space is only part of the width.
2. $V_{ext}=w\cdot d\cdot h$
3. = $(w-2t)\cdot(d-2t)\cdot(h-a-2t) - b^2\cdot w$; should be more or less equal to gross volume V but with rounding error
4. = $(w-2t)\cdot(d-2t)\cdot a-b^2\cdot w$; space for compressor, condenser, etc.
5. $=V_{ext}-V_{gross'}-V_{extcmp}$
6. $=V_{gross} - V_{net}$; space for lamp, evaporator, etc.

7.8.9. Average values from CECED 2014 database (for wine cooler not enough reliable data)

The average wall thickness of the appliances is an approximation. Note that it is an average not just from the database but it is also an average per unit: Generally speaking the wall thickness of the sides is smaller than average and the wall thickness at the bottom and back is larger than average.

The figure 33 gives the spread/distribution of the approximated wall thickness versus the gross volume in the CECED 2014 database.

The equations in figure 33 come from linear regression, which gives a better approximation, i.e. higher R2 value, than other (exponential, logarithmic, etc.) regression lines. Only in case of chest freezers, category 9, reliability of the regression is very low and there is practically no relationship between wall thickness and volume of the appliance. For wine coolers there are not enough data to even make an approximation and a proxy of t=4cm is assumed in the calculations in the next table.

The red dot in each graph represents the average value.

Table 30 gives the surface areas that are useful to calibrate the values in the BOM and could be useful in Tasks 5 and 6 for energy calculations.

Based on the geometry and auxiliary parameters[117] the Bills-of-Material in Table 31 are established. Figure 34 gives some more detail on the typical materials mix from of hermetic compressors.

[117] E.g. densities: Steel/iron 7.8, aluminium 2.7, glass 2.58, plastics 0.9-1.1, PUR foam (cyclopentane blowing agent) 0.035 kg/dm³.

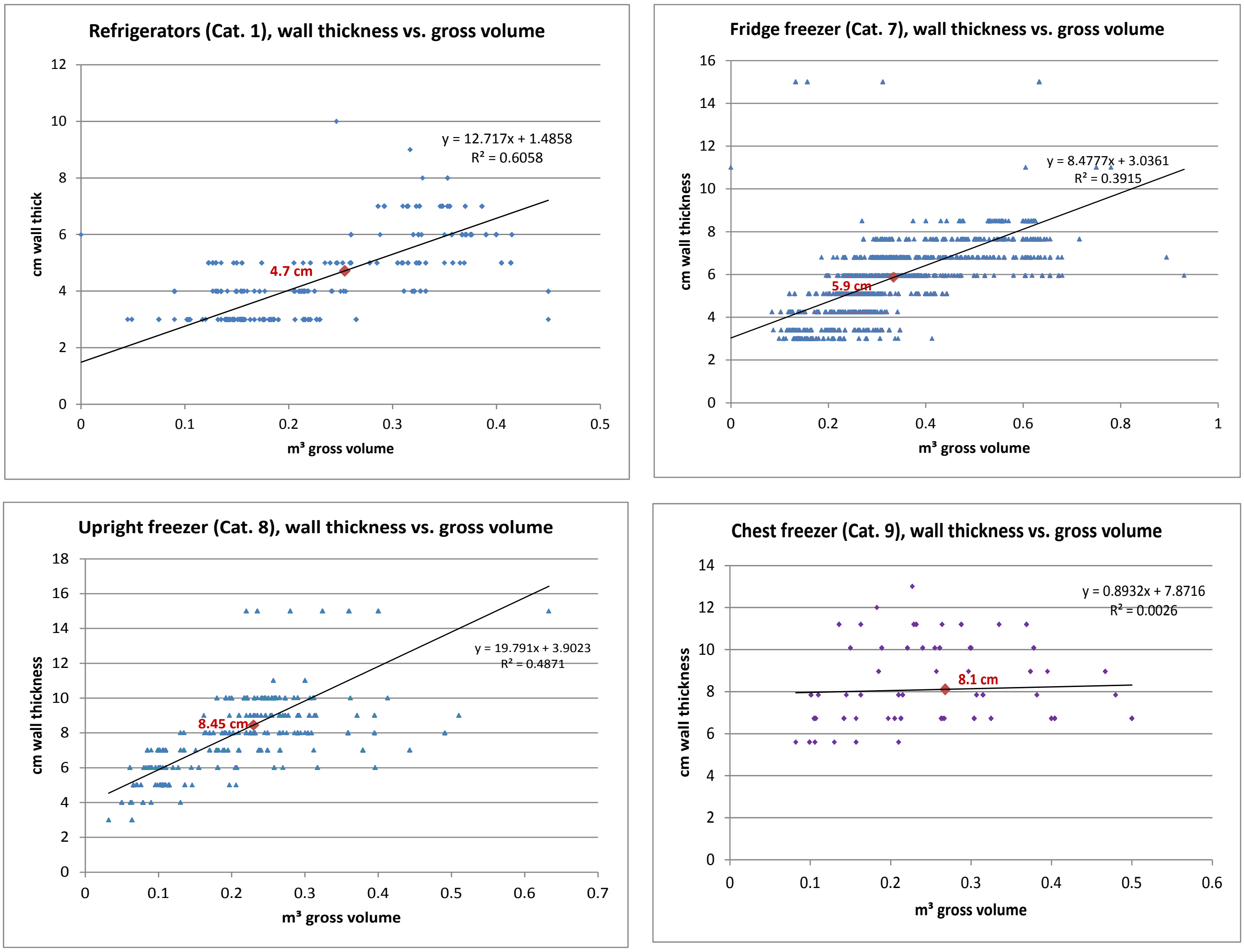


Figure 33. Distribution of approximated wall thickness versus gross volume for categories 1, 7, 8 and 9 in the CECED 2014 database. (source: VHK 2015)

Table 30. Derived surfaces and door gasket length from CECED 2014 data (base cases)

	Category	Neutral envelope surface (***A**rf*)	condenser surface (***A**cd*)	Door gasket length (***L**dr*)
	Unit	dm²	*dm²*	*cm*
	Note	*1*	*2*	*3*
1	**Refrigerator**	33.75	6.27	374
2	**Wine cooler**	28.05	4.62	318
7	**Fridge-freezer**	45.13	8.99	578
8	**Upright freezer**	38.66	7.75	412
9	**Chest freezer**	36.28	6.47	350

Notes:

1. $A_{rf} = 2\cdot(w-t)\cdot(d-t) + 2\cdot[(h-t-a)\cdot(d-t)-(b+0.5t)^2] + 2\cdot(w-t)\cdot(h-t-a)$; 'neutral' means the envelope surface exactly between the inner and outer envelope surface, i.e. where the temperature is the average between inside and outside temperature.
2. $A_{cd} = w\cdot(h-a-b)$
3. $L_{dr} = 2\cdot(w+(h-a))$; for Cat. 7 add $2w$

Table 31. Household refrigeration appliances: Bills of Materials (BOM)

Base case name→	COLD1	COLD2	COLD7	COLD8	COLD9	
net volume (litres)	**247**	**187**	**294**	**205**	**261**	All without no-frost, Refrigerant R600a,
gross volume (litres)	**254**	**210**	**334**	**230**	**268**	Blowing agent cyclopentane,
categories	**1**	**2**	**7**	**8**	**9**	
Material mass→	**g**	**g**	**g**	**g**	**g**	*EcoReport Category*
PRODUCT						**3-Ferro**
Iron & misc. ferro	10956	8217	17407	15908	13662	23-Cast iron
Mixed steel+plastic	57	43	8	800	170	22-St tube/profile
Stainless Steel	63	47	971	156	0	25-Stainless 18/8 coil
Steel other	2773	2080	1551	1573	1859	22-St tube/profile
Steel sheet	10693	8020	14157	14728	9459	21-St sheet galv.
Total ferro	***24542***	***18407***	***34094***	***33166***	***25150***	
						4-Non-ferro
Al	945	2002	1518	829	3360	26-Al sheet/extrusion
Cu tube	1847	1385	2139	1887	1242	30-Cu tube/sheet
Cu wiring 230V	275	206	308	316	275	29-Cu wire
Total non-ferro	***3067***	***3594***	***3965***	***3033***	***4877***	
						1-BlkPlastics
ABS	775	581	950	1167	206	10-ABS
EPS - Insulation	3	2	44	2	0	6-EPS
HDPE	56	42	96	677	53	2-HDPE
PP	950	713	1751	2187	883	4-PP
PS	5837	4378	10059	12058	2310	5-PS
PVC	352	264	398	618	2117	8-PVC
SAN	0	0	0	1440	0	9-SAN
Elastomers (NBR)	76	57	236	69	48	1-LDPE
Total bulk plastics	***8049***	***6037***	***13533***	***18218***	***5617***	
						2-TecPlastics
PA	58	44	22	64	43	11-PA 6
PC & POM	26	20	11	24	10	12-PC
PU Foam - Insulation	5996	4497	10090	10857	10431	15-Rigid PUR
Total tech. plastics	***6080***	***4560***	***10124***	***10946***	***10484***	
						5-Coating
Coating	***65***	***42***	***224***	***144***	***100***	39-powder coating
						6-Electronics
Capacitor	2	2	22	11	8	44-big caps & coils
PWBs, switches, lamp	84	63	200	320	27	98-controller board
Thermostat	149	112	165	90	134	98-controller board
Total electronics	***235***	***176***	***387***	***421***	***169***	
						7-Misc.
Glass	7452	19153	6966	0	0	54-Glass for lamps
Paper (manual)	197	197	307	185	120	57-Office paper
Total misc.	***7649***	***19350***	***7273***	***185***	***120***	
						Other
Lubricating oil	154	116	209	187	250	
Refrigerant	33	25	49	65	83	
Other*	126	95	143	136	150	
Total other	***313***	***235***	***401***	***388***	***483***	
TOTAL PRODUCT weight	**50000**	**52400**	**70000**	**66500**	**47000**	
Cardboard	1588	1271	2940	2129	1619	57-Cardboard
EPS	1137	910	1383	1151	1902	6-EPS
LDPE foil	273	218	283	361	596	1-LDPE
PP	34	27	39	53	70	4-PP
TOTAL PACKAGING	**3033**	**2426**	**4644**	**3693**	**4188**	
TOTAL PRODUCT & PACKAGING	**53033**	**54826**	**74644**	**70193**	**51188**	

* 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. with update and addition wine cooler(COLD2)

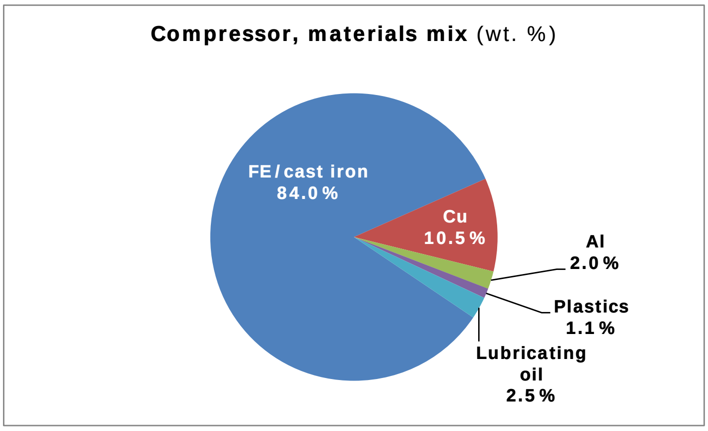


Figure 34. Hermetic compressor, typical materials mix (source: ENEA/ ISIS, Preparatory Study Ecodesign Lot 13: Domestic Refrigerators & Freezers, Task 5, final report, October 2007)

Compared to the products in the 2007 preparatory study, based on an analysis of 2005 models, the products have not only become 10 % larger in net volume, but also heavier. An exact comparison is not possible because the 2005 industry database did not specify the product weight; the 2005 BOMs were based on industry indications of typical products and not on a database average. Nonetheless, from the comparison between the BOM 2005 and the BOM 2014 in table 31 it is plausible that there has been a 15-20 % weight increase for categories 1 (refrigerators), 7 (fridge-freezers) and 8 (upright freezers). The exception is chest freezers (COLD9), where there has been almost no change.

The weight increase is due not only to the larger net volume of the appliance, but even more due to the larger wall thickness especially of fridge-freezers and upright freezers. The amount of PUR insulation material for these categories has increased by 20 %. Also the steel chassis and envelope surface of the cabinet have increased by around 15 %. The PS inner-liner has increased by around 10 %.

The efficiency of refrigeration cooling systems has improved, leading to weight increase: Condenser and evaporator surfaces are bigger (heavier), more tube-and-fin evaporators are used, circulation fans have become ubiquitous and there are more double thermostat models (plus double compressor or inverter-controlled compressors).

Last but not least, over the last decade the steel-wire shelves, that were still common 10 years ago, have been replaced by glass shelves. This substitution adds some 10 % weight to e.g. the average refrigerator (category 1).

10.1.2 Other manufacturing and EoL inputs

The MEERP methodology requires data on:

- Primary scrap production during sheet metal manufacturing
- Packaging materials
- Volume and weight of the packaged product
- Actual means of transport employed in shipment of components, sub-assemblies and finished products
- Materials flow and collection effort at end-of-life (secondary waste), to landfill/ incineration/ recycling/ re-use (industry perspective)
- Technical product life (time-to-failure of critical parts)

In this review study, in contrast to a fully-fledged preparatory study, the inputs from the 2007 preparatory study can be used.

Table 32. Details of assembly, distribution, repair and end-of-life
(source: ENEA/ ISIS, Preparatory Study Ecodesign Lot 13: Domestic Refrigerators & Freezers, Task 5, final report, October 2007)

	Unit	**COLD1**	**COLD7**	**COLD8**	**COLD9**
ASSEMBLY					
Electricity (lighting+tools)	kWh	31.5	25.34	26.51	17.65
Heating (building)	MJ	11.6	15.69	16.8	6.64
Water	m3	0.048	0.228	0.18	0.08
Auxiliary materials:					
lubricant	g	27	27	27	27
cleaning agent	g	8	8	8	8
nitrogen	g	43	84	43	43
argon	g	5	5	5	5
oxygen	g	27	27	27	27
helium	g	1.7	1.7	1.7	1.7
PRIMARY SCRAP (sheetmetal)		3%	3%	3%	3%
DISTRIBUTION					
Distance	km	1235	1467	563	2444
Transport mode		70% truck/ 30% ship			
REPAIR	km	20	20	20	20
spare parts e.g. thermostat, glass shelve, gasket (1% of product weight					
END OF LIFE					
landfill		5%	5.50%	6%	5%
Recycling & re-use		85%	82.5%	84%	83%
heat recovery (mainly PUR)		10%	12%	13%	12%
REFRIGERANT		No fugitive emissions			

End-of-Life aspects have been discussed in paragraphs 7.3 and 7.4, updated after the first stakeholder meeting. As mentioned there, the first-time usage period is 12-13 years (in kitchen), followed by a 3-4 year (re)use (second hand sale in the EU, transfer to the garage, student homes of the children). Furthermore, there is an unknown fraction of discarded household refrigeration appliances which are shipped as ‘waste’ to Africa.

11 Base case environment and economics (Task 5)

11.1 Product-specific inputs

In addition to the product-specific inputs presented in Chapter 10 and previous chapters, the assessment of the environmental and monetary impact through the EcoReport tool in the MEErP requires some additional input data.

For the analysis of the End-of-Life not only the current Bill of Materials is needed, but also how the stock and product weight has evolved over the past 16 years. This will determine the total mass of products that is currently being disposed. Table 33 gives the results of the estimate, based on data in the current and previous preparatory study (see also Annex C). The composition of the materials mix is assumed to be roughly the same (see Table 31).

Table 33. Household refrigeration appliances. Non-energy materials balance for EoL (inputs)

	sold 16 years ago (L=16)*			2015					
Base Case	**Sales**	**Unit weight**	**Weight total**	**Sales**	**Weight**	**Weight total**	**Stock**	**Stock weight**	**Weight total**
	million	*kg*	*kt*	*million*	*kg*	*kt*	*million*	*kg*	*kt*
COLD1	3.5	41.7	146	3.6	53.0	191	57	47.4	2700
COLD2	0.2	50.2	10	0.3	54.8	16	4	52.5	210
COLD7	9.7	65.9	639	11.6	74.6	866	171	70.3	12016
COLD8	2.4	56.5	136	1.4	70.2	98	41	63.3	2597
COLD9	2.5	50.3	126	2.6	51.2	133	30	50.8	1523
Total/avg.	***18.3***	***57.7***	***1057***	***19.5***	***66.9***	***1305***	***303***	***62.9***	***19046***

*= 1999 weight estimated from data 2005 (source: preparatory study 2007)

Based on the same sources, table 34 shows the evolution of the energy use per unit, resulting in the ratio of the energy use of the average installed stock products and the average new sales. This is an important EcoReport input (cell Inputs!D362).

Table 34. Household refrigeration appliances. Ratio energy new/stock

	2005	**avg. stock: 8 years old (2006)***			**2014**					**New / Stock**
Base Case	**Energy per unit**	**Sales 2006**	**Energy per unit**	**Energy sales**	**Sales 2014**	**Energy per unit**	**Energy sales**	**Stock 2014**	**Energy stock****	**ratio energy per unit**
		million	*kWh/a*	*GWh/a*	*million*	*kWh/a*	*GWh/a*	*million*	*GWh/a*	*per unit*
COLD1	164	3.55	159	563	3.6	118	425	57	9041	0.744
COLD2	320	0.25	311	78	0.3	237	71	4	1243	0.763
COLD7	324	10.6	317	3362	11.5	259	2979	171	54230	0.817
COLD8	275	1.9	267	506	1.4	232	284	41	10929	0.869
COLD9	301	2.55	294	749	2.6	240	624	30	8816	0.817
Total/avg.	***286***	***18.9***	***279***	***5258***	***19.4***	***226***	***4383***	***303***	***84259***	***0.82***

**= 2006 data derived from interpolation between 2005 (from 2007 prep. study) and 2014*
***=Stock energy 2014 calculated from 2014 stock numbers and 2006 energy per unit*

Based on prices in Task 2 (Verbraucher Zentrale) and additional desk-research by the study team Table 35 presents the calculation of the base case prices (column 'avg. unit price') and additional price information that is not only relevant for the EcoReport but also for Task 6 (design options).

Table 35. Basecase price information

Basecase	Energy label class	popu-la-tion	energy	net volume	built-in	no frost	price per class	cost of saving	price per litre	avg unit price	msp	ratio price / msp	sales	A+ base price
		n=	*kWh/a*	*litre*	*%*	*%*	*euros*	*eur/kWh*	*eur/litre*	*euros*	*euros*	*-*	*million*	*euros*
COLD1	**A+**	1120	131	240	36%	9%	€ 456	ref	1.90					
	A++	1228	105	257	50%	7%	€ 514	€ 2.23	2.00	495	202	2.5	3.6	420
	A+++	158	71	271	36%	6%	€ 623	€ 3.21	2.30					
COLD2	**B**	28	206	198	0%	0%	€ 792	€ 7.82	4.00					
	A	27	150	193	0%	0%	€ 1 448	€ 11.71	7.50	1344	336	4.0	0.3	792
	A+	11	124	289	0%	0%	€ 2 023	€ 22.13	7.00					
	A++	3	111	512	0%	0%	€ 3 072	€ 80.69	6.00					
COLD7	**A+**	5397	301	319	18%	52%	€ 520	ref	1.63					
	A++	3984	226	296	32%	38%	€ 574	€ 0.72	1.94	557	231	2.4	11.5	466
	A+++	1057	154	310	32%	26%	€ 682	€ 1.50	2.20					
COLD8	**A+**	1498	253	183	33%	48%	€ 366	ref	2.00					
	A++	1159	218	219	16%	66%	€ 482	€ 3.31	2.20	439	217	2.0	1.4	320
	A+++	189	168	289	0%	71%	€ 751	€ 5.39	2.60					
COLD9	**A+**	322	256	264	0%	1%	€ 343	ref	1.30					
	A++	103	194	255	0%	0%	€ 370	€ 0.43	1.45	356	215	1.7	2.6	343
	A+++	20	126	241	0%	0%	€ 482	€ 1.65	2.00					
Sales weighted average										**522**	**224**	**2.31**		**435**

Notes:

Population is number of models in CECED 2014 database; Energy is without correction factors; Built-in and no frost shares per label class are taken from the CECED 2014 database. Price per label class is derived from Verbraucherzentrale (Germany 2014, see Task 2, Chapter 6) and desk-research by the study team (especially for categories 2, 8 and 9); Cost of saving means the increment in euros versus the lower label class divided by the energy saving in kWh/a; Price per litre is an auxiliary parameter to show consistency. The average price per basecase is a weighted average (with the population) of price per label class; Manufacturer selling price (msp) is estimated based on Eurostat production and trade data (see Task2 /Chapter 6); Ratio between average unit price and msp gives an indication of retail and VAT share in the price; Sales 2014 are given here for purpose of weighting; The A+ base price, which can be used in the analysis of design options, is based on the average A+ unit price, corrected for a 15% price premium for the no-frost share and a 20% price premium for the built-in share.

Inputs for distribution are given in Table 28 (packaged volume). Additional information on various other production and distribution parameters is taken from table 32. Average repair distance is assumed to be 50 km (round-trip).

11.2 Base Case Environmental Impact Assessment

New EcoReport files were established for all 5 base cases and outputs are presented hereafter.

Table 36 shows the materials input of the new products, representing a total weight of 1.3 Mt.

Table 36. EcoReport output: Non-energy materials input (99% production, 1% repair in use), in kt

MATERIALS	unit	COLD1	COLD2	COLD7	COLD8	COLD9	TOTAL
Bulk Plastics	kt	35	2	179	52	11	**278**
TecPlastics	kt	22	1	119	29	14	**185**
Ferro	kt	89	6	399	87	33	**614**
Non-ferro	kt	11	1	46	8	6	**73**
Coating	kt	0	0	3	0	0	**3**
Electronics	kt	1	0	5	1	0	**7**
Misc.	kt	34	6	120	6	2	**168**
Extra	kt	0	0	0	0	0	**0**
Auxiliaries	kt	0	0	0	0	0	**0**
Refrigerants	kt	0	0	1	0	0	**1**
Total weight	kt	**192**	**17**	**870**	**183**	**67**	**1 329**

The materials-mix consists of ferro metals (46%), bulk-plastics (21%), technical plastics, i.e. mainly PUR for insulation (14%). The 'Misc.' section (13%) comprises mainly glass-shelves in refrigerators (COLD1) and fridge-freezers (COLD7).

Table 37 gives the output of materials to disposal, recycling and stock change. It illustrates the difference between the current material input in table 36 (1329 kt) and the actual output of discarded materials to disposal and recycling, i.e. 1048 kt. This stock change of +280 kt means that in the future (over the next 16 years) we can expect a higher materials output.

Table 37. EcoReport output: Non-energy materials output to disposal, recycling and stock change, in kt

MATERIALS		COLD1			COLD2			COLD7			COLD8			COLD9			TOTAL		
	unit	disp	rec	stk	dis	rec	stk	dis	rec	stk	dis	rec	stk	dis	rec	stk	dis	rec	stk
Bulk Plastics	kt	3	23	8	0	1	1	16	115	47	5	35	12	2	16	-7	26	191	61
TecPlastics	kt	2	15	5	0	1	1	10	77	32	3	19	7	3	20	-9	18	132	35
Ferro	kt	3	65	21	0	3	2	15	279	106	3	64	20	3	53	-23	24	463	127
Non-ferro	kt	0	8	3	0	1	0	2	32	12	0	6	2	1	10	-4	3	57	13
Coating	kt	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	2	1
Electronics	kt	0	0	0	0	0	0	1	2	1	0	1	0	0	0	0	2	3	2
Misc.	kt	9	17	8	1	2	2	30	58	32	2	3	1	1	3	-2	43	83	42
Extra	kt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Auxiliaries	kt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigerants	kt	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
TOTAL	**kt**	**18**	**128**	**46**	**2**	**8**	**7**	**74**	**565**	**231**	**13**	**128**	**42**	**10**	**102**	**-45**	**116**	**932**	**280**
																	1 048		**280**

Table 38 gives the Life Cycle Assessment for every (new) Base Case in 2014, per impact category and life cycle phase. Table 39 gives a summary for the sales weighted average unit.

Table 38. EcoReport output: Environmental Life Cycle Assessment per Base Case in 2014

IMPACTS per unit		COLD1				COLD2				COLD7				COLD8				COLD9			
Other Resources & Waste		Prod	Dstr	Use	EoL	Prod	Dstr	Use	EoL	Prod	Dstr	Use	EoL	Prod	Dstr	Use	EoL	Prod	Dstr	Use	EoL
Energy primary	GJ	4.9	1.2	19.1	-0.9	5.5	1.0	34.2	-0.8	7.1	1.6	37.4	-1.3	12.7	1.8	29.3	-2.3	2.2	0.7	34.6	-1.0
o/w electricity	MWh	0.2	0.0	2.1	0.0	0.1	0.0	3.8	0.0	0.2	0.0	4.1	0.0	0.5	0.0	3.2	-0.1	0.1	0.0	3.8	0.0
Water (process)	m³	0.4	0.0	0.0	-0.1	0.6	0.0	0.0	-0.1	0.7	0.0	0.0	-0.2	1.1	0.0	0.0	-0.2	0.3	0.0	0.0	-0.2
Waste, non-haz.	kg	22.3	0.6	10.0	-5.4	19.5	0.5	17.8	-3.7	32.5	0.8	19.5	-7.5	55.8	1.0	15.3	-13.0	13.3	0.4	18.1	-7.2
Waste, haz.	kg	0.2	0.0	0.3	0.0	0.2	0.0	0.5	0.0	0.3	0.0	0.6	-0.1	0.5	0.0	0.5	-0.1	0.1	0.0	0.5	-0.1
Emissions (Air)																					
GHG	t CO2 eq.	0.3	0.1	0.8	-0.1	0.3	0.1	1.5	-0.1	0.4	0.1	1.6	-0.1	0.6	0.1	1.3	-0.1	0.1	0.0	1.5	-0.1
Acidification	kg SO2 eq.	2.0	0.2	3.6	-0.5	2.3	0.2	6.5	-0.4	2.8	0.3	7.1	-0.6	4.6	0.4	5.5	-1.0	0.9	0.1	6.5	-0.4
VOC	kg	0.0	0.0	0.4	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.8	0.0
POP	µg i-Teq	0.2	0.0	0.0	-0.1	0.2	0.0	0.1	0.0	0.3	0.0	0.1	-0.1	0.5	0.0	0.1	-0.1	0.1	0.0	0.1	-0.1
Heavy Metals	g Ni eq.	0.4	0.0	0.2	-0.1	0.5	0.0	0.4	-0.1	0.6	0.0	0.4	-0.2	0.9	0.0	0.3	-0.2	0.4	0.0	0.4	-0.2
PAHs	g Ni eq.	0.8	0.0	0.1	-0.2	0.7	0.0	0.1	-0.1	1.4	0.1	0.1	-0.3	2.9	0.1	0.1	-0.6	0.2	0.0	0.1	-0.1
PM, dust	kg	0.5	3.1	0.1	-0.1	0.6	2.4	0.1	-0.1	0.8	4.1	0.2	-0.1	1.3	4.4	0.1	-0.2	0.2	1.9	0.1	-0.1
Emissions (Water)																					
Heavy Metals	g Hg/20	0.3	0.0	0.1	-0.1	0.3	0.0	0.2	-0.1	0.4	0.0	0.2	-0.1	0.6	0.0	0.1	-0.2	0.2	0.0	0.2	-0.1
Eutrophication	kg PO4	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0

Table 39. Environmental impacts per life cycle stage

IMPACTS per unit		COLD (sales weighted average)			
Other Resources & Waste		Produce	Distribute	Use	EoL
Energy primary	GJ	6.4	1.4	33.0	-1.2
o/w electricity	MWh	0.2	0.0	3.7	0.0
Water (process)	m³	0.6	0.0	0.0	-0.2
Waste, non-haz.	kg	29.5	0.7	17.2	-7.4
Waste, haz.	kg	0.3	0.0	0.5	-0.1
Emissions (Air)					
GHG	t CO2 eq.	0.3	0.1	1.4	-0.1
Acidification	kg SO2 eq.	2.5	0.3	6.2	-0.6
VOC	kg	0.0	0.0	0.7	0.0
POP	µg i-Teq	0.3	0.0	0.1	-0.1
Heavy Metals	g Ni eq.	0.6	0.0	0.3	-0.2
PAHs	g Ni eq.	1.2	0.0	0.1	-0.2
PM, dust	kg	0.7	3.6	0.1	-0.1
Emissions (Water)					
Heavy Metals	g Hg/20	0.4	0.0	0.1	-0.1
Eutrophication	kg PO4	0.1	0.0	0.0	0.0

The following two diagrams aim to facilitate the interpretation of the above tables.

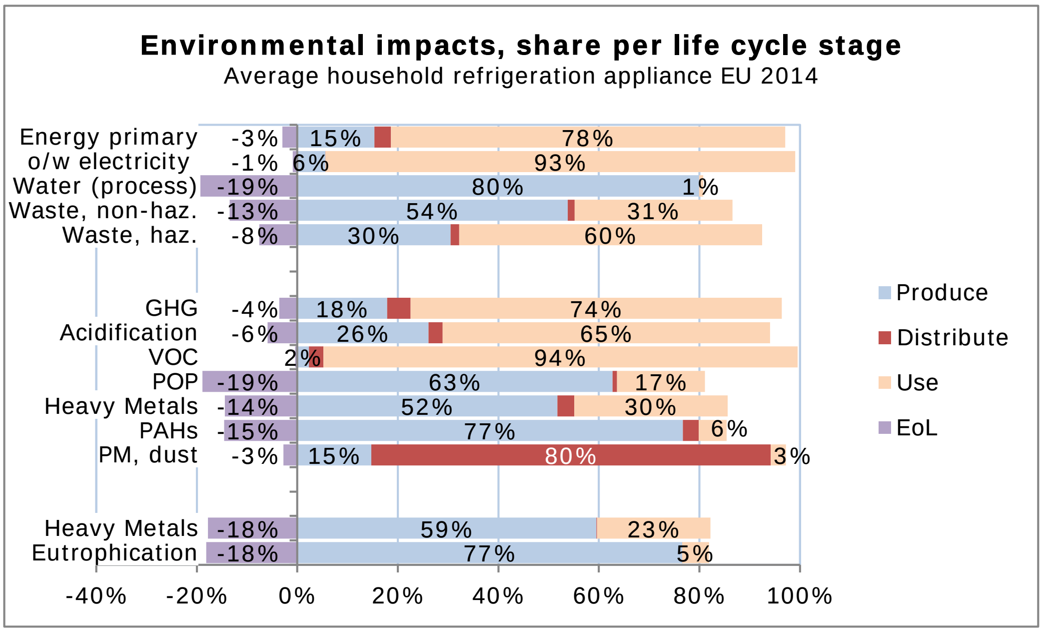


Figure 35. Environmental impacts, share per life cycle stage

Figure 35 shows that for many environmental impacts the use phase makes up around three quarters of the impact. This is the case for primary energy, electricity, hazardous waste, greenhouse gases (GHG), acidifying emissions, volatile organic compounds (VOC). For non-hazardous waste, process water, persistent organic pollutants (POP), heavy metals emitted to air and water, polycyclic aromatic hydrocarbons (PAHs) and eutrophication the production phase is dominant. For particulate matter (PM) the emissions from distribution are dominant.[118]

Figure 36 gives data normalized against share in the EU totals as given in the EcoReport. This gives an idea of the relative share ('importance') of each impact category in the EU. The basis (index 100) is 'electricity', which for this product group is the highest with a share of 3.14 %. The second most important is primary energy with an index 36, which means 0.36*3.14%= 1.2 % of the EU total. GHG and acidification emissions score around 0.8 %. Possibly PM (0.6 %) for distribution may still be relevant if the underlying data are correct, but the share of other impact categories is very small (0.1-0.2 % or less).

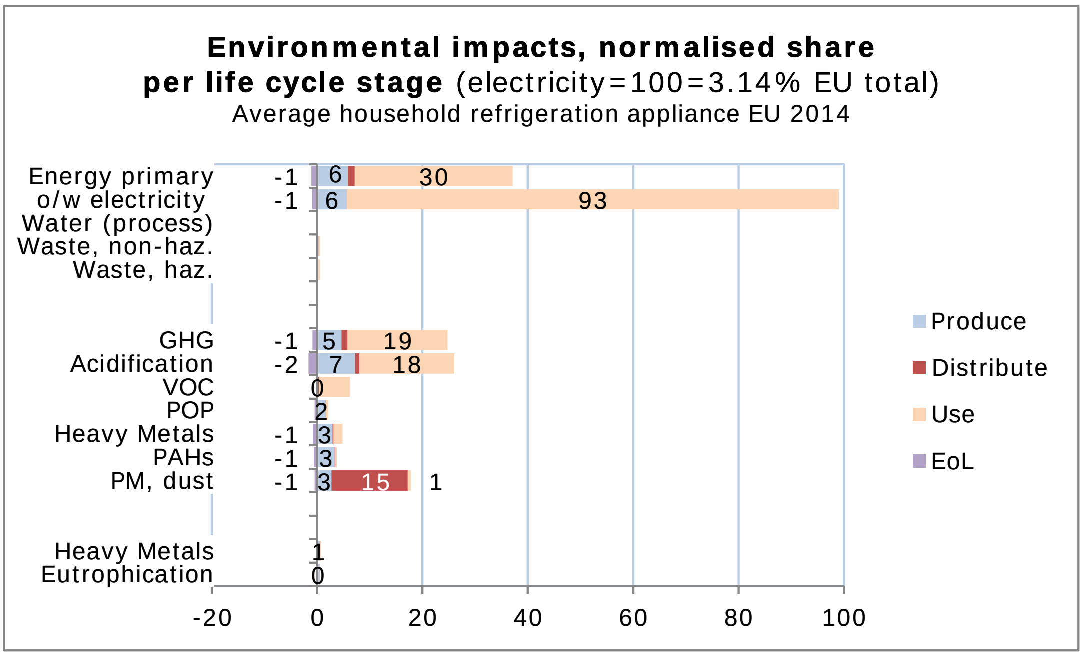


Figure 36. Environmental impacts, share per life cycle stage (electricity=100=3.14% of EU total)

The overall conclusion is that the use phase is still the dominant life cycle phase which is responsible, for the most relevant impacts, for at least three quarters of the total environmental impact.

11.3 Base Case (monetary) Life Cycle Costs for consumer

Table 40 gives the monetary Life Cycle Costs (LCC) for new products sold on the EU market in 2014, both per unit and for the projected EU stock. The LCC comprises the purchase price and discounted running costs over the product life (16 years). For the EU totals both items (per unit) are multiplied with the 2014 sales.

[118] Note that the MEErP specific emissions for means of transport relate to older data, i.e. it is believed that current values per means of transport may be higher.

Both discount rate and the escalation rate for the electricity tariffs are set at 4 %, following MEErP. This means that for the calculation of the present worth factor (PWF) they compensate each other and PWF is 16 years.

Table 40. Monetary Life Cycle Costs, for consumer plus external costs, per NEW unit: purchase and discounted running costs over Life (16 years) [discount rate 4%; electricity tariff escalation rate 4%]

	COLD1		COLD2		COLD7		COLD8		COLD9		TOTAL	
	per unit	EU	per unit	EU	per unit	EU	per unit	EU	per unit	EU	per unit	EU
	€	mln. €	€	mln. €	€	mln. €	€	mln. €	€	mln. €	€	mln. €
Product Price	495	1782	1344	403	557	6461	439	1141	356	463	528	10251
Electricity	433	1537	777	194	850	9026	666	1698	787	1476	714	13931
Total consumer	**928**	**3319**	**2121**	**597**	**1407**	**15487**	**1105**	**2839**	**1143**	**1939**	**1240**	**24182**
External damages												
- o/w production	81	290	73	22	110	1271	78	202	87	113	97	1899
- o/w use	44	155	78	20	86	911	67	171	79	149	72	1406
- o/w EoL	7	24	6	2	9	102	8	21	13	17	8	165
Total external costs	**131**	**469**	**158**	**43**	**204**	**2284**	**153**	**395**	**179**	**279**	**178**	**3470**
Total societal costs	**1059**	**3788**	**2279**	**641**	**1611**	**17771**	**1258**	**3234**	**1322**	**2217**	**1418**	**27651**

As the table shows, in 2014 the product price of the average new product sold amounts to €528 and the running costs over the product life (in euros 2014) amount to €714. EU total acquisition costs are 10.3 billion euros and the discounted running costs (energy) 13.9 billion euros. In total, the energy costs make up 57 % of the total LCC and the purchase costs 43 %.

Contrary to the situation during the 2007 preparatory study, there are now no or negligible End-of-Life costs incorporated in the purchase price[119].

External damages ('Societal life cycle costs')[120] are calculated with the MEErP EcoReport and add another 15 % (3.5 billion euros), bringing the total societal costs of household refrigeration appliances to 27.6 billion euros.

11.4 EU Totals

Tables 41 and 42 give the total environmental impacts of the installed stock in the year 2014, respectively per base case and for the EU total. Table 42 also shows the shares of the impacts in the EU totals (as illustrated in figure 36).

The total electricity consumption of the installed stock of household refrigeration appliances in EU-2014 is 87 TWh/year, i.e. more than 3% of the EU-total electricity final consumption. Greenhouse gas emissions amount to 39 Mt CO2 equivalent (0.8 % of EU total). This makes household refrigeration appliances the most important large electric household appliance in terms of environmental impact.

[119] The 2007 preparatory study calculates End-of-Life costs of €61 per unit. In many EU countries the so-called 'recupel' (BE), 'verwijderingsbijdrage' (NL), 'Entsorgungsbeitrag' (AT, DE), etc. for consumers has never been introduced, recently abolished or diminished to a figure below € 10 per unit.

[120] Explained in the MEErP, Part 1, Paragraph 7.6 and based on a publication by the European Environmental Agency (EEA, Revealing the costs of air pollution, Technical Report No. 15/2011, Copenhagen, Nov. 2011). Amongst others it looks at the costs of CO2 abatement (based on emission trading prices) and monetary indicators for extra health care costs from emisson of pollutants.

Table 41. EcoReport output: Environmental Life Cycle Assessment per Base Case, STOCK 2014

IMPACTS		COLD1				COLD2				COLD7				COLD8				COLD9			
Other Resources & Waste		Prod	Dstr	Use	EoL	Prod	Dstr	Use	EoL	Prod	Dstr	Use	EoL	Prod	Dstr	Use	EoL	Prod	Dstr	Use	EoL
Energy primary	PJ	18	4	91	-3	2	0	11	0	82	18	486	-15	18	2	86	-3	6	2	79	-3
o/w electricity	TWh	1	0	10	0	0	0	1	0	3	0	54	0	1	0	10	0	0	0	9	0
Water (process)	mln. m3	2	0	0	0	0	0	0	0	8	0	0	-2	2	0	0	0	1	0	0	0
Waste, non-haz.	kt	80	2	48	-19	6	0	6	-1	373	10	254	-86	78	1	45	-18	34	1	41	-19
Waste, haz.	kt	1	0	1	0	0	0	0	0	3	0	8	-1	1	0	1	0	0	0	1	0
Emissions (Air)																					
GHG	Mt CO2 eq.	1	0	4	0	0	0	0	0	4	1	21	-1	1	0	4	0	0	0	3	0
Acidification	kt SO2 eq.	7	1	17	-2	1	0	2	0	32	4	92	-7	6	0	16	-1	2	0	15	-1
VOC	kt	0	0	2	0	0	0	0	0	0	0	11	0	0	0	2	0	0	0	2	0
POP	g i-Teq	0.8	0.0	0.2	-0.2	0.1	0.0	0.0	0.0	3.6	0.1	1.2	-1.0	0.7	0.0	0.2	-0.2	0.3	0.0	0.2	-0.2
Heavy Metals	ton Ni eq.	1.5	0.1	0.9	-0.4	0.2	0.0	0.1	0.0	7.3	0.5	5.0	-1.8	1.3	0.1	0.9	-0.3	0.9	0.1	0.8	-0.6
PAHs	ton Ni eq.	3.0	0.2	0.3	-0.6	0.2	0.0	0.0	0.0	15.8	0.6	1.3	-2.9	4.1	0.1	0.2	-0.8	0.5	0.1	0.2	-0.2
PM, dust	kt	1.8	11.1	0.4	-0.3	0.2	0.7	0.0	0.0	8.8	47.6	2.0	-1.5	1.8	6.2	0.4	-0.3	0.6	4.9	0.3	-0.2
Emissions (Water)																					
Heavy Metals	ton Hg/20	1.1	0.0	0.4	-0.3	0.1	0.0	0.0	0.0	4.8	0.0	2.1	-1.3	0.9	0.0	0.4	-0.2	0.6	0.0	0.4	-0.4
Eutrophication	kt PO4	0.3	0.0	0.0	-0.1	0.0	0.0	0.0	0.0	1.3	0.0	0.1	-0.3	0.3	0.0	0.0	-0.1	0.1	0.0	0.0	-0.1

Prod.=Production phase (incl. materials), Dstr.= Distribution, Use=Use phase (incl. repair), EoL=End-of-Life balance (debit-credit), GHG= Greenhouse Gas emissions (WP-100), AP=Acidification potential, VOC=Volatile Organic Compounds, POP=Persistent Organic Pollutants, PAHs=Polycyclic Aromatic Hydrocarbons, PM=Particulate Matter.

Table 42. Environmental Life Cycle Assessment TOTALS, STOCK 2014

IMPACTS		TOTAL ***(max)***					%EU
Other Resources & Waste		Produce	Distribute	Use	EoL	TOTAL	(TOTAL)
Energy primary	PJ	125	27	***753***	-24	**881**	1.20%
o/w electricity	TWh electric	4	0	***84***	-1	**87**	3.14%
Water (process)	mln. m3	***12***	0	0	-3	**9**	0.00%
Waste, non-haz.	kt	***572***	14	394	-143	**837**	0.02%
Waste, haz.	kt	5	0	***12***	-1	**16**	0.02%
Emissions (Air)							
GHG	Mt CO2 eq.	7	2	***32***	-1	**39**	0.81%
Acidification	kt SO2 eq.	48	5	***143***	-11	**185**	0.87%
VOC	kt	0	0	***17***	0	**18**	0.20%
POP	g i-Teq	***6***	0	2	-2	**6**	0.08%
Heavy Metals	ton Ni eq.	***11***	1	8	-3	**17**	0.18%
PAHs	ton Ni eq.	***24***	1	2	-4	**22**	0.14%
PM, dust	kt	13	***71***	3	-2	**84**	0.57%
Emissions (Water)							
Heavy Metals	ton Hg/20	***7.4***	0.0	3.3	-2.2	**9**	0.03%
Eutrophication	kt PO4	***2.0***	0.0	0.2	-0.5	**2**	0.02%

Table 43 gives the total expenditure on household refrigeration appliances for the EU 2014. Total EU acquisition costs for 19.4 million new household refrigeration appliances are 10.3 billion euros (€528/unit), while consumers spend over 17.1 billion euros on the energy bill for 303 million household refrigeration appliances installed (€878/unit). Total consumer expenditure is thus estimated at 27.4 billion euros (€1404/unit) in the EU 2014.

Table 43. Expenditure, for consumer plus external costs, EU total 2014 (STOCK)

	COLD1		COLD2		COLD7		COLD8		COLD9		TOTAL	
	per unit	EU	per unit	EU	per unit	EU	per unit	EU	per unit	EU	per unit	EU
	€	mln. €	€	mln. €	€	mln. €	€	mln. €	€	mln. €	€	mln. €
Product Price	495	1782	1344	403	557	6461	439	1141	356	463	528	10251
Electricity	582	2066	1019	255	1040	11048	766	1954	964	1807	878	17130
Total consumer	**1077**	**3848**	**2363**	**658**	**1597**	**17509**	**1205**	**3095**	**1320**	**2270**	**1404**	**27381**
External damages												
- o/w production	81	290	73	22	110	1271	78	202	87	113	97	1899
- o/w use	59	209	103	26	105	1115	77	197	97	182	89	1729
- o/w EoL	7	24	6	2	9	102	8	21	13	17	8	165
Total external costs	**146**	**523**	**182**	**50**	**223**	**2488**	**163**	**421**	**197**	**312**	**194**	**3793**
Total societal costs	**1223**	**4371**	**2545**	**708**	**1820**	**19997**	**1368**	**3516**	**1517**	**2582**	**1599**	**31173**

12 Design Options (Task 6)

12.1 Options (description of single and combined options)

The main base case characteristics are presented in the table 44 below using results obtained in previous tasks. Energy and net volume are average values weighted by the number of products in the CECED 2014 database in each category.

Table 44. Main characteristics of the base cases

Basecase	Energy label class	energy	net volume	Main Climate Class
		kWh/a	*litre*	
COLD1	A+	114	250	SN-T
COLD2	B	167	224	N
COLD7	A+	257 [237 (2T) / 280 (1T)]	309	SN
COLD8	A+	233	205	SN
COLD9	A+	236	261	SN-T

All the base cases are static appliances, not no-frost nor of the built-in type. Regarding combined appliances, there is an important energy consumption difference between units with 1 and 2 thermostats. Most common combined appliances with two doors also use two thermostat and consequently, this is kept as the base case for category 7. The base for this category used is thus about 14 % more efficient that the category average.

Note that there is not necessarily a perfect correlation between the energy use and the EEI, as the EEI formula takes into account several correction factors to evaluate the reference value and also because these values are average of products of different volumes (and then of different reference lines). Thus, only the energy consumption is used as a reference in what follows. The energy consumption, based upon the 2014 CECED database analysis, is not corrected for the impact of the new IEC 62552:2015 standard.

The list of design options is presented in Table 45 below.

Table 45. List of design options

Option	Description	Efficiency characteristics	Comment	Used for categories
C1	Compressor nominal COP improvement	COP=1.72	Available for all sizes	1,2,7,8,9
C2	Compressor nominal COP improvement	COP=1.85	Only available for rated cooling capacity larger than 60 W, may require oversizing	1,2,7,8,9
C3	Compressor nominal COP improvement	COP=1.98	Only available for rated cooling capacity larger than 80 W, may require oversizing	1,2,7,8,9
VSD	Variable frequency drive	Variable with the base case	COP and minimum capacity that can be reached vary with compressor size	1,2,7,8,9
I1	Increased insulation thickness	+ 1 cm as compared to base case	Available for all appliances.	1,2,7,8,9
I2	Increased insulation thickness	+ 2 cm as compared to base case	May not be applicable to built-in appliances.	1,2,7,8,9

I3	Increased insulation thickness	+ 3 cm as compared to base case	May not be applicable to built-in appliances. May not be readily applied for all categories.	1,2,7,8,9
I4	Use of vacuum insulated panels, 70 % of door area covered	Panels 2 cm thickness, conductivity 0.0035 $Wm^{-1}.K^{-1}$	Does not apply to wine cooler with glass	1,7,8,9
I5	Use of vacuum insulated panels, 50 % of lateral and back sides covered	Panels 1 or 2 cm thickness, conductivity 0.0035 $Wm^{-1}.K^{-1}$	For wine coolers, with thinner insulation, 1 cm is used, 2 cm otherwise.	1,2,7,8,9
D1	Glass door double glazing E-coating, krypton fill	Uvalue = 1.3 $W.m^2.K^{-1}$	Applied to wine cooler with glass only	2
D2	Glass door triple glazing E-coating, krypton fill (heavy door)	Uvalue = 0.8 $W.m^2.K^{-1}$	Applied to wine cooler with glass only	2
PCM	Phase change material (water for refrigerator or water and ammonium chloride solution for freezer)	Cycle frequency (and cycling losses) divided by two, small increase in evaporation and condensing temperatures.		1,2,7,8,9
F1	Improved convection heat transfer with indoor fan and multiflow	0.8 W fan, +40 % increase in the convection coefficient	Applied to static evaporators only.	1,2,7,8,9
F2	Improved condenser heat transfer with outdoor fan	0.68 W fan, +40 % increase in the convection coefficient	Applied to static wire-and-tube condensers only	1,2,7,8,9

Explanations and sources are given hereafter by option category.

Compressor design options (C1, C2, C3 and VSD)

Compressor improvement potential depends on size. The Figure 37 below shows the maximum COP and capacity ranges for three of the main LBP R600a compressor manufacturers (SECOP, Jiaxipera, Embraco). The maximum COP values that can be reached hence depend on compressor size below about 85 W. In case the compressor base case estimated capacity is smaller than 85 W, compressor oversizing impact to reach higher efficiency levels is taken into account.

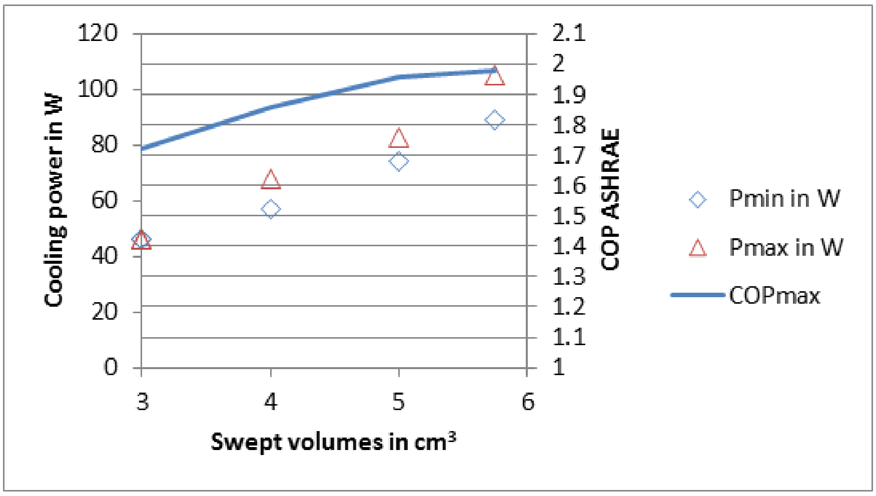


Figure 37. Best available compressor COP and capacity range (ASHRAE conditions) versus size (swept volume in cm^3), LBP, R600a

In the same manner, the compressor efficiency of the VSD solution is limited. The figure 38 gives some of the Embraco LBP R600a compressor efficiency levels with various operating frequencies. Only one point on the compressor curve is considered in the evaluation of design options below, depending on each base case: a minimum capacity of about 30 W with a COP of 1.5, and a COP of 1.85 for minimum capacity above 60 W. In addition, 0.5 W increase in the PCB consumption is included to allow the upgrade.

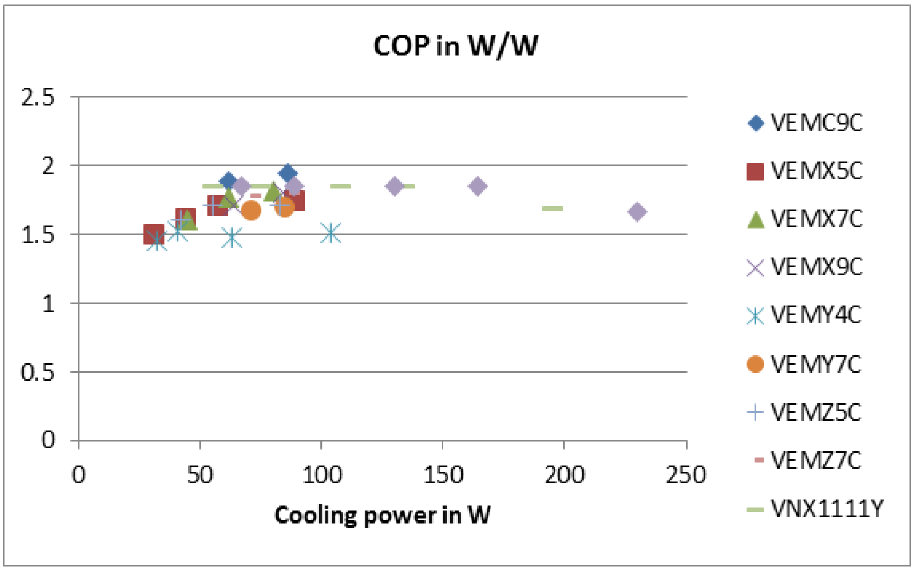


Figure 38. Variable speed compressor efficiency

Insulation options (I1 to I5)

Increased insulation thickness: the maximum insulation levels in 2014 on the market have been identified in Task 5. From the average insulation levels, an increase of 3 cm is already done for highest efficient products of a similar volume in each category. Options I1, I2 and I3 correspond to increase of 1 cm. As in task 4, polyurethane cyclopentane foam is used as the reference insulation. Its thermal conductivity is fixed at 0.020 $W.m^{-1}.K^{-1}$.

VIP integration: vacuum insulation panels 2 cm thick, with thermal conductivity of 0.0035 $W.m^{2}.K^{-1}$ are considered[121]. It is assumed that they are used to replace insulation, but cannot cover a complete panel door because of structural problems. The same values as in the EuP Lot 13 study[122] are used for the two options: in the case of I4, 70 % of the door is covered with panels - this represents about 15 % of the area of the cold volume - and 50 % of the cabinet walls in the case of I5 (this represents about 30 % of the area of the cold volume).

Door options for wine coolers (with glass)

Standard wine coolers are supposed to be equipped with double glazing E-coating windows (argon fill). A first option is to use krypton instead of argon. A second option is to use a triple glazing, krypton fill. Respective U values are, according to the Ecodesign Windows study, 1.7, 1.3 and 0.8 $W.m^{2}.K^{-1}$.

Phase change material

Phase change material helps stabilizing the temperature in the refrigerated volume. When the compressor works, the phase change material solidifies, and absorbs the refrigerator heat when the compressor stops. The first consequence is that the cycling

[121] Greenblatt, Jeffery B.. Technical Support Document for the Final Rule on Residential Refrigerators, Refrigerator-Freezers and Freezers. U.S. Department of Energy, 2011.
[122] 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.

frequency of the compressor is divided by roughly 2[123], and so are cycling losses, as these are proportional to the cycle frequency. This roughly corresponds to a 5 % gain in efficiency for most base cases. There seems to be in addition an increase in the evaporation temperature (and consequently of the condensing temperature). Following Yusufoglu (2015) results, an extra 7 % of evaporator temperature difference is assumed. The impact much depends on the base case design but is much lower than the cycling impact.

Heat exchanger options (F1 and F2)

The Regent Report gives typical products temperature difference across the heat exchangers for recent and well-designed products[124].

Table 46. Temperature difference across heat exchangers

	Regent Report[90] **2015**		
Appliance Category	1	8+9	7
Evaporator temperature difference (K)	15	10	8
Condenser temperature difference (K)	10	12	10

It is clear that the condenser temperature difference was already much reduced, from 18 K to 10 K (category 1), and to 12 K (categories 8 and 9).

Further gains could be reached from a shift to forced convection heat exchangers.

Another simple option is to add a fan to increase the air speed over the static heat exchangers.

F1: This was an option considered for upright freezers by the US DOE on a wire-and-tube heat condenser. This option was also tested recently on a 300 L bottom-mount combined EU refrigerator freezer of class A++ (height of 1.75 m)[125]. It is shown that with a simple computer fan of 0.68 W and a plastic bracket to orientate the flow, it is possible to increase the efficiency of this A++ product by 6 % and of a similar A+++ product by 5 %. This corresponds to an increase of the heat transfer capability of the wire-and-tube condenser of about 40 %, with acceptable noise at this power level (i.e. lower than the one of the compressor).

F2: Regarding natural-convection evaporators, forced convection heat changers could also offer substantial gains. The Fantini[126] thesis is of particular interest here. The heat transfer intensity was studied in a brewed refrigerator. It could be shown that the heat transfer increase of the evaporator due to the existing DC centrifugal 2.5 W fan was limited. However, it was shown that a different design of the air distribution channel at the different glass shelves (so called "multiflow" arrangement) with a 0.8 W DC tangential fan could increase heat exchange intensity of the evaporator by at least 40 %.

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[123] Y. Yusufoglu, T. Apaydin, S. Yilmaz, H.O. Paksoy, Improving Performance of Household refrigerators by Incorporating Phase Change Materials, International Journal of Refrigeration, 2015.
[124] 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.
[125] Hofmanas, I., Reseearches of heat exchange of a wire-and-tube condenser for the increase of refrigerator's efficiency, Summary of Doctoral Dissertation Technological Sciences, Energetics and Power Engineering (06T), 2014, Kaunas
[126] Fantini, M. Innovative techniques to reduce energy consumption of household refrigerators, Politecnico Di Milano, Thesis 2013.

12.2 Impacts (environmental improvement/saving)

All design options focus on energy consumption, identified previously as the main cause of environmental impacts.

The simplified model described previously in Task 4 (Chapter 9) is used to identify the base case characteristics and to estimate the impact of the different options for each base case. The same notations as in the task 4 report are used in Table 47 (Base cases 1, 2, 8, 9) and 48 (Base case 7) below.

Average insulations and condenser and evaporator temperature differences have been discussed in Task 4. For all the base cases, no condenser fan is assumed (and consequent fan power is zero). The electric power consumption Eaux is due to the PCB and is considered to be of 0.5 W, all year long. Starting from these values, the nominal COP of the compressor is adjusted in order to reach the required energy consumption level.

Regarding the wine cooler (COLD 2 base case), the glass door heat losses are integrated in the calculation of the heat load for the walls (Uwall), which explains the high heat load for the walls (Uwall). The heat conductivity of the door has been assumed to be of 1.7 $W.m^{-2}.K^{-1}$. In order to have a compressor with a COP close to 1.5, the insulation level (average wall thickness) has been evaluated to 2 cm for a standard unit (much less than for the COLD 1 base case).

In the case of the COLD 7 base case, a two thermostat unit is considered. In that case, a three-way valve (also called diverter valve) switches the refrigerant flow from the compressor alternatively to the refrigerator and to the freezer. This explains why there are in fact two nearly separated cooling circuits, with two sets of evaporating and condensing conditions. It has been assumed that the load was equally split between the refrigerator and freezer unit. The coefficient of performance is then simply the average of the COP of both circuits. The cycling coefficient is calculated based upon the average load of the two circuits. Regarding the evaporator circuit, it is assumed that a 20 K temperature across the evaporator can be reached in case enough evaporator surface area is available[127].

In order to check the feasibility of the temperature differences across the heat exchangers for the specific base case heat loads, estimates of evaporator surfaces and of maximum heat that can be extracted at the condenser have been computed. More details on how these values are computed are given in **ANNEX D**. Comparing Aev and Aev_max enables to make sure enough heat transfer surface is available to extract the heat load from the cold volume, at the specific evaporating condition. Comparing the Pcond_required and Pcond_max enables to ensure there is enough space on the back of the appliance (or on the surfaces were normally a condenser is put), to extract all the heat from the unit for the given condensing temperature.

[127] Yoon, Won Jae; Jung, Hae Won; Chung, Hyun Joon; and Kim, Yongchan, "An Experimental Study on the Performance of a Two-Circuit Cycle with Parallel Evaporators for a Domestic Refrigerator-Freezer" (2010). International Refrigeration and Air Conditioning Conference. Paper 1042

Table 47. Base case models geometric and energy consumption parameters, all but COLD7 base case

Base case		COLD 1	COLD 2	COLD 8	COLD 9
Vrf	refrigerated volume (m^3)	0.250	0.224	0.203	0.260
	refrigerated volume (litres dm^3)	250	224	203	260
Arf	refrigerator envelope surface (m^2)	3.154	2.565	3.233	3.286
Acd	condenser area (m^2)	0.654	0.485	0.743	1.254
Acp	compressor area (m^2)	0.136	0.143	0.138	0.240
Ldr	door perimeter length (m)	3.89	3.242	4.2	3.22
w	width (m)	0.545	0.571	0.55	0.96
d	depth (m)	0.57	0.5	0.6	0.7
h	height (m)	1.45	1.1	1.6	0.9
a	air passage height below unit (m)	0.05	0.05	0.05	0.05
b	height & depth compressor area (m)	0.2	0.2	0.2	0.2
t	average wall thickness (m)	0.050	0.020	0.085	0.080
Tc	compartment temperature (°C)	5	12	-20	-20
Ta	ambient temperature (°C)	25	25	25	25
k	heat conductivity (W/mK)	0.020	0.020	0.020	0.020
Uwall	heat transfer coefficient wall (W/m^2K)	0.370	1.000	0.235	0.250
Ptrans	transmission heat loss (W)	23	39	34	37
Umisc	heat transfer coefficient door gasket and misc. load (W/mK)	0.080	0.080	0.030	0.030
Pmisc	door and misc. heat loss Ldr*Udoor (W)	6	3	6	4
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	30	42	40	41
Eloss tot	annual heat energy loss (kWhth/a)	259	367	350	362
ΔTev	evaporator temperature difference (K)	17	22	10	10
ΔTcd	condenser temperature difference K	10	13	12	12
Tev	evaporator temperature (°C)	-12	-10	-30	-30
Tcd	condenser temperature (°C)	35.0	38.0	37.0	37.0
COPnom	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1.644	1.53	1.62	1.655
Pnom	Nominal compressor cooling power (W)	63	63	141	141
P	Cool power (W)	120	127	104	104
Cool. Load Ratio	Ratio of heat load to cool power	26%	33%	38%	40%
Cycling losses	Part load performance degradation losses (in % COP)	9%	8%	8%	8%
COP	COP value with actual Tev and Tcd temperatures	2.8	2.5	1.7	1.7
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	2.5	2.3	1.5	1.6
Eaux	electricity CPU and possible fan (kWhel/a)	4.4	8.8	4.4	4.4
AE	**annual electricity consumption (kWhel/a)**	**114**	**167**	**233**	**236**
EVAP REALITY CHECK					
h_evap	Evaporator convective heat transfer coefficient W/m2.K	6.8	7.1	5.5	4.7
Aev	Evaporator surface of the unit (m2)	0.27	0.27	0.72	0.87
Aevap max	Evaporator surface available (m2)	0.51	0.46	1.40	1.23
COND REALITY CHECK					
Pcond required	Heat to be extracted at condenser (W)	157	170	158	157
Pcond max	Max heat the condenser can extracted on refrigerator back surface (W)	177	176	148	250

Table 48. Base case models geometric and energy consumption parameters, COLD7 base case

	Base case	COLD 7
Vrf	refrigerated volume (m³)	0.309
	refrigerated volume (litres dm³)	309
Arf	refrigerator envelope surface (m²)	3.679
Acd	condenser area (m²)	0.799
Acp	compressor area (m²)	0.148
Ldr	door perimeter length (m)	5.47
w	width (m)	0.59
d	depth (m)	0.59
h	height (m)	1.605
a	air passage height below unit (m)	0.05
b	height & depth compressor area (m)	0.2
t	average wall thickness (m)	0.055
Tc	compartment temperature (°C)	-2.5
Ta	ambient temperature (°C)	25
k	heat conductivity (W/mK)	0.020
Uwall	heat transfer coefficient wall (W/m²K)	0.364
Ptrans	transmission heat loss (W)	37
Umisc	heat transfer coefficient door gasket and misc. load (W/mK)	0.080
Pmisc	door and misc. heat loss Ldr*Udoor (W)	12
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	49
Eloss tot	annual heat energy loss (kWhth/a)	428
Δtev_r	Refrigerator evaporator temperature difference (K)	20
Δtev_f	Freezer evaporator temperature difference (K)	8
ΔTcd_r	Refrigerator condenser temperature difference K	15
ΔTcd_f	Freezer condenser temperature difference K	10
Tev_r	Refrigerator evaporator temperature (°C)	-15
Tev_f	Freezer evaporator temperature (°C)	-28
Tcd_r	Refrigerator condenser temperature (°C)	40
Tcd_f	Freezer condenser temperature (°C)	35
Pnom	Nominal compressor cooling power (W)	141
COPnom	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1.54
P_r	Refrigerator cooling power (W)	235
P_f	Freezer cooling power (W)	121
COP_r	Refrigerator COP (-)	2.4
COP_f	Freezer COP (-)	1.7
COP	Average COP (supposing the load is equally shared between refrigerator and freezer)	2.1
Cool. Load Ratio	Ratio of heat load to cool power (ave. of freezer and evaporator load)	31%
Cycling losses	Part load performance degradation losses (in % COP)	9%
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	1.9
Eaux	electricity CPU and possible fan (kWhel/a)	8.8
AE	**annual electricity consumption (kWhel/a)**	**237**
EVAP REALITY CHECK		
h_evap_r	Evaporator convective heat transfer coefficient W/m2.K	6.7
Aev_r	Evaporator surface of the unit (m2)	0.18
Aevap max_r	Evaporator surface available (m2)	0.41
h_evap_f	Evaporator convective heat transfer coefficient W/m2.K	5.3
Aev_f	Evaporator surface of the unit (m2)	0.58
Aevap max_f	Evaporator surface available (m2)	1.21
COND REALITY CHECK		
Pcond required_r	Heat to be extracted at condenser (W) (refrigerator operation)	319
Pcond required_r	Max heat the condenser can extracted on refrigerator back surface (W) (refrigerator operation)	340
Pcond max_f	Heat to be extracted at condenser (W) (freezer operation)	181
Pcond max_f	Max heat the condenser can extracted on refrigerator back surface (W) (freezer operation)	216

For the COLD8 base case, the heat to be extracted at the condenser is a bit higher thanthe maximum calculated, but lies within the uncertainty of the correlation used for the heat transfer. It was thus decided to conserve the insulation and heat exchangers temperature differences.

For the estimate of improvements brought by individual and cumulative design options, an energy balance is made at resp. the evaporator and condenser sides in order to ensure the heat flow can be extracted for the respective evaporation and condensation temperatures and the given load.
At the evaporator, when the compressor capacity increases (in case of oversizing or increased evaporating temperature), the temperature difference across the heat exchanger needs to increase until an equilibrium is reached. The same is done at the condenser. The heat extracted at the condenser is supposed to be the cooling capacity plus 85 % of the compressor electric power (supposing 15 % heat losses from the

compressor shell to the ambient). In addition, there are estimates of convective coefficients at the evaporator and condenser respectively with evaporating and condensing temperatures.
Pressure losses on the refrigerant sides are not considered, as it is not practically feasible with such a simplified model. The impact of this hypothesis is thought to be limited on the relative improvement due to the options.

The impact of the individual design options are then presented for the five base cases in Tables 49 to 53. These tables give all input used for the calculations of options, except area shown before, which does not change for the design options.

Table 49. Impact of individual design options, base case COLD 1

	Base case	COLD1	C1	C2	C3	VSD	I1	I2	I3	I4	I5	PCM	F1	F2
Vrf	refrigerated volume (m^3)	0.250	0.250	0.250	0.250	0.250	0.249	0.248	0.248	0.250	0.250	0.252	0.250	0.250
	refrigerated volume (litres dm^3)	250	250	250	250	250	249	248	248	250	250	252	250	250
Arf	refrigerator envelope surface (m^2)	3.154	3.154	3.154	3.154	3.154	3.245	3.336	3.429	3.154	3.154	3.165	3.154	3.154
Acd	condenser area (m^2)	0.654	0.654	0.654	0.654	0.654	0.689	0.725	0.762	0.654	0.654	0.654	0.654	0.654
Acp	compressor area (m^2)	0.136	0.136	0.136	0.136	0.136	0.141	0.146	0.151	0.136	0.136	0.136	0.136	0.136
Ldr	door perimeter length (m)	3.89	3.89	3.89	3.89	3.89	3.97	4.05	4.13	3.89	3.89	3.89	3.89	3.89
w	width (m)	0.545	0.545	0.545	0.545	0.545	0.565	0.585	0.605	0.545	0.545	0.545	0.545	0.545
d	depth (m)	0.57	0.57	0.57	0.57	0.57	0.59	0.61	0.63	0.57	0.57	0.573	0.57	0.57
h	height (m)	1.45	1.45	1.45	1.45	1.45	1.47	1.49	1.51	1.45	1.45	1.45	1.45	1.45
a	air passage height below unit (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
b	height & depth compressor area (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
t	average wall thickness (m)	0.050	0.050	0.050	0.050	0.050	0.060	0.070	0.080	0.050	0.050	0.050	0.050	0.050
Tc	compartment temperature (°C)	5	5	5	5	5	5	5	5	5	5	5	5	5
Ta	ambient temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25
k	heat conductivity (W/mK)	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Uwall	heat transfer coefficient wall (W/m^2K)	0.40	0.40	0.40	0.40	0.40	0.33	0.29	0.25	0.36	0.32	0.40	0.40	0.40
Ptrans	transmission heat loss (W)	25	25	25	25	25	22	19	17	23	20	25	25	25
Umisc	heat transfer coefficient door gasket and misc. load (W/mK)	0.080	0.080	0.080	0.080	0.080	0.070	0.060	0.050	0.080	0.080	0.080	0.080	0.080
Pmisc	door and misc. heat loss Ldr*Udoor (W)	6	6	6	6	6	6	5	4	6	6	6	6	6
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	31	31	31	31	31	27	24	21	29	26	32	32	31
Eloss tot	annual heat energy loss (kWhth/a)	276	276	276	276	276	238	210	186	254	230	276	277	276
ΔTev	evaporator temperature difference (K)	17.0	17.0	17.0	19.9	11.4	15.7	14.6	13.7	16.2	15.3	17.0	14.0	17.2
ΔTcd	condenser temperature difference K	10.0	9.9	9.8	11.4	6.8	10.4	10.8	11.1	10.3	10.6	10.0	11.0	7.5
Tev	evaporator temperature (°C)	-12.0	-12.0	-12.0	-14.9	-6.4	-10.7	-9.6	-8.7	-11.2	-10.3	-12.0	-9.0	-12.2
Tcd	condenser temperature (°C)	35.0	34.9	34.8	36.4	31.8	35.4	35.8	36.1	35.3	35.6	35.0	36.0	32.5
COPnom	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1.64	1.73	1.85	1.98	1.50	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
Pnom	Nominal compressor cooling power (W)	63	63	63	86	31	63	63	63	63	63	63	63	63
P	Cool power (W)	120	120	120	142	79	126	132	137	124	128	120	136	122
Cool. Load Ratio	Ratio of heat load to cool power	26%	26%	26%	22%	40%	22%	18%	16%	23%	20%	26%	23%	26%
Cycling losses	Part load performance degradation losses (in % COP)	9%	9%	9%	10%	7%	10%	10%	11%	10%	10%	5%	10%	9%
COP	COP value with actual Tev and Tcd temperatures	2.8	2.9	3.1	3.0	3.2	2.8	2.9	2.9	2.8	2.9	2.8	2.9	2.9
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	2.5	2.6	2.8	2.7	3.0	2.6	2.6	2.6	2.5	2.6	2.6	2.6	2.7
Eaux	electricity CPU and possible fan (kWhel/a)	4.4	4.4	4.4	4.4	8.8	4.4	4.4	4.4	4.4	4.4	4.4	6.2	6.1
AE	annual electricity consumption (kWhel/a)	114	109	101	107	102	97	85	75	104	94	109	111	110
	REDUCTION IN CONSUMPTION (%)		5%	11%	6%	11%	14%	25%	34%	8%	18%	4%	3%	4%

[Column I6 removed]

Table 50. Impact of individual design options, base case COLD 2

	Base case	COLD2	C1	C2	C3	VSD	I1	I2	I3	I5	PCM	F1	F2	D1	D2
Vrf	refrigerated volume (m^3)	0.224	0.224	0.224	0.224	0.224	0.223	0.221	0.220	0.224	0.224	0.224	0.224	0.224	0.224
	refrigerated volume (litres dm^3)	224	224	224	224	224	223	221	220	224	224	224	224	224	224
Arf	refrigerator envelope surface (m^2)	2.565	2.565	2.565	2.565	2.565	2.643	2.804	2.970	2.565	2.565	2.565	2.565	2.565	2.565
Acd	condenser area (m^2)	0.485	0.485	0.485	0.485	0.485	0.514	0.574	0.637	0.485	0.485	0.485	0.485	0.485	0.485
Acp	compressor area (m^2)	0.143	0.143	0.143	0.143	0.143	0.148	0.158	0.168	0.143	0.143	0.143	0.143	0.143	0.143
Ldr	door perimeter length (m)	3.242	3.242	3.242	3.242	3.242	3.322	3.482	3.642	3.242	3.242	3.242	3.242	3.242	3.242
w	width (m)	0.571	0.571	0.571	0.571	0.571	0.591	0.631	0.671	0.571	0.571	0.571	0.571	0.571	0.571
d	depth (m)	0.5	0.5	0.5	0.5	0.5	0.52	0.56	0.6	0.5	0.5	0.5	0.5	0.5	0.5
h	height (m)	1.1	1.1	1.1	1.1	1.1	1.12	1.16	1.2	1.1	1.1	1.1	1.1	1.1	1.1
a	air passage height below unit (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
b	height & depth compressor area (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
t	average wall thickness (m)	0.020	0.020	0.020	0.020	0.020	0.030	0.050	0.070	0.020	0.020	0.020	0.020	0.020	0.020
Tc	compartment temperature (°C)	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Ta	ambient temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25	25
k	heat conductivity (W/mK)	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Uwall	heat transfer coefficient wall (W/m^2K)	1.00	1.00	1.00	1.00	1.00	0.67	0.40	0.29	0.76	1.00	1.00	1.00	1.00	1.00
Ptrans	transmission heat loss (W)	39	39	39	39	39	31	25	23	32	39	39	39	36	32
Umisc	heat transfer coefficient door gasket and misc. load (W/mK)	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.060	0.080	0.080	0.080	0.080	0.080	0.080
Pmisc	door and misc. heat loss Ldr*Udoor (W)	3	3	3	3	3	3	4	3	3	3	3	3	3	3
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	42	42	42	42	42	34	29	26	36	42	42	42	39	35
Eloss tot	annual heat energy loss (kWhth/a)	367	367	367	367	367	300	251	226	313	367	369	367	341	309
ΔTev	evaporator temperature difference (K)	22.0	22.0	22.1	24.6	15.4	19.8	18.1	17.2	20.2	22.0	18.4	22.4	21.2	20.1
ΔTcd	condenser temperature difference K	13.0	12.7	12.5	14.0	8.8	13.9	14.7	15.1	13.8	13.0	14.6	9.6	13.4	13.8
Tev	evaporator temperature (°C)	-10.0	-10.0	-10.1	-12.6	-3.4	-7.8	-6.1	-5.2	-8.2	-10.0	-6.4	-10.4	-9.2	-8.1
Tcd	condenser temperature (°C)	38.0	37.7	37.5	39.0	33.8	38.9	39.7	40.1	38.8	38.0	39.6	34.6	38.4	38.8
COPnom	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1.53	1.73	1.85	1.98	1.50	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53
Pnom	Nominal compressor cooling power (W)	63	63	63	80	31	63	63	63	63	63	63	63	63	63
P	Cool power (W)	127	127	127	143	87	138	148	153	136	127	146	129	131	137
Cool. Load Ratio	Ratio of heat load to cool power	33%	33%	33%	29%	48%	25%	19%	17%	26%	33%	29%	32%	30%	26%
Cycling losses	Part load performance degradation losses (in % COP)	8%	8%	8%	9%	6%	9%	10%	10%	9%	4%	9%	8%	9%	9%
COP	COP value with actual Tev and Tcd temperatures	2.5	2.9	3.1	3.0	3.3	2.6	2.7	2.7	2.6	2.5	2.7	2.7	2.6	2.6
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	2.3	2.6	2.8	2.7	3.1	2.4	2.4	2.4	2.4	2.4	2.4	2.5	2.3	2.4
Eaux	electricity CPU and possible fan (kWhel/a)	8.8	8.8	8.8	8.8	13.1	8.8	8.8	8.8	8.8	8.8	11.0	10.9	8.8	8.8
AE	annual electricity consumption (kWhel/a)	167	148	138	143	131	135	112	101	141	160	162	158	155	139
	REDUCTION IN CONSUMPTION (%)		11%	17%	14%	21%	19%	33%	39%	15%	4%	3%	5%	7%	17%

Table 51. Impact of individual design options, base case COLD 7

Base case		**COLD7**	**C1**	**C2**	**C3**	**VSD + C2**	**I1**	**I2**	**I3**	**I4**	**I5**	**PCM**	**F1**	**F2**
Vrf	refrigerated volume (m^3)	0.309	0.309	0.309	0.309	0.309	0.309	0.308	0.307	0.309	0.309	0.309	0.309	0.309
	refrigerated volume (litres dm^3)	309	309	309	309	309	309	308	307	309	309	309	309	309
Arf	refrigerator envelope surface (m^2)	3.679	3.679	3.679	3.679	3.679	3.778	3.878	3.979	3.679	3.679	3.679	3.679	3.679
Acd	condenser area (m^2)	0.799	0.799	0.799	0.799	0.799	0.839	0.879	0.920	0.799	0.799	0.799	0.799	0.799
Acp	compressor area (m^2)	0.148	0.148	0.148	0.148	0.148	0.153	0.158	0.163	0.148	0.148	0.148	0.148	0.148
Ldr	door perimeter length (m)	5.47	5.47	5.47	5.47	5.47	5.59	5.71	5.83	5.47	5.47	5.47	5.47	5.47
w	width (m)	0.59	0.59	0.59	0.59	0.59	0.61	0.63	0.65	0.59	0.59	0.59	0.59	0.59
d	depth (m)	0.59	0.59	0.59	0.59	0.59	0.61	0.63	0.65	0.59	0.59	0.59	0.59	0.59
h	height (m)	1.605	1.605	1.605	1.605	1.605	1.625	1.645	1.665	1.605	1.605	1.605	1.605	1.605
a	air passage height below unit (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
b	height & depth compressor area (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
t	average wall thickness (m)	0.055	0.055	0.055	0.055	0.055	0.065	0.075	0.085	0.055	0.055	0.055	0.055	0.055
Tc	compartment temperature (°C)	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
Ta	ambient temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25
k	heat conductivity (W/mK)	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Uwall	heat transfer coefficient wall (W/m^{2}K)	0.364	0.364	0.364	0.364	0.364	0.308	0.267	0.235	0.329	0.292	0.364	0.364	0.364
Ptrans	transmission heat loss (W)	37	37	37	37	37	32	28	26	33	30	37	37	37
Umisc	heat transfer coefficient door gasket and misc. load (W/mK)	0.080	0.080	0.080	0.080	0.080	0.065	0.055	0.045	0.080	0.080	0.080	0.080	0.080
Pmisc	door and misc. heat loss Ldr*Udoor (W)	12	12	12	12	12	10	9	7	12	12	12	12	12
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	49	49	49	49	49	42	37	33	45	42	49	49	49
Eloss tot	annual heat energy loss (kWhth/a)	428	428	428	428	428	368	325	289	397	364	428	430	428
Δtev_r	Refrigerator evaporator temperature difference (K)	20.0	20.0	20.0	20.1	13.9	18.6	17.4	16.4	19.2	18.4	20.0	16.8	20.2
Δtev_f	Freezer evaporator temperature difference (K)	8.0	8.0	8.0	8.0	5.1	7.3	6.7	6.2	7.6	7.2	8.0	8.0	8.2
ΔTcd_r	Refrigerator condenser temperature difference K	15.0	14.6	14.4	14.2	9.7	15.8	16.4	17.0	15.4	15.9	15.0	16.9	11.1
ΔTcd_f	Freezer condenser temperature difference K	10.0	9.7	9.5	9.4	6.1	10.3	10.5	10.7	10.2	10.3	10.0	10.0	7.6
Tev_r	Refrigerator evaporator temperature (°C)	-15.0	-15.0	-15.0	-15.1	-8.9	-13.6	-12.4	-11.4	-14.2	-13.4	-15.0	-11.8	-15.2
Tev_f	Freezer evaporator temperature (°C)	-28.0	-28.0	-28.0	-28.0	-25.1	-27.3	-26.7	-26.2	-27.6	-27.2	-28.0	-28.0	-28.2
Tcd_r	Refrigerator condenser temperature (°C)	40.0	39.6	39.4	39.2	34.7	40.8	41.4	42.0	40.4	40.9	40.0	41.9	36.1
Tcd_f	Freezer condenser temperature (°C)	35.0	34.7	34.5	34.4	31.1	35.3	35.5	35.7	35.2	35.3	35.0	35.0	32.6
Pnom	Nominal compressor cooling power (W)	141	141	141	141	70.5	141	141	141	141	141	141	141	141
COPnom	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1.54	1.725	1.85	1.98	1.85	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
P_r	Refrigerator cooling power (W)	235	236	236	236	160	251	263	275	243	253	235	273	238
P_f	Freezer cooling power (W)	121	121	121	121	74	125	129	132	123	126	121	121	124
COP_r	Refrigerator COP (-)	2.4	2.7	2.9	3.1	3.7	2.5	2.5	2.6	2.4	2.5	2.4	2.6	2.5
COP_f	Freezer COP (-)	1.7	1.9	2.1	2.2	2.4	1.7	1.8	1.8	1.7	1.7	1.7	1.7	1.8
COP	Average COP (supposing the load is equally shared between refrigerator and freezer)	2.1	2.3	2.5	2.7	3.1	2.1	2.1	2.2	2.1	2.1	2.1	2.2	2.2
Cool. Load Ratio	Ratio of heat load to cool power (sum of freezer and evaporator load)	31%	31%	30%	30%	48%	25%	21%	18%	28%	25%	31%	29%	30%
Cycling losses	Part load performance degradation losses (in % COP)	9%	9%	9%	9%	6%	9%	10%	10%	9%	9%	4%	9%	9%
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	1.9	2.1	2.3	2.4	2.9	1.9	1.9	2.0	1.9	1.9	2.0	2.0	2.0
Eaux	electricity CPU and possible fan (kWhel/a)	8.8	8.8	8.8	8.8	13.1	8.8	8.8	8.8	8.8	8.8	8.8	11.0	10.7
AE	annual electricity consumption (kWhel/a)	237	211	197	184	161	201	177	156	218	199	226	229	228
REDUCTION IN CONSUMPTION (%)			11%	17%	22%	32%	15%	25%	34%	8%	16%	4%	3%	4%

Table 52. Impact of individual design options, base case COLD 8

	Base case	**COLD8**	**C1**	**C2**	**C3**	**VSD (+C2)**	**I1**	**I2**	**I3**	**I4**	**I5**	**PCM**	**F1**	**F2**
Vrf	refrigerated volume (m^3)	0.203	0.203	0.203	0.203	0.203	0.203	0.202	0.201	0.203	0.203	0.203	0.203	0.203
	refrigerated volume (litres dm^3)	203	203	203	203	203	203	202	201	203	203	203	203	203
Arf	refrigerator envelope surface (m^2)	3.233	3.233	3.233	3.233	3.233	3.326	3.421	3.517	3.233	3.233	3.233	3.233	3.233
Acd	condenser area (m^2)	0.743	0.743	0.743	0.743	0.743	0.781	0.820	0.860	0.743	0.743	0.743	0.743	0.743
Acp	compressor area (m^2)	0.138	0.138	0.138	0.138	0.138	0.143	0.148	0.153	0.138	0.138	0.138	0.138	0.138
Ldr	door perimeter length (m)	4.2	4.2	4.2	4.2	4.2	4.28	4.36	4.44	4.2	4.2	4.2	4.2	4.2
w	width (m)	0.55	0.55	0.55	0.55	0.55	0.57	0.59	0.61	0.55	0.55	0.55	0.55	0.55
d	depth (m)	0.6	0.6	0.6	0.6	0.6	0.62	0.64	0.66	0.6	0.6	0.6	0.6	0.6
h	height (m)	1.6	1.6	1.6	1.6	1.6	1.62	1.64	1.66	1.6	1.6	1.6	1.6	1.6
a	air passage height below unit (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
b	height & depth compressor area (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
t	average wall thickness (m)	0.085	0.085	0.085	0.085	0.085	0.095	0.105	0.115	0.085	0.085	0.085	0.085	0.085
Tc	compartment temperature (°C)	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Ta	ambient temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25	25
k	heat conductivity (W/mK)	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Uwall	heat transfer coefficient wall (W/m^2K)	0.24	0.24	0.24	0.24	0.24	0.21	0.19	0.17	0.22	0.20	0.24	0.24	0.24
Ptrans	transmission heat loss (W)	34	34	34	34	34	32	29	28	32	28	34	34	34
Umisc	heat transfer coefficient door gasket and misc. load (W/mK)	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Pmisc	door and misc. heat loss Ldr*Udoor (W)	6	6	6	6	6	6	6	6	6	6	6	6	6
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	40	40	40	40	40	37	35	34	37	34	40	40	40
Eloss tot	annual heat energy loss (kWhth/a)	350	350	350	350	350	327	308	294	326	299	350	352	350
ΔTev	evaporator temperature difference (K)	10.0	10.0	10.0	10.0	5.3	9.5	9.1	8.8	9.4	8.7	10.0	7.4	10.0
ΔTcd	condenser temperature difference K	12.0	11.8	11.6	11.4	8.0	12.3	12.5	12.7	12.3	12.7	12.0	13.4	9.1
Tev	evaporator temperature (°C)	-30.0	-30.0	-30.0	-30.0	-25.3	-29.5	-29.1	-28.8	-29.4	-28.7	-30.0	-27.4	-30.0
Tcd	condenser temperature (°C)	37.0	36.8	36.6	36.4	33.0	37.3	37.5	37.7	37.3	37.7	37.0	38.4	34.1
COPnom	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1.62	1.73	1.85	1.98	1.85	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62
Pnom	Nominal compressor cooling power (W)	141	141	141	141	71	141	141	141	141	141	141	141	141
P	Cool power (W)	104	105	105	105	72	107	109	111	108	112	104	119	109
Cool. Load Ratio	Ratio of heat load to cool power	38%	38%	38%	38%	55%	35%	32%	30%	35%	31%	38%	34%	37%
Cycling losses	Part load performance degradation losses (in % COP)	8%	8%	8%	8%	6%	8%	8%	9%	8%	9%	4%	8%	8%
COP	COP value with actual Tev and Tcd temperatures	1.7	1.8	1.9	2.0	2.3	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.8
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	1.5	1.6	1.8	1.9	2.1	1.5	1.5	1.5	1.5	1.5	1.6	1.6	1.6
Eaux	electricity CPU and possible fan (kWhel/a)	4.4	4.4	4.4	4.4	8.8	4.4	4.4	4.4	4.4	4.4	4.4	6.9	6.7
AE	annual electricity consumption (kWhel/a)	233	219	203	189	171	218	205	195	217	199	224	231	223
	REDUCTION IN CONSUMPTION (%)		6%	13%	19%	27%	7%	12%	16%	7%	15%	4%	1%	4%

Table 53. Impact of individual design options, base case COLD 9

Base case		**COLD9**	**C1**	**C2**	**C3**	**VSD (+C2)**	**I1**	**I2**	**I3**	**I4**	**I5**	**PCM**	**F1**
Vrf	refrigerated volume (m³)	0.260	0.260	0.260	0.260	0.260	0.259	0.258	0.257	0.260	0.260	0.260	0.260
	refrigerated volume (litres dm³)	260	260	260	260	260	259	258	257	260	260	260	260
Arf	refrigerator envelope surface (m²)	3.286	3.286	3.286	3.286	3.286	3.373	3.460	3.549	3.286	3.286	3.286	3.286
Acd	condenser area (m²)	1.254	1.254	1.254	1.254	1.254	1.319	1.386	1.454	1.254	1.254	1.254	1.254
Acp	compressor area (m²)	0.240	0.240	0.240	0.240	0.240	0.245	0.250	0.255	0.240	0.240	0.240	0.240
Ldr	door perimeter length (m)	3.22	3.22	3.22	3.22	3.22	3.3	3.38	3.46	3.22	3.22	3.22	3.22
w	width (m)	0.96	0.96	0.96	0.96	0.96	0.98	1	1.02	0.96	0.96	0.96	0.96
d	depth (m)	0.7	0.7	0.7	0.7	0.7	0.72	0.74	0.76	0.7	0.7	0.7	0.7
h	height (m)	0.9	0.9	0.9	0.9	0.9	0.92	0.94	0.96	0.9	0.9	0.9	0.9
a	air passage height below unit (m)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
b	height & depth compressor area (m)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
t	average wall thickness (m)	0.080	0.080	0.080	0.080	0.080	0.090	0.100	0.110	0.080	0.080	0.080	0.080
Tc	compartment temperature (°C)	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Ta	ambient temperature (°C)	25	25	25	25	25	25	25	25	25	25	25	25
k	heat conductivity (W/mK)	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Uwall	heat transfer coefficient wall (W/m²K)	0.250	0.25	0.25	0.25	0.25	0.22	0.20	0.18	0.23	0.20	0.25	0.25
Ptrans	transmission heat loss (W)	37	37	37	37	37	34	31	29	35	30	37	37
Umisc	heat transfer coefficient door gasket and misc. load (W/mK)	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Pmisc	door and misc. heat loss Ldr*Udoor (W)	4	4	4	4	4	4	5	5	4	4	4	4
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	41	41	41	41	41	38	36	34	39	35	41	42
Eloss tot	annual heat energy loss (kWhth/a)	362	362	362	362	362	334	313	295	342	303	362	364
ΔTev	evaporator temperature difference (K)	10	10.0	10.0	10.1	5.9	9.6	9.2	8.9	9.7	8.9	10.0	8.1
ΔTcd	condenser temperature difference K	12	11.9	11.7	11.5	6.8	12.3	12.5	12.6	12.2	12.6	12.0	13.1
Tev	evaporator temperature (°C)	-30	-30.0	-30.0	-30.1	-25.9	-29.6	-29.2	-28.9	-29.7	-28.9	-30.0	-28.1
Tcd	condenser temperature (°C)	37.0	36.9	36.7	36.5	31.8	37.3	37.5	37.6	37.2	37.6	37.0	38.1
COPnom	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1.655	1.73	1.85	1.98	1.85	1.66	1.66	1.66	1.66	1.66	1.66	1.66
Pnom	Nominal compressor cooling power (W)	141	141	141	141	59	141	141	141	141	141	141	141
P	Cool power (W)	104	104	104	105	59	107	109	111	106	110	104	115
Cool. Load Ratio	Ratio of heat load to cool power	40%	40%	40%	39%	70%	36%	33%	30%	37%	31%	40%	36%
Cycling losses	Part load performance degradation losses (in % COP)	8%	8%	8%	8%	4%	8%	8%	9%	8%	9%	4%	8%
COP	COP value with actual Tev and Tcd temperatures	1.7	1.7	1.9	2.0	2.3	1.7	1.7	1.7	1.7	1.7	1.7	1.7
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	1.6	1.6	1.7	1.9	2.2	1.5	1.6	1.6	1.5	1.6	1.6	1.6
Eaux	electricity CPU and possible fan (kWhel/a)	4.4	4.4	4.4	4.4	8.8	4.4	4.4	4.4	4.4	4.4	4.4	7.1
AE	annual electricity consumption (kWhel/a)	236	229	213	198	170	221	206	194	225	200	230	237
	REDUCTION IN CONSUMPTION (%)		3%	10%	16%	28%	7%	13%	18%	5%	15%	3%	0%

Table 54 below summarizes the results for the five base cases.

Table 54. Impact of individual design options per base case, summary

Option	Description	COLD1	COLD2	COLD7	COLD8	COLD9
C1	Compressor nominal COP improvement	5%	11%	11%	6%	3%
C2	Compressor nominal COP improvement	11%	17%	17%	13%	10%
C3	Compressor nominal COP improvement	6%	14%	22%	19%	16%
VSD	Variable frequency drive	11%	21%	32%	27%	28%
I1	Increased insulation thickness	14%	19%	15%	7%	7%
I2	Increased insulation thickness	25%	33%	25%	12%	13%
I3	Increased insulation thickness	34%	39%	34%	16%	18%
I4	Use of vacuum insulated panels, 70 % of door are covered	8%	NA	8%	7%	5%
I5	Use of vacuum insulated panels, 50 % of lateral and back sides covered	18%	15%	16%	15%	15%
D1	Glass door double glazing E-coating, krypton fill	NA	7%	NA	NA	NA
D2	Glass door triple glazing E-coating, krypton fill (heavy door)	NA	17%	NA	NA	NA
PCM	Phase change material (water for refrigerator or water and ammonium chloride solution for freezer)	4%	4%	4%	4%	3%
F1	Improved convection heat transfer with indoor fan and multiflow	3%	3%	3%	1%	0%
F2	Improved condenser heat transfer with outdoor fan	4%	5%	4%	4%	NA

Corrected VSD gain (at equal COP)			
	COPnom	**COP VSD**	**Gain VSD (at equal COPnom)**
COLD1	1,64	1,50	18%
COLD2	1,53	1,50	23%
COLD7	1,54	1,85	18%
COLD8	1,62	1,85	16%
COLD9	1,66	1,85	19%

Regarding insulation, results are largely in line with the original insulation level already in place.
The PCM option is about constant as for all base cases, compressor runtime fractions are similar and so are cycling losses. Thus the PCM gain is about half the cycling losses.
F1 and F2 options are assumed to help increase the capacity of the heat exchanger without increasing their surface. They give small but non-negligible gains for refrigerators, however, the gains for freezers are respectively very low (COLD8) or negative (COLD9).
The gain of the inverter option is shown, net of the COP variation. Except for COLD2 base case, the gain lies between 16 and 19 %. Only the COLD2 base case has a larger improvement, because of larger temperature differences at design conditions.

12.3 Costs per option

The price of the base cases as well as the estimated manufacturer selling price have been given in Task 4 and is summarized below. As mentioned in part 12.2, the base case COLD7 is a two thermostat appliance, more efficient and more expensive.

Table 55. Base case price information

Basecase	**energy**	**net volume**	**avg unit price**	**msp**	**ratio price / msp**
	kWh/a	*litre*	euros	euros	-
COLD1	114	250	495	202	2,5
COLD2	167	224	1344	336	4,0
COLD7	257 [237 (2T) / 280 (1T)]	309	557 [569 (2T) / 545 (1T)]	231 [236 (2T) / 226 (1T)]	2,4
COLD8	233	205	439	217	2,0
COLD9	236	261	356	215	1,7

To evaluate the cost of the options, an engineering approach was adopted. The product prices have been decomposed starting from their component B2B prices using multipliers to reach manufacturer selling prices. Each component cost has been evaluated on the basis of its OEM estimated B2B price.

Table 56. General cost structure

COMPONENTS	UNITARY PRICE (per unit, m, kg, liter) x Quantity	MULTIPLIER 1	MULTIPLIER 2
COLD CIRCUIT			
	Compressor		F_OEM
	Evaporator(s) / aspiration storage volume		F_MANUF
Option	PCM		F_MANUF
	Condensor		F_MANUF
	Capillary Tube		F_OEM
	Filter Drier		F_OEM
	Tubing liquid gaz		F_OEM
	Refrigerant charge		F_OEM
CABINET, INSULATION, DOOR, GASKET, SHELVES GLASSES ...			
	Cabinet / door steel sheet		F_MANUF
	Insulation PUR cyclopentane		F_MANUF
Option	VIP Panel 20 mm		F_MANUF
	Indoor liner		F_MANUF
	Door Gasket		F_OEM
	Glass shelves	FINISH	F_OEM
	Plastic door shelves	FINISH	F_OEM
	Drawers	FINISH	F_OEM
	Handle	FINISH	F_OEM
Option F1	Multiflow	FINISH	F_OEM
ELECTRIC			
	Lamp	FINISH	F_OEM
	Door lamp switch	FINISH	F_OEM
	Thermostat	FINISH	F_OEM
	220 V shore	FINISH	F_OEM
	Electric wire	FINISH	F_OEM
	PCB	FINISH	F_OEM
Option F1 and F2	Fan(s)		F_OEM
	TOTALS	Subtotal Components	Sub total Overheads, margin ...
	Manufacturer selling price	TOTAL	
	Base case price	TOTAL x ratio price / msp	

The variations in the component prices are linked to the primary quantity, volume of PUR foam varying with volume, size of heat exchangers, and so on. These quantities are linked to the units' physical characteristics.

The multiplicative factors are used to tune each base case price to the manufacturer selling price, while keeping the same links between the component prices and the physical parameters of the units, which vary. The primary parameters are F_OEM and F_MANUF, which account for labour, energy, overheads, investment costs and margin. Given the limited number of components uses, they also account missing components (and costs) in the cost structure. For equipment directly bought from OEM and easily assembled on the refrigerating appliance, F_OEM represents mainly overhead / margin. For equipment manufactured on site or necessitating transformation before assembling, F_MANUF (bigger multiplier) is used. FINISH is a supplementary parameter required to adjust the price of the unit without changing its efficiency: low values means there is little margin for fancy accessories and to stick to the manufacturer selling price without entailing F_OEM and F_MANUF. High value may also means as for wine cooler (COLD2 base case), that some components are not represented in the model, in addition to expensive wood shelves.

The COLD2 structure contains additionally a door, while the COLD7 base case contains also a diverter valve line.

The multipliers are given below for each base case model.

Table 57. Cost structure: main elements by model

	COLD1	COLD2	COLD7	COLD8	COLD9
F_OEM	1.37	1.67	1.31	1.21	1.37
F_MANUF	2.50	3.05	2.00	1.67	2.00
FINISH	1.66	3.50	1.66	1.00	1.00
Total component / raw material value in Euros	111	139	147	150	124
Total component / raw material value in % of MSP	55%	41%	62%	69%	58%
Overhead, energy, labor … in Euros	91	197	89	67	91
Overhead, energy, labor … in % of MSP	45%	59%	38%	31%	42%
Manufacturer selling price (MSP)	202	336	236	217	215

Compressor design options (C1, C2, C3 and VSD)

A compressor price increase of 10 USD[128] for 0.3 point improvement in nominal COP has been used[129]. VSD for compressor is supposed to cost 50 % more than compressors enabling to reach the same efficiency level. There is no price increase with the size of the compressor.

Insulation options (I1 to I5)

Increased insulation thickness: the quantity of foam (volume) required is estimated and multiplied by its supply price.

VIP integration: the volume of VIP added is computed. The unitary cost is of 20 USD / m^2. The same volume of foam is discounted. This is probably largely overestimating the cost of replacement (once a VIP panel is integrated, there is no need for very large PUR foam insulation) but ensures in all cases there is no structural issue.

Door options for wine coolers (with glass)

The cost increase for D1 and D2 options is given in Task 4, D1 glass door extra cost is 0.5 % and D2 triple glazing glass door is 17 %.

Phase change material
The cost from Yusufoglu[130] have been used, 0.45 USD per kg, considering 3 mm thick packs.

Heat exchanger options (F1 and F2)

The unit cost of each fan is 1.8 euro. For the option 1, a multi-flow is required. The estimated component cost is of 1.8 euro before applying the FINISH coefficient.

The list of design options costs computed for all base cases is shown in table 58 below.

[128] With a change USD / EURO of 0.9 in the model.
[129] Greenblatt, Jeffery B.. Technical Support Document for the Final Rule on Residential Refrigerators, Refrigerator-Freezers and Freezers. U.S. Department of Energy, 2011.
[130] Y.Yusufoglu, T. Apaydin, S. Yilmaz, H.O. Paksoy, Improving Performance of Household refrigerators by Incorporating Phase Change Materials, International Journal of Refrigeration, 2015.

Table 58. Price increase of products encompassing design options

Option	COLD1	COLD1	COLD2	COLD2	COLD7	COLD7	COLD8	COLD8	COLD9	COLD9
	Euros	%	Euros	%	Euros	%	Euros	%	Euros	%
	495		1344		569		439		356	
C1	10	2%	39	3%	21	4%	11	2%	5	1%
C2	24	5%	64	5%	35	6%	23	5%	13	4%
C3	33	7%	82	6%	49	9%	36	8%	22	6%
VSD	43	9%	90	7%	135	24%	129	29%	102	29%
I1	31	6%	70	5%	31	5%	25	6%	16	4%
I2	64	13%	228	17%	64	11%	52	12%	33	9%
I3	98	20%	399	30%	98	17%	79	18%	51	14%
I4	54	11%	NA	NA	29	5%	36	8%	20	6%
I5	114	23%	125	9%	76	13%	79	18%	58	16%
D1	NA	NA	1	0%	NA	NA	NA	NA	NA	NA
D2	NA	NA	97	7%	NA	NA	NA	NA	NA	NA
PCM	10	2%	11	1%	8	1%	9	2%	10	3%
F1	14	3%	12	0,9%	16	3%	12	3%	5	1%
F2	7	1%	44	3%	5	1%	6	1%	NA	NA

The cost of the options is not constant whatever the unit but varies with the cost structure explained above. In addition, it should be noted that the compressor options are proportional to the difference in COP between the option and the nominal COP value for the specific base case. This explains also part of the variation, including for the VSD design option.

12.4 Analysis LLCC and BAT

12.4.1 Ranking of options by LLCC versus efficiency

The following parameters are used for the life cycle cost calculations:

- No maintenance costs. There are probably minor reparation costs but these are low and not variable with any of the design options considered. Their impact on the evaluation of the design options is thus null.
- No end-of-life cost (this is supposed to be included in the product price).
- Electricity rate from Task 2: 0.205 euro / kWh
- Lifetime of the units: 16 years

In addition, as suggested in the MEErP, it is supposed that the LCC can be calculated as:

$$LCC = PP + N*OE + EoL$$

with

- PP: the purchase price
- N: the lifetime of the unit
- OE: the electricity expenditure
- EoL in our case, the end of life fee, integrated into the product price.

Based on the previous findings, the simple payback time and LCC can be computed for each individual design option. They are presented hereunder in a table and a graph for each base case. Design options are classified in the table by increasing simple payback time.

Table 59. COLD1. LCC of individual options.

	Energy consump-tion (kWh)	Energy consump-tion gain (%)	Price (Euros)	Price increase	Price increase (%)	SPB	LCC
	Euros	%	Euros	Euros	Percent	Years	Euros
BC	114		495				837
C1	109	4.7%	505	9.58	2%	9	831
I1	97	14.5%	526	30.89	6%	9	819
C2	101	11.1%	520	24.37	5%	10	824
PCM	109	4.3%	505	9.74	2%	10	832
I2	85	25.4%	559	63.64	13%	11	814
I3	75	34.1%	593	98.08	20%	13	819
F2	110	3.7%	506	11.21	2%	13	836
VSD	99	13.5%	547	51.94	10%	17	843
C3	107	6.4%	528	33.17	7%	23	848
I4	104	8.4%	549	54.20	11%	28	863
I5	94	17.6%	609	114.15	23%	28	891
F1	111	2.8%	514	18.54	4%	29	846

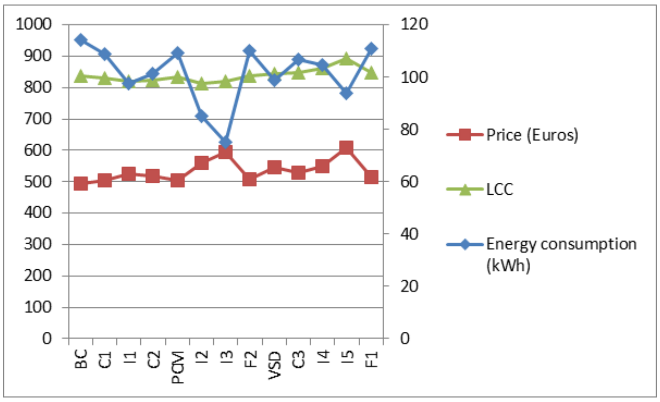


Table 60. COLD2. LCC of individual options.

	Energy consumptio n (kWh)	Gain in %	Price (Euros)	Price increase (Euros)	Price increase in %	SPB	LCC
BC	167		1344				1892,04582
D1	155	7.5%	1345	0.68	0%	0.27	1852
F2	158	5.3%	1355	10.81	1%	5.96	1874
PCM	160	4.1%	1356	12.41	1%	8.74	1882
C1	148	11.3%	1383	38.88	3%	10.05	1869
I1	135	19.2%	1414	70.46	5%	10.73	1857
C2	138	17.2%	1408	63.82	5%	10.82	1862
VSD	131	21.3%	1434	90.30	7%	12.35	1865
C3	143	14.2%	1426	82.13	6%	16.84	1896
D2	139	16.7%	1441	97.40	7%	17.01	1898
I2	112	32.8%	1571	227.57	17%	20.27	1940
I5	141	15.4%	1469	125.17	9%	23.66	1933
I3	101	39.5%	1743	398.64	30%	29.49	2074
F1	162	3.1%	1388	44.33	3%	41.67	1919

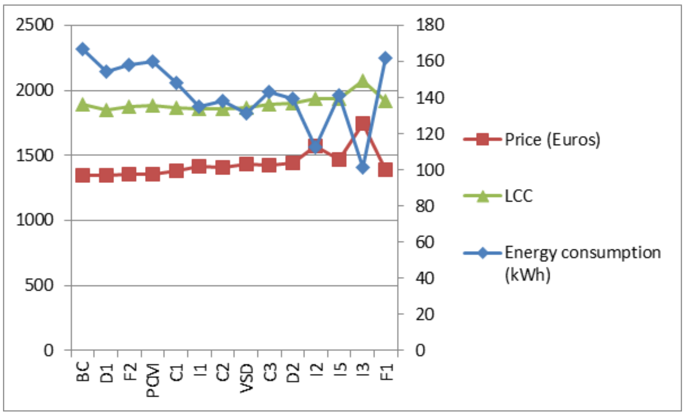


Table 61. COLD7. LCC of individual options.

	Energy consumption (kWh)	Gain in %	Price (Euros)	Price increase (Euros)	Price increase in %	SPB	LCC
BC	237		569				1345
F2	228	3.9%	575	5.21	0.0	2.79	1321
PCM	226	4.4%	577	7.64	0.0	3.61	1319
C1	211	10.8%	590	20.72	0.0	3.94	1282
C2	197	16.9%	604	34.75	0.1	4.24	1249
I1	201	14.8%	600	30.64	0.1	4.25	1261
C3	184	22.3%	619	49.35	0.1	4.56	1222
I2	177	25.3%	633	63.56	0.1	5.18	1213
I3	156	34.0%	667	98.19	0.2	5.96	1180
I4	218	7.8%	598	28.63	0.1	7.61	1314
VSD + C2	161	31.8%	704	135.04	0.2	8.76	1234
I5	199	15.8%	645	76.02	0.1	9.89	1298
F1	229	3.2%	585	15.60	0.0	10.03	1336

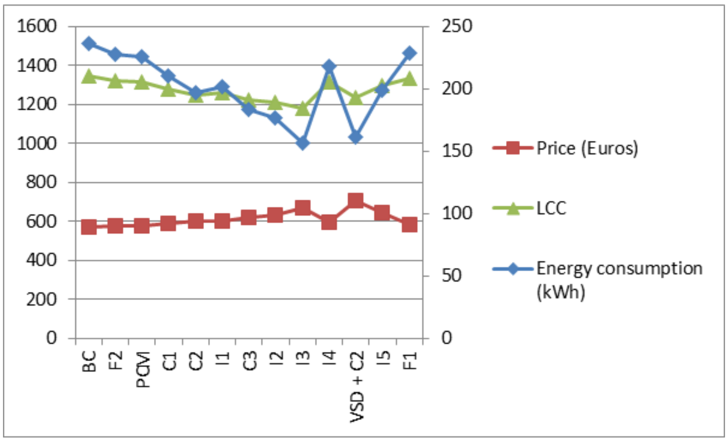


Table 62. COLD8. LCC of individual options.

	Energy consumption (kWh)	Gain in %	Price (Euros)	Price increase (Euros)	Price increase in %	SPB	LCC
BC	233		439				1139
F2	223	4.5%	445	6.04	1%	2.91	1114
C1	219	6.3%	450	10.57	2%	3.57	1105
C2	203	12.9%	463	23.15	5%	3.84	1072
C3	189	18.8%	476	36.24	8%	4.13	1044
PCM	224	3.9%	448	9.14	2%	4.97	1121
I1	218	6.7%	465	25.39	6%	8.15	1118
I2	205	12.0%	491	51.76	12%	9.27	1107
VSD	171	26.6%	569	129.21	29%	10.42	1083
I3	195	16.3%	518	79.13	18%	10.43	1105
I4	217	6.9%	476	36.18	8%	11.25	1127
I5	199	14.9%	518	78.62	18%	11.30	1114
F1	231	1.2%	451	12.08	3%	22.46	1143

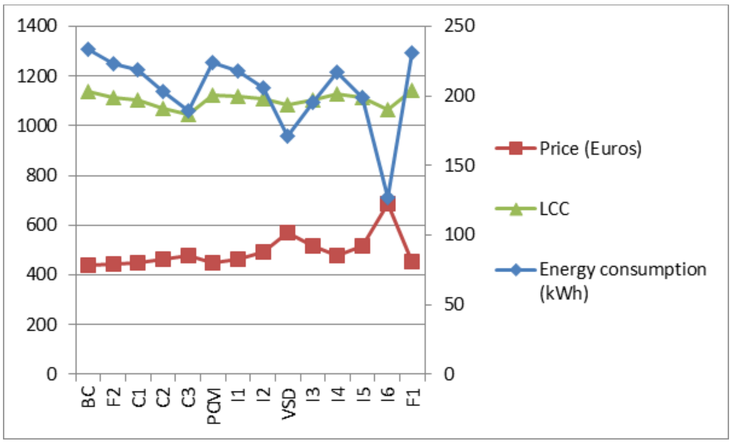
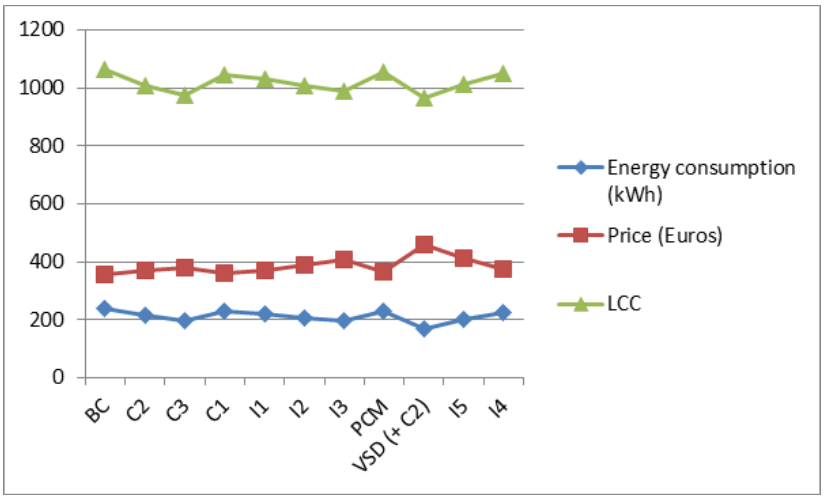


Table 63. COLD9. LCC of individual options.

	Energy consumption (kWh)	Energy consumption gain (%)	Price (Euros)	Price increase	Price increase (%)	SPB	LCC
BC	236		356				1064
C2	213	9.9%	369	13.40	4%	2.9	1007
C3	198	16.0%	378	22.43	6%	3.0	973
C1	229	3.1%	360	4.73	1%	3.2	1047
I1	221	6.6%	372	15.75	4%	5.1	1033
I2	206	12.7%	388	32.67	9%	5.4	1007
I3	194	17.6%	406	50.56	14%	6.1	989
PCM	230	2.7%	365	9.74	3%	7.6	1054
VSD (+C2)	170	28.0%	457	101.68	29%	7.7	968
I5	200	15.4%	413	57.71	16%	7.9	1012
I4	225	4.6%	376	20.03	6%	9.2	1051



For cumulative design options, the simple payback time criterion is used to prioritize the simple design options to be added. Because of complex energy interactions, this does not give perfectly smoothed curves. Energy interactions are taken into account thanks to the energy model described in Task 4 and in part 12.2 above.

Tables and curves of the cumulated design options are presented hereafter per base case.

In addition, market data are used to draw reference LCC curve, using product prices indicated in Task 5 (Chapter 10, Table 35). The prices per litre for each energy label class of table 35 are multiplied by the base case net volume in order to obtain the price of a unit with the same volume and of different efficiency rank as seen from the market. The life cycle cost is then also computed for these units and added to the LCC graph of cumulative options below for comparison. It can be noted from Table 35 that for category 8, the average volume of the A+++ product class is much larger than for the base case ; as a consequence, the comparison is not meaningful. The same is true for A+ and A++ wine coolers. Except for these 2 cases, the comparison is convincing : most of the points added with these market prices lie on the LCC curve. The model still tends to underestimate the potential because of higher prices of cumulative design options as compared to prices issued from market data for A++ and A+++ energy label grades.

Table 64. COLD1. LCC of cumulative options.

Anchor points					A++	LLCC			A+++	BEP			BAT
Option	**BC**	**F2**	**C1**	**PCM**	**I1**	**C2**	**F1**	**I2**	**I3**	**C3**	**VSD**	**I4**	**I5**
Energy consumption (kWh)	114	110	105	100	85	80	77	67	59,1	61,2	64,9	59,4	51
Gain in %		4%	8%	12%	25%	30%	33%	41%	48%	46%	43%	48%	55%
Price (Euros)	495	502	511	521	552	567	581	614	650	658	669	710	836
Price increase in %		1%	3%	5%	11%	14%	17%	24%	31%	33%	35%	43%	69%
SPB		7,6	8,5	9,1	9,6	10,2	11,3	12,4	13,7	15,0	17,3	19,1	26,4
LCC	869	862	855	850	832	828	833	834	843	859	882	904	1003
EEI	36	40	39	37	31	29	28	25	22	23	24	22	19

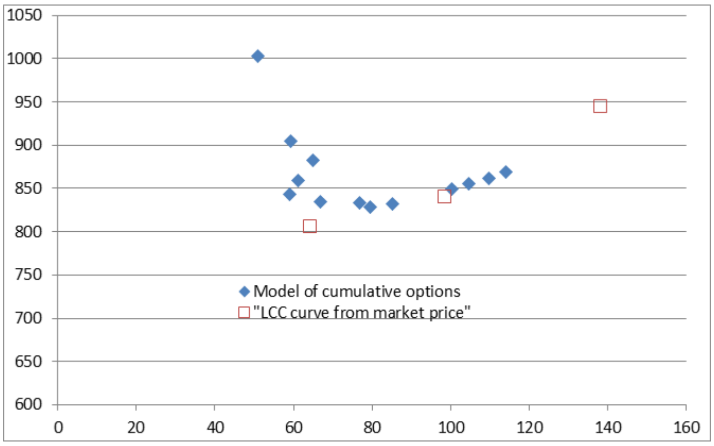


Table 65. COLD2. LCC of cumulative options.

Anchor points					A+		LLCC	A++		BEP		A+++		BAT
Option	**BC**	**D1**	**F2**	**PCM**	**C1**	**C2**	**I1**	**C3**	**VSD**	**D2**	**F1**	**I5**	**I2**	**I3**
Energy consumption (kWh)	167	155	146	140	125	117	92	94	92	81	78	67	57	50
Gain in %		7%	13%	16%	25%	30%	45%	44%	45%	52%	53%	60%	66%	70%
Price (Euros)	1344	1345	1355	1368	1406	1431	1502	1520	1530	1631	1686	1810	1973	2149
Price increase in %		0%	1%	2%	5%	7%	12%	13%	14%	21%	25%	35%	47%	60%
SPB		0.3	2.7	4.3	7.3	8.7	10.5	12.1	12.3	16.6	19.2	23.4	28.5	34.5
LCC	1892	1852	1835	1826	1815	1814	1802	1829	1831	1895	1941	2031	2159	2314
EEI	56	52	49	47	42	39	31	32	31	27	26	23	19	17

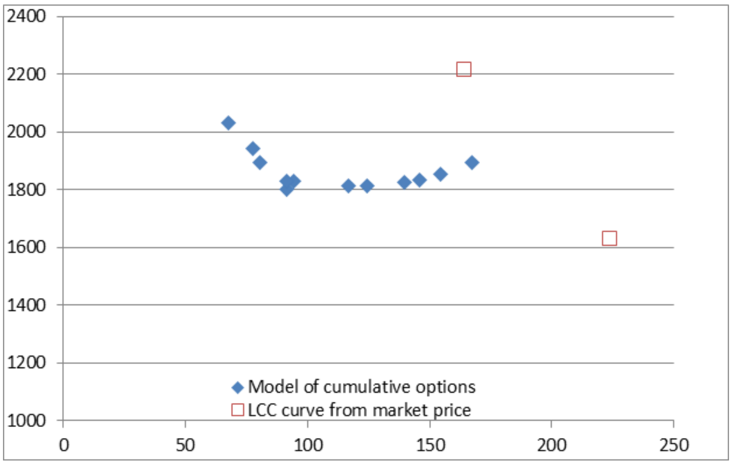


Table 66. COLD7. LCC of cumulative options.

Anchor points		A++					A+++	LLCC					BAT
	BC	PCM	C1	C2	C3	F2	I1	I2	F1	I4	I3	I5	VSD
Energy consumption (kWh)	237	226	202	188	176	169	141	122	116	108	95	82	80
Gain in %		4%	15%	21%	26%	28%	40%	48%	51%	54%	60%	65%	66%
Price (Euros)	569	577	598	612	627	638	672	708	731	757	792	880	995
Price increase in %		1%	5%	8%	10%	12%	18%	24%	28%	33%	39%	55%	75%
SPB		3.6	4.0	4.3	4.6	5.0	5.3	5.9	6.5	7.1	7.7	9.8	13.3
LCC	1345	1319	1259	1229	1203	1193	1135	1109	1111	1111	1105	1148	1257
EEI	33	32	28	26	25	24	20	17	16	15	13	11	11

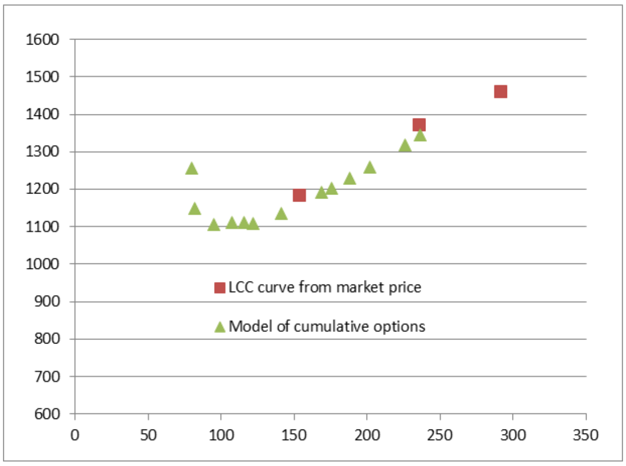


Table 67. COLD8. LCC of cumulative options.

Anchor points		A++	A++						LLCC	A+++			BAT
Option	BC	F2	C1	C2	C3	PCM	F1	I1	I2	I3	I4	I5	VSD
Energy consumption (kWh)	233	223	209	195	182	175	172	160	151	143	135	118	117
Gain in %		4%	10%	16%	22%	25%	26%	31%	35%	39%	42%	49%	50%
Price (Euros)	439	445	456	469	482	491	503	528	555	583	622	708	805
Price increase in %		1%	4%	7%	10%	12%	14%	20%	26%	33%	42%	61%	83%
SPB		2.9	3.4	3.8	4.1	4.4	5.1	6.1	7.0	8.0	9.3	11.6	15.7
LCC	1205	1177	1142	1108	1079	1064	1066	1053	1050	1053	1066	1094	1190
EEI	35	33	31	29	27	26	26	24	23	21	20	18	18

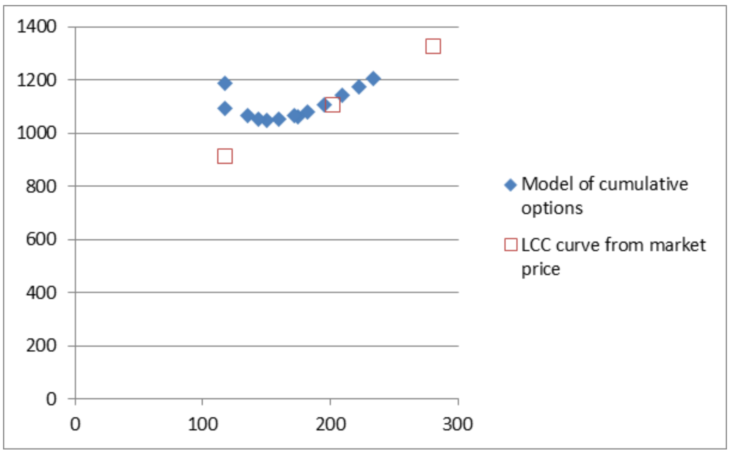
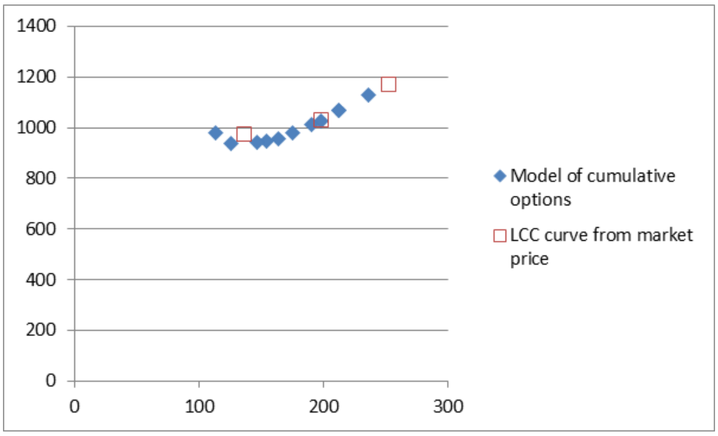


Table 68. COLD9. LCC of cumulative options.

Anchor points				A++					LLCC	A+++ / LLCC	BAT
Option	**BC**	**C2**	**C1**	**C3**	**PCM**	**I1**	**I2**	**I3**	**I4**	**I5**	**VSD (+ C2)**
Energy consumption (kWh)	236	213	213	198	191	176	164	154	147	126	113
Gain in %		10%	10%	16%	19%	26%	31%	35%	38%	47%	52%
Price (Euros)	356	369	369	378	388	404	421	440	462	526	607
Price increase in %		4%	4%	6%	9%	14%	18%	24%	30%	48%	71%
SPB		2.9	2.9	3.0	3.6	4.0	4.5	5.1	5.9	7.7	10.3
LCC	1130	1067	1067	1029	1013	980	958	945	943	938	979
EEI	38	34	34	32	31	28	26	25	24	20	18



The table below summarizes Base Case, Least LCC, BEP (Break-Even Point where LCC improved design= LCC BC) and BAT values identified per category.

Table 69. Summary main characteristics of BC, LLCC, BEP and BAT

base case	**energy**					**money**				
		BC	**LLCC**	**BEP**	**BAT**		**BC**	**LLCC**	**BEP**	**BAT**
COLD1	**kWh/a**	114	80	61	51	**Price (€)**	495	567	658	836
	EEI	36	29	22	19	**LCC (€)**	869	828	859	1003
	% gain	ref	30%	33%	69%	**SPB (yr)**	ref	10.2	15	26.4
COLD2	**kWh/a**	167	92	81	50	**Price (€)**	1344	1502	1631	2149
	EEI	56	31	27	17	**LCC (€)**	1892	1802	1895	2314
	% gain	ref	45%	52%	70%	**SPB (yr)**	ref	10.5	16.6	34.5
COLD7	**kWh/a**	237	122	na	80	**Price (€)**	569	708	na	995
	EEI	33	20	na	11	**LCC (€)**	1345	1109	na	1257
	% gain	ref	48%	na	66%	**SPB (yr)**	ref	5.9	na	13.3
COLD8	**kWh/a**	233	151	na	117	**Price (€)**	439	555	na	805
	EEI	35	23	na	18	**LCC (€)**	1205	1050	na	1190
	% gain	ref	35%	na	50%	**SPB (yr)**	ref	7	na	15.7
COLD9	**kWh/a**	236	147	na	113	**Price (€)**	356	462	na	607
	EEI	38	24	na	18	**LCC (€)**	1130	943	na	979
	% gain	ref	38%	na	52%	**SPB (yr)**	ref	5.9	na	10.3

BC=Base Case; LLCC=Least Life Cycle Costs point; BEP=Break-Even Point; BAT= Best Available Technology. EEI=Energy Efficiency Index (current regulation); LCC=Life Cycle Costs (euros). SPB=Simple Payback Period (years); na=not available

Discussion for no-frost appliances

In principle, all the design options for static household refrigeration appliances also apply to no-frost appliances, except for the fact that the indoor fan is not a 'design option' but a necessity for a no-frost appliance. There are some inherent energy penalties in using no-frost technology. The impact is shown in Chapter 8 (analysis of the CECED database) and discussed in paragraph 9.3.7 (no-frost compensation in US and Australian measures), leading ultimately to a proposal for a compensation factor of in the metric in paragraph 9.4.

What we would have liked to discuss, but which is not possible due to lacking test data, are design options that apply only to no-frost appliances, e.g. variable ('smart') demand-driven defrosting intervals. Unfortunately, although the variable defrosting can now be measured in the new IEC test standard, the new test standard has not been implemented yet and there is no obligation by manufacturers to release accurate test data on the issue. Hence, the single no-frost compensation factor seems to be the only way forward.

Discussion for built-in appliances

Likewise, all design options for freestanding appliances also apply to built-in appliances. For the most part, the compensation factor for 'built-in', proposed in paragraph 9.4 derives for the most part from the difference in test procedure. The only exception for built-in appliances may be in the insulation thickness, hence the most extreme option might not be feasible because the inner volume would become too small to be acceptable for consumers (result in 'significant negative impact on functionality').

In conclusion, there seems to be a potential to improve the efficiency of refrigerators and freezers. Depending on the category, the least life cycle cost (LLCC) point gives savings from 30 to well over 40 % with respect to the average new product. Benchmarks for Best Available Technology (BAT) show savings of 60-70 % with respect to the average new product.

12.4.2 Long-term BNAT and system analysis

Given the fact that the design options above already include the best available technology for compressors, including linear compressors, there are no BNAT (Best Not yet Available Technology) options that we feel will come to market within a time-period that is relevant for reshaping the Ecodesign and Energy Labelling measures.

BNAT options, presented during the 1st stakeholder meeting, include magnetic cooling, thermo-acoustic cooling, Stirling cycles, pulse tubes and full-vacuum insulation. These technologies either were found not to have an advantage over the current Carnot cycle or, for magnetic cooling and economic full-vacuum, still very much in an experimental stage. These long-term BNAT options will be further discussed in the Technology Roadmap report, i.e. for the benefit of the EC DG RTD[131] in its program development.

For the 2nd stakeholder meeting we invite stakeholders again to indicate whether we are missing out on important saving opportunities by not including the BNAT options

[131] European Commission, Directorate-General for Research and Innovation

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ANNEX A: Definitions IEC 62552-1[132]

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

2.2
condenser

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

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**

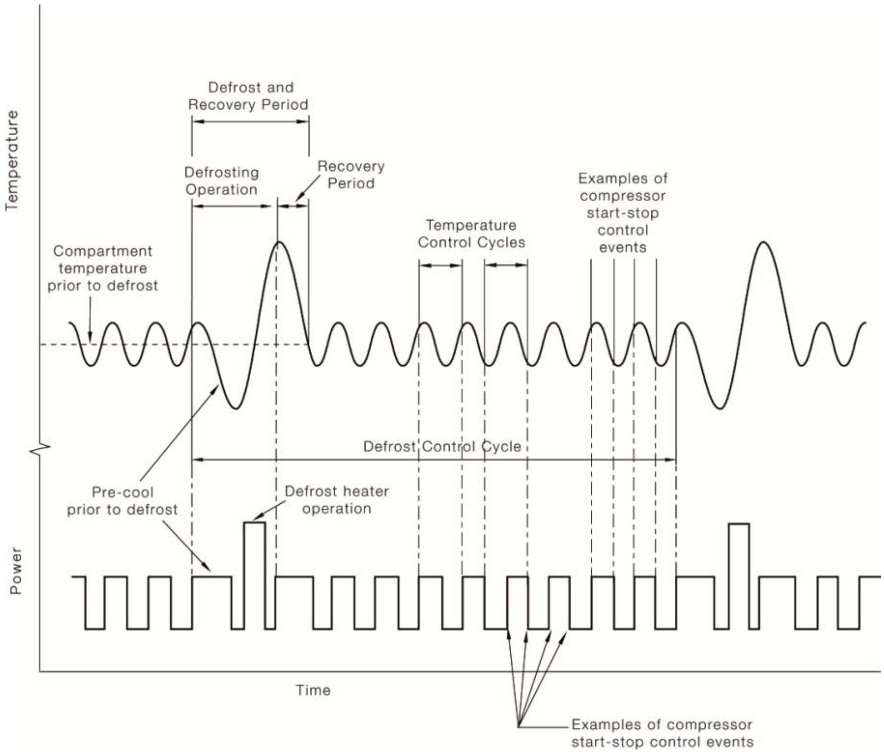


Figure 1 – Illustration of selected definitions

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.[133]

Table B.1. 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=2 5°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.

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

Table B.2. 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 C.1. 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.

ANNEX D: COP and capacity modelling

The standard refrigeration cycle includes an IHX (Intermediate heat exchanger between the suction line and the liquid line leaving the condenser) (Figure 1a). Subcooling (3-3' - Figure 1b), which increases the cooling capacity of the cycle, is linked to the superheat temperature difference (1-1' - Figure 1a) by the IHX.

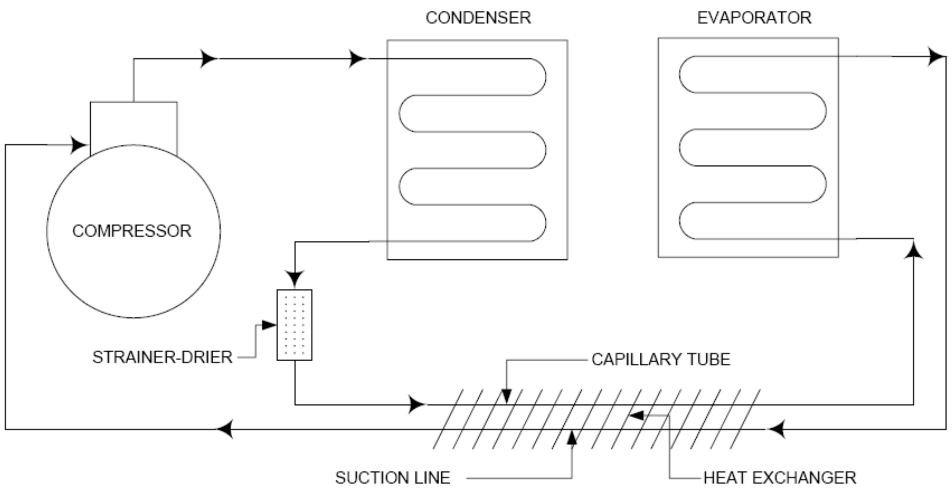


Figure D.1a: Standard refrigeration circuit for domestic refrigerators

Despite evaporation and condensation temperature variations, standardized performance data have specific subcooling and superheating conditions which make it difficult to compare directly the coefficient of performance (COP) of these ratings to the COP in real appliances. The same is true of the cooling capacity.

A typical refrigerator cycle is presented in Figure 1b below. Both ASHRAE and CECOMAF standard rating conditions consider a suction temperature of 32.2 °C. And in both cases, the cooling capacity is the enthalpy difference between points 4 and 1'. In the real cycle (Figure 1b), the superheat is not useful to the cooling capacity which thus is lower, it is the enthalpy difference between point 4 and 1.

In the ASHRAE standard conditions, T3' is fixed to 32.2 °C, which gives a large subcooling for standard conditions (54.4-32.2=22.2 K). This subcooling temperature difference decreases when the condensing temperature decreases, down to 0 when the condensation temperature is 32.2 °C.
In the CECOMAF standard, the subcooling temperature difference is 0 K. Hence, the cooling capacity is underestimated.
In the real cycle, T3' temperature dpends on the efficiency of the IHX and of the operating conditions.

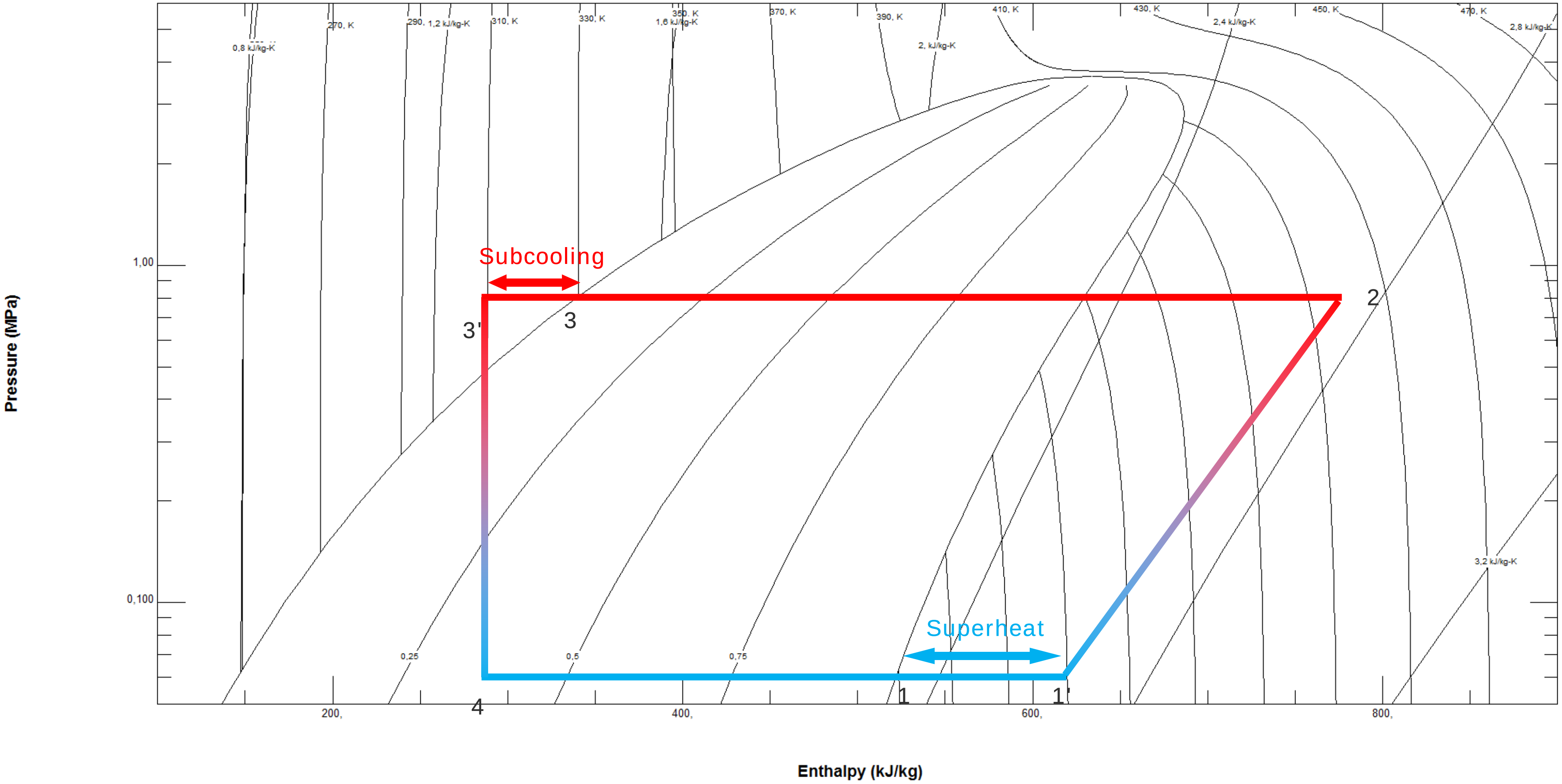
Because of these differences, we seek to model the performance of the compressor starting from manufacturer data and to add a simple IHX model.

Only Embraco gives performance data over a large set of different evaporating and condensing conditions so their data is used to derive COP and capacity curves of typical compressor integrated in a typical refrigeration cycle. Both capacity and COP are modelled as capacity is required to compute the degradation of performance due to cycling.

In order to model the capacity and COP variation with Tev and Tcd, the following approach is adopted:

- regression of the volumetric and isentropic efficiency for ASHRAE conditions with varying Tev and Tcd,
- integration of the IHX,
- cycle calculation for varying Tev and Tcd and real cycle conditions (subcooling and superheating is supposed to be zero in the condenser and evaporator resp. and to fully develop in the IHX),
- Fitting of cooling capacity (4-1) and of the COP using compressor like polynomials of Tev and Tcd.

Figure D.1b: Refrigeration cycle in the Enthalpy - Pressure (log) diagram



In order to model the capacity and COP variation with Tev and Tcd, the following approach is adopted:

- regression of the volumetric and isentropic efficiency for ASHRAE conditions with varying Tev and Tcd,
- integration of the IHX,
- cycle calculation for varying Tev and Tcd and real cycle conditions (subcooling and superheating is supposed to be zero in the condenser and evaporator resp. and to fully develop in the IHX),
- Fitting of cooling capacity (4-1) and of the COP using compressor like polynomials of Tev and Tcd.

The volumetric efficiency Eta_V is the ratio between the effective mass flow and of the theoretical maximum flow for the given gas density (which depends on the suction temperature, the evaporating temperature and to a less extent on the condensing temperature).

Eta_V = mf/(N.rho_suc.V_swept)

With

- Eta_V : volumetric efficiency in %
- mf = gas mass flow given by the manufacturer $kg.s^{-1}$
- N : Frequency of rotation of the compressor in s^{-1}
- rho_suc : density at the suction of the compressor in $kg.m^{-3}$
- V_swept : volume of the cyclinder in cm^3

Eta_V can be estimated as a linear function of the compression ratio with a linear curve and following coefficients. For the specific compressor considered:

Eta_V = a_V.PI+b_V

With

- a_V = -0.02
- b_V = 0.87

The ratio a_V/b_V in this example is close -2.2 % and is generally close to -2 %. This ratio indicates the mass flow loss with an increase in pressure ratio which is linked to the compressor. The absolute nominal capacity characterizes the nominal volumetric efficiency and gives access to the a_V value, typically lying between 0.85 and 0.9 for compressors in this range.

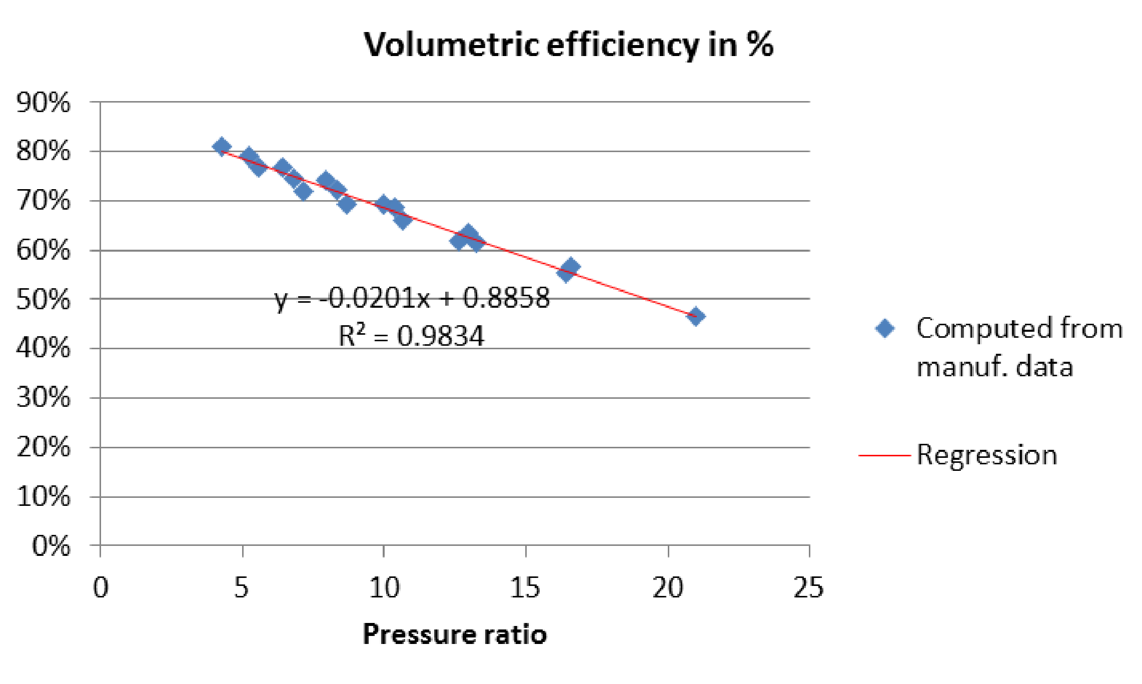


Figure D.2: Computed volumetric efficiency versus pressure ratio and regression curve

Isentropic efficiency characterizes the compression efficiency. It is defined as:

Eta_is = (mf.DHis) / Pe

With

- Eta_is : isentropic efficiency in % (note that the compression is not adiabatic, and that this isentropic efficiency in fact includes deviation versus the reversible adiabatic transformation plus heat losses through the compressor shell).
- mf = gas mass flow given by the manufacturer $kg.s^{-1}$
- DHis : enthalpy difference in an adiabatic reversible compression J.kg-1
- Pe : electric power consumed by the compressor W

We estimate Eta_is as a non-linear function of the compression ratio with the following equation and coefficients:
Eta_is = if PI >= PImax, Eta_is = a_is + b_is. (PI / PImax)
Else
Eta_is = (a_is+b_is.(PI/PImax)).(PI/PImax)/((1-c_is)+c_is.(PI/PImax))
PImax is the compression ratio corresponding to Eta_is_max
a_is, b_is and c_is are regression coefficients.

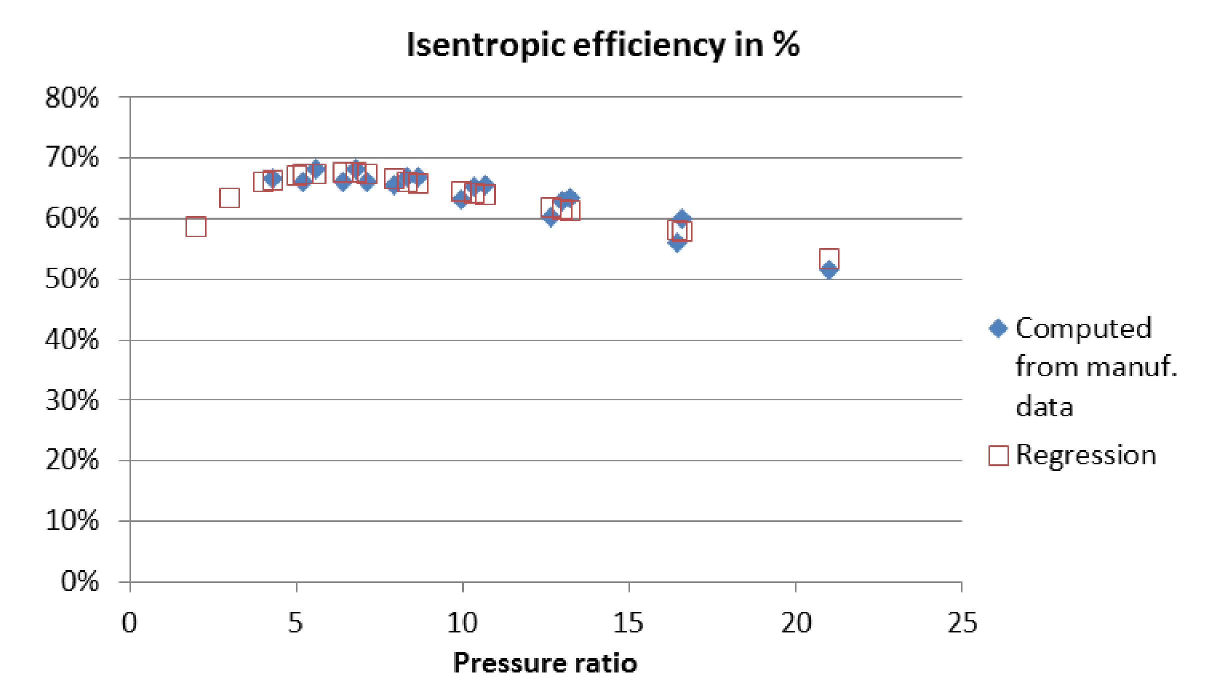


Figure D.3: Computed isentropic efficiency versus pressure ratio and regression curve

In the Figure 3, the optimal pressure ratio (giving the highest isentropic efficiency), lies 5, which is typical of refrigerator operating conditions. Other compressors may be optimized for compression ratios of 8 to 9, which is more typical of freezers operating conditions. Hence, two separate curves are kept to represent refrigerator and freezer compressors.

In order to compute the thermodynamic conditions at the inlet of the expansion valve and thus to calculate the enthalpy and liquid gas mass fraction at the inlet of the evaporator (Figures 1a and 1b), it is supposed that:

- the subcooled liquid / superheat heat exchanger is of constant efficiency with a value of 80 %[134].
- this means that the liquid temperature variation below saturation and before the expansion valve is of T3' = T3 + 0.8 * (Tev - Tcond).
- superheat and suction temperature can then be computed thanks to the heat balance of the intermediate heat exchanger ; as the mass flow rate in this heat exchanger is the same for gas (1-1') and liquid (3-3'), T1' = T1 + Cp_liq / Cp_gas * (T3' - T3). The subcooling temperature difference is thus typically between 65 and 70 % of the superheat temperature difference.

For a standard cycle, the values of interest are defined as follows:

mf= Eta_V.N.rho_suc.V_swept
Pc = mf.(h1-h4)
Pe = (mf.DHis) / Eta_is
COP=Pc/Pe

With the hypothesis above, it is possible to define correction maps for

[134] Ref to be added.

- COP / COPnom as a function of Tev and Tcond
- Pc / Pcnom as a function of Tev and Tcond

Maps are thus proposed for refrigerator optimized and freezer optimized compressors for COP/COP_nom and Pc/Pc_nom. These tabulated correction enable to deduct the COP and cooling capacity from the knowledge of Te evaporation temperature in °C) and Tc (condensation temperature in °C):

y = c1 + c2*te + c3*tc + c4*te^2 + c5*te*tc + c6*tc^2 + c7*te^3 + c8*tc*te^2 + c9*te*tc^2 + c10*tc^3

The following table gives an illustration of the calculation with the polynomial equation above and a comparison with the Carnot-based formula in the main report.

Table D.1. COP calculation (stationary)

Calculation of COP with empirical formula

Input:

Tcd	-19		
Tev	46	**COPnom**	**Pc nom (in W)**
NOMINAL COP or Pc		1.7	47

Calculation:

terms	multiplier	multiplier values		calculated result	
	name	for COP	for Pc	COP terms	Pc terms
-	c1	6.652824	4.117907	6.65	4.12
Tev	c2	0.192766	0.152086	-3.66	-2.89
Tcd	c3	-0.194250	-0.028372	-8.94	-1.31
Tev²	c4	0.002446	0.002061	0.88	0.74
*Tev*Tcd*	c5	-0.004600	-0.000866	4.02	0.76
Tcd²	c6	0.002458	0.000030	5.20	0.06
Tev³	c7	0.000013	0.000010	-0.09	-0.07
*Tcd*Tev²*	c8	-0.000033	-0.000009	-0.55	-0.15
*Tev*Tcd²*	c9	0.000031	0.000001	-1.26	-0.04
Tcd³	c10	-0.000012	0.000000	-1.14	-0.01
TOTAL multiplier				*1.12*	*1.21*

Output:

ACTUAL COP or Pc	1.90	57

Calculation of COP from Carnot efficiency (same inputs)

COP Carnot =(Tev+273.15)/(Tcd-Tev)	
at nominal ASHRAE conditions (Tcd=54.4 oC, Tev=-23.3 oC)	
COP Carnot_nom	3.22
at actual inputs Tev=-19; Tcd=46	
COP Carnot	3.91
Ratio COP Carnot/COP Carnot nom = multiplier	1.22

Output:

ACTUAL COP	2.07

Table D.2 . Comparison (category 1)

Vnet	litres	42	107	184	331
COPnom		1.7	1.7	1.7	1.7
Tev	oC	-19	-14	-12	-10
Tcd	oC	46	39	34	31
Actual COP1		1.9	2.48	2.93	3.35
Actual COP2		2.07	2.59	3	3.39
Overestimate		8.9%	4.4%	2.4%	1.2%

Reality checks heat exchanger capacity

Reality check for condenser capacity (Cat. 1 example):

Capacity required (estimate from empirical formula)
Pcd_req=P(Tev, Tcd)*(1+0.85*1/COP(Tev, Tcd))

Maximum capacity available (estimate from empirical formula)
Pcd_max=(31*ΔTcd-40)*Acd

Reality check for evaporator capacity (Cat. 1 example):

Evaporator capacity h_{ev} in W/m²K, depending on evaporator temperature T_{ev} [°C] and area width w [m]

$$h_{ev} = 5.103 \cdot 10^{-8} \cdot \left(\frac{(8+273.15)^4 - (T_{ev}+273.15)^4}{(8-T_{ev})}\right) + 2.75 \cdot \frac{\left(\frac{T_{ev}}{22}\right)^{0.29}}{\left(\frac{w}{0.6}\right)}$$

Evaporator surface A_{ev} required in m² as a function of cooling power Pc [W], evaporator temperature difference ΔT_{ev} [K] and evaporator capacity h_{ev} [W/m²K]

$$A_{ev} = \frac{Pc}{\Delta T_{ev}} \cdot \frac{1}{h_{ev}}$$

Note that the above reality checks are only intended to verify the order of magnitude but not deemed accurate enough to use directly in the calculation.

ANNEX E: Minutes 1st Stakeholder meeting

Minutes of the 1st Stakeholder meeting Ecodesign & Labelling Review household refrigeration appliances

Date: Wednesday 2015-01-07, 10.00-16.10h
Place: European Commission, Berlaymont building, Brussels
The list of attendants is attached as a table at the end of the document.

Introduction

Mr René Kemna (VHK, chair), opens the meeting for the Ecodesign and labelling Review of household refrigeration appliances. Structure of this meeting will follow the interim report published on the website.

Angeliki Malizou (ANEC/ BEUC) asks why the study is just 1 year. This is short compared to the white good studies (1,5 year) and at the website a Consultation Forum meeting is scheduled for December, while the final report is also due that month is this not too quick?

Andras Toth (EC) replies that for the white good studies also other DG's are involved e.g. DG ENV is involved in the washing machines study. Concerning the timing, we might prolong the contract as the study proceeds but nothing has been decided on that issue yet. The CF meeting date is not fixed anymore because of this uncertainty.

Hans-Paul Siderius (NL) adds that it is useful to have more time for the study. This study depends on the outcome of the new Energy Label and there is a new test standard which allows a more rigorous approach to check more aspects (correction factors etc.)

Scope Art. 1

Hans-Paul Siderius (NL) states that it is necessary to find objective criteria to separate Houshold (HH) from non-household (non-HH) if this is not possible then keep the scope as it is at the moment otherwise there might be potential loopholes. For HH appliances the Low Voltage Directive (LVD) is applicable and for non-HH the Machine Directive (MD) applies. This might not be 100% waterproof but this has significant consequences on how to test safety.

The chair replies that the LVD is self-declaration and it seems like a shift rather than a solution of the problem.

Edouard Toulouse (ECOS) adds to the discussion that if you only mention HH in the scope some products might not be labelled for instance fridges in hotels, work places etc. They do not see themselves as HH appliances, but energy labels make also sense for these groups.

Anette Michel (TopTen) agrees with ECOS. All minibars and wine coolers (no matter if for commercial or household use) need to be explicitly and clearly in the scope. At a lot 12 CF meeting in July 2014 the Commission had said that these product would be covered by the household refrigeration regulations, so this should be guaranteed. Accordingly, non-HH appliances should be kept in the scope, and it should be well coordinated with the regulations on professional and commercial refrigeration appliances – in order not to leave any loopholes.

The chair states that when adding more categories the market surveillance authorities will have even more difficulties to check the appliances due to the fact that all these categories will have different requirements. We have to be careful that we do not double regulate products in the HH appliances regulations and in the professions appliances regulation.

Hans-Paul Siderius (NL) prefers a technical definition of HH appliances and not declaration if a product is a HH appliance or not because this can create a shift (loophole) towards non-HH appliances. The requirements should be verifiable by market surveillance authorities.

The chair replies that it is not only a question of Market surveillance being able to test products, the question is also why would market surveillance test products that only represent 1% of the total. Should they spend resources on these products while others cover a larger share of the market?
He agrees with the technical definition argument and adds that this is currently also added in the washing machines and ventilation regulation.

Bruno Vermoesen (BSH) states that he agrees with the proposed use of LVD and MD. In the LVD, “household and similar” is the term used, so examples of products mentioned by ECOS and TopTen would be included in this definition. HH appliances not installed in households would thus be still in the scope.

Mike Rimmer (UK) is a bit worried that by defining boundaries loopholes might be created or new market niches. Market surveillance not only checks Ecodesign requirements but also WEEE and other requirements that apply for this product on a pass or fail basis.

The chair asks to send in the rest of comments on this topic in writing.

Art. 2

Hans-Paul Siderius (NL) states that the new IEC standard has more streamlined definitions and they are useful for HH and/or similar use. When possible a more simple way is preferred to define the scope and avoid loopholes. In the Working Documents later on in the process the position (main text/ ANNEX) can be determined.

The chair adds that we are trying to get a clear unambiguous definition of the scope and a way to do this is look at technical definitions but also definitions in the regulation.

No problems or issues were raised by the stakeholders to define the scope with text/ definitions from the IEC standard.

Part 2.

BSH stated that there was a mistake on the slides, the minutes needed to be hours in the discussion of the temperature rise test.

Part 3. Energy efficiency

Edouard Toulouse (ECOS) states to be careful with compensation factors. It seems like the industry is asking for too many exemptions/ compensation. He would also like to see a more balanced analysis in the report. It seems that the industries point of view is overrepresented and asks to incorporate point of views of Intertek and Topten more in the report. Furthermore, he would like to see more explanations why household wine storage appliances have for instance glass doors, if this just is for aesthetics then you open a Pandora box and everybody wants an exemption or compensation factor.

The chair answers that issues addressed in the Omnibus study are discussed in this report. Different opinions, points of views and data are included in the report and not only the standpoint of the industry.

Edouard Toulouse (ECOS) asks if built-in appliances are penalised based on energy consumption?

Anette Michel (Topten) shows some slides, addressing the issues of reference lines and correction factors. (The slides are on the project website)

The chair answers that this is a complex issue and not all pros and cons are available at this moment to answer the question.

Martien Janssen (Re/genT) answers to the question of the glass door that this is not an issue. This comes from the wine coolers who installed glass doors for commercial markets. This is the main reason for their existence. Furthermore, we did not ask for a compensation factor for wine cooler glass doors, we (as industry) asked for a separate category.

Hans-Paul Siderius (NL) adds that if the focus is too much on discussing glass doors this will divert the discussion away from the technical discussion that in his opinion needs to be held. For instance a focus on non-linear possibilities (presented by the chair before break) would be better. In his opinion the built-in refrigerators can be in the same category as stand-alone but have a different compensation factor. A different component is not a reason to give those products a different treatment. Because this is a complex product he would propose a second stakeholder meeting to discuss technical issues in more detail. He adds that he would have expected the consultants more to give their own expert opinion rather than asking the stakeholders to respond to open questions.

The chair replies that at this stage we are trying to strike a balance between having an open discussion without influencing the stakeholders too much and supplying the information-ingredients that would allow the stakeholders to make an informed decision. This distinction, i.e. between opinions and information, can also be found in the interim report. The alternative is writing a report with a strong opinion that would be unduly polemic at a stage (Task 1 to 4) where we still have to do considerable research. As regards ‘overly representing the industry position’ [E. Toulouse] , the chair explains that the study team tries to take everyone’s opinion into account. In that context we work with and not against any of the stakeholders. For instance, we have reported and are fully aware of the NGO and MS opinion on the climate correction and other compensation factors. We have, in January, confronted the industry with the issue and, by the end of April, the industry –not without internal struggle—came forth with a proposal that completely eliminates the climate correction factor and proposes several issues that signify simplification and a better transparency. It does not mean that we would support everything (see questions on weighting factor, wine storage and built-in categories) but we believe in a dialogue. Likewise, we do not a priori agree on everything that MS and NGOs propose –e.g. the chair did not anticipate the strong support for the non-household part of the scope—but we will take it into account and try to work it out together with the stakeholders.

Ina Rüdenauer (Öko-Institut) asks how it is possible that fridge-freezers (combi) have a higher energy consumption up to 70%? Is there a technical reason for this?

Martien Janssen (Re/genT) answers this question that it is historically related. In 1995 reference lines were set up for fridges and combinations (fridge/freezer). These reference lines are very different in inclination. The one for refrigerators is almost flat, so when increasing the size it almost consumes the same energy, which is technically completely impossible. So most likely there was a bias in the data, but due to this factor you get a very different effect when adding a certain volume of fridge to a freezer in category 7 then when you just take that in category 1. We conclude that the one for fridges is far too flat to be technical justifiable. So if the inclination of these lines would match each other better, the difference would disappear.

Jochen Haerlen (BSH) states what is defined in standard test conditions represents the usage conditions at home. Stand-alone appliance are described to stand alone in a test chamber and then is measured, but when looking into the market (e.g. Spain) 60-70% of the stand-alone fridges are built-in and this creates a complete different situation. The stand-alone appliance consumes significantly more energy when built-in. So while what is described in the standard for built-in appliances corresponds to reality, for stand-alone appliances in a lot of cases in some markets they are not placed in the middle of a room (like in the test standard) and the declared/ measured energy consumption is too low compared to real life. This is one of the reasons why the industry says we need two different categories and we need to make it more transparent and that happens with narrowing down the categories to stand-alone and built-in.

The chair replies that from testing alone the differences would be around 8-10% between stand-alone and built-in appliances.

Mario Vargas (Electrolux) tries to answer the question where the 70% extra energy consumption comes from (question Öko-institut). When he adds the energy consumption of a separate freezer and fridge the total energy consumption is almost equal to that of a combi with same capacity. E.g. Combi of 300 litre fridge and 100 litre freezer consumes 809Wh/d (A+). And two separate appliances 300l[135] fridge 262Wh/d and 100l freezer 596 Wh/d total consumption is 858 Wh/d. The fridge compared to a combi is clearly a big difference because there is a freezing part included in the combi. We need to compare a combi with a freezer/ fridge combination not only compared to a fridge. So instead of saving energy we might be wasting energy.

The chair wants to remind the stakeholders that when talking about calculations the main question here was linearly 24 or 25°C? Does somebody have an opinion on this weighting factor between 16 and 32°C? 25 is what people are used to as a figure but 24 is what roughly gives the same outcome as what we have today, taking into account the efficiency of the Carnot cycle.

Hans-Paul Siderius (NL) has a preliminary preference for having the same outcome, i.e. 24 degree. Nobody will mind whatever you decide. The explanation of Martien underlines the necessity to look into a new technical/physical approach with a new test standard instead of continuing what we developed in the ’90s. This could then eliminate the issues shown in Anette Michels presentation.

Angeliki Malizou (ANEC/ BEUC) states that a compensation factor needs to have a strict explanation, why multi doors get compensation or not. Transparency is the corner stone to be trustworthy.

The chair explains that multi-door compensation is not a compensation for opening the doors but for the leakages. Each compartment has a different temperature to store different types of food as discussed in Task 3 of the report and presentation.

[135] Corrected to most likely values

BSH states that 25°C is a recommendation from the standardisation body CENELEC, not only because it is a value that is well-known but also to solve a practical issue with portable cooling boxes that have a problem to reach the refrigerator-temperature (+4 oC) at 32 °C ambient temperature. These cooling boxes are in the scope of the regulation and –given that it was impossible to test them at 32 °C—the idea was to continue to make them the exception that could be tested at a single ambient temperature of 25°C. But if we can solve that problem in another way, the industry is not against using a weighting factor based on 24 degrees (meaning weighting factor 0.5).

The chair adds that when using 24 or 25°C you stay much closer to the original values and the (error in) recalculating the effect of the new standard on old standard data is much less. As regards the cooling box problem, he suggests to simply test at pantry-temperature (17 degrees inside) and at both ambient temperatures. That should be doable even for Peltier boxes.

Edouard Toulouse (ECOS) agrees with Hans-Paul to look into new classification, we have a new test standard so there is no need to stay with the old situation.

The chair agrees that we do not need to stay with the current situation, but we need to have a foundation to build-upon.

LCC/Resource efficiency
Edouard Toulouse (ECOS) asks the study writers to rethink the replacement of products. This might not be 1 on 1, people might decide to buy bigger ones. We would like to see more precise data and analysis behind this. Furthermore, he states that products will have similar lifetimes in the future so prolongation of lifetime and shipping to Africa seems unbelievable. He would like to see information requirements on spare parts and technical lifetime on the label.

The chair asks to get written comments on the lifetime prolongation issue. In the Netherlands there was a big scandal that second hand fridges where shipped off to Africa instead of being discarded/recycled. In Task 3 it was shown that at the current improvement rates the prolongation of the life time for this product is Not-A-Good-Thing for the environment and resources efficiency.

Market analysis Task 2

Ina Rüdenauer (Öko-Institut) asks why there was a sudden increase in sales of multi-use appliances in 2014? Was this due to the development of correction factors or climate classes?

The chair thinks that there is a general trend that with current technology it is easier to meet the ‘tropical’ test conditions (i.e. at 43 oC ambient) and –given the advantage of a better energy label rating—manufacturers then declare their product as tropical Concerning the multi-use sales it is not a market trend but more of a problem in the CECED database, where manufacturers since 2010 (when multi-use was significant) ignored or incorrectly classified their multi-use appliances and now –in view of updating the database for analysis—corrected this.

Marco Imparato (CECED Italy) agrees with the explanation of the chair.

User Analysis task 3

Hans-Paul Siderius (NL) states that a new regulation influences the end-of-life for new fridges. They become more energy efficient, use other resources/ materials, etc.. The figures shown in the presentation date back to 1990-1995. Updating this figure to current or future (2026) situation might change the end-of-life data.

The chair answers that most improvement (energy) took place between 1995 and 1999. This progress continued afterwards but it is slowing down and most likely will stop in the future, but when that is I cannot predict. But the study team, also taking into account the remarks of ECOS earlier, will add prominently in the report that there is a large uncertainty for a prediction so far in the future (i.e. in 2026 when newly regulated fridges will be discarded).

Edouard Toulouse (ECOS) adds that it is not only energy consumption that needs to be calculated but also CO_2, 1 to 1 replacement etc.

The chair answers that the current figures shows that circular economy does not work for this product and that there is no grounds to recommend to the Commission to take measures in that direction. The only thing, as mentioned, is to indicate that there is uncertainty whether in the long term future this will still be the case.

Jochen Haerlen (BSH) states that we need a solution for peak shaving but does not see freezers or fridges as a product that should be used. The end user should be in control what happens to the product and not the energy company. It is more advisable to cool down during the night to a colder freezer temperature and shut down the product during the day for a couple of hours.

The chair replies that the suitability to be used as a smart appliance would not necessarily be part of minimum ecodesign measures. It could be an icon to add to an energy label or even only a product information in a technical fiche.

Hans-Paul Siderius (NL) states that this is not the correct place to discuss this issue as there is a complete study focussing on smart appliances.

Sarah Bogaert (VITO) adds that on the website http://www.eco-smartappliances.eu the first documents have been published and the discussion rather takes place in this study then in this meeting.

The chair adds that in the assignement and kick-off meeting the Commission explicity asked the study team to look into the smart appliance isse for the Technology roadmap. But this could possibly be re-discussed.

Technical analysis Task 4

Jochen Haerlen (BSH), reacting to the slides, acknowledges thatforced air circulation can improve heat exchanger temperature difference , but you have to consider the electrical energy you need in order to run the fan. Simple calculation: if you have a A+++ appliance (small) and you use a 2W fan in order to improve the condensing temperature, you increase the total energy consumption by 10% just by adding the fan. If you want to gain 10% by reduced condensing temperature you have to reduce this condensing temperature by at least 5K, but then you are just on the same level. When looking at the figure presented, the delta T is 8K and then you are already somehow at the physical limit.

Stephanie Barrault (Armines) answers we have to take into account the added consumption. But due to more efficient fans we are saving energy on this part. Anyway, we will take into account the various trade-offs.

Mario Vargas (Electrolux) states that most technologies presented by Stephanie are currently used in products except for the magnetic option.

The chair asks the stakeholder if they have more information on technologies or possible future technologies to let us know. He asks how many models currently in the market have anti-sweat heaters?

Jochen Haerlen (BSH) answers that these can be found in appliances with dispensers (drink/ ice etc.). A guesstimate is a they are present in less than 10% of the European household refrigeration appliances.

AOB

Andras Toth (European Commission) explains the current status of the Energy labelling Directive. The consequences for the current study are unclear, but we can propose class limits without putting a label on it.

The chair asks if according to rumours the upper 2 classes will stay empty compared to 1 at this moment. What do we need to take into account?

Hans-Paul Siderius (NL) replies that 6 classes can be made to 5 by combing 2 classes so he does not see a problem in that. He thinks it might be useful to take into account all features of the MEPS and discuss this in a second stakeholder meeting.

Jochen Haerlen (BSH) asks if there is any decision already what is the delta between the efficiency classes? Will it be kept at today as an absolute delta or will it be relative? The chair answers that we have no idea at this moment. It will depend on research in later tasks.

The chair thanks everybody for coming and participating. Due to the holiday the stakeholders have 2 months' time to hand in written comments, i.e. deadline is is 31st of August 2015.

Meeting closes at 16.10h.

List of participants

First name	Surname	Company / organisation name
Ciara	Leonard	AB Electrolux
Angeliki	Malizou	ANEC/BEUC
Stéphanie	Barrault	ARMINES
Andrea	Harrer	BAM Federal Institute for Materials Research and Testing
Jochen	Haerlen	BSH Hausgeraete GmbH
Bruno	Vermoesen	BSH Home Appliances Group
Félix	Mailleux	CECED
Matteo	Rambaldi	CECED
Marco	Imparato	CECED Italia
Marie	Baton	CLASP
Mike	Rimmer	Department of Energy and Climate Change UK
Chloe	Fayole	ECOS
Edouard	Toulouse	ECOS
Mario	Vargas	Electrolux

Simonetta	Fumagalli	ENEA
Andras	Toth	European Commission
Karim	Tarzi	Honeywell
Kevin	Lane	Kevin Lane Oxford Ltd
Edoardo Natale	Oldani	LG Electronics
Hans-Paul	Siderius	Netherlands Enterprise Agency
Ina	Rüdenauer	Öko-Institut e.V.
Martien	Janssen	RE/genT BV
Anette	Michel	Topten International
Rene	Kemna	VHK
Roy	van den Boorn	VHK
Sarah	Bogaert	VITO/Energyville
Enzo	Rivis	Whirlpool Europe