

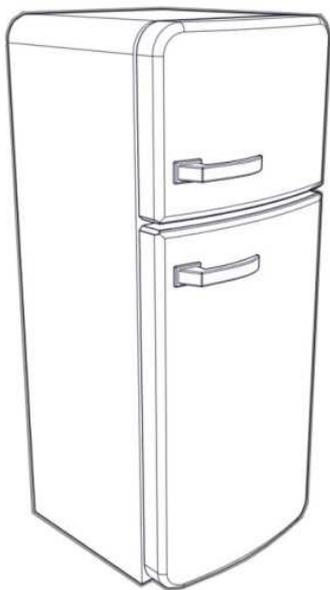


Preparatory/review study

Commission Regulation (EC) No. 643/2009
with regard to **ecodesign requirements for
household refrigeration appliances**

and

Commission Delegated Regulation (EU) No.
1060/2010 with regard to **energy labelling of
household refrigeration appliances**



FINAL REPORT

Prepared by

VHK and ARMINES

in collaboration with Viegand & Maagøe and Wuppertal Institute
contract co-ordination VITO

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Prepared by

Study team:

Van Holsteijn en Kemna B.V. (VHK), The Netherlands, project leader;
Association pour la Recherche et le Développement des Méthodes et Processus Industriels (ARMINES), France, technical specialist (Task 4, 6) & technology roadmap;

In collaboration with:

Viegand & Maagøe ApS (VM), Denmark, reviewer;
Wuppertal Institute for Climate, Environment and Energy GmbH, Germany, reviewer.

Contract manager:

Vlaamse Instelling voor Technologisch Onderzoek NV (VITO), Belgium

Study team contact: René Kemna, VHK (p.l.);

Contractual matters: Karolien Peeters, VITO.

Project website: www.ecodesign-fridges.eu

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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 SO ₂ 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 ₅ H 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}
CO ₂ , 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
<i>L, ltr</i>	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)
PO ₄ , 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)

<u>Symbol</u>	<u>Parameter</u>
<i>A</i>	'Auto-defrost' compensation factor
<i>A</i>	Refrigerator envelope surface (m^2), usually with suffix
<i>a</i>	Air passage height below unit (m)
<i>A_{cd}</i>	Condenser area (m^2)
<i>AE, AEC, E</i>	Annual Energy consumption, in kwh/a
<i>B</i>	Built-in compensation factor
<i>b</i>	Height & depth compressor area (m)
<i>c</i>	Suffix for compartment-specific parameters
<i>C</i>	Combi-factor
<i>COP</i>	COP value with actual T_{ev} and T_{cd}
<i>COP_{cyc}</i>	Avg. Cop actual t_{ev} and t_{cd} & cycling loss
<i>COP_{nom}</i>	Nominal compressor COP at -23.3/54.4 °C, sub-cooling 32.2 °C
<i>Cycling loss</i>	Part load losses (in % COP)
<i>D</i>	Multidoor compensation factor
<i>d</i>	Depth (m)
<i>E₁₆</i>	Daily energy consumption, in kwh/d, at 16 °C ambient test
<i>E₃₂</i>	Daily energy consumption, in kwh/d, at 32 °C ambient test
<i>E_{aux}</i>	Electricity CPU and possible fan (kwhel/a)
<i>E_{daily}</i>	Daily (24h) energy consumption E_{daily} , in Wh
<i>E_{loss tot}</i>	Annual heat energy loss (kwh _{th} /a)
<i>eq</i>	Suffix, means 'equivalent' for compartment
<i>F, f</i>	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
<i>Load factor</i>	Ratio of heat load to cool power
M, N	Correction parameters for equivalent volume
P	Power, in W
P_c	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 V_{eq})
<i>SAE, SAEC</i>	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/m ² K)
V	Volume
V	Refrigerated volume (m ³ or litre)
V_{eq}	Equivalent volume
V_{gros}	Gross inner volume, including technical spaces e.g. For evaporator, lighting, etc.
V_{net}	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
$\Delta T_{cold}, \Delta T_{ev}$	Temperature difference between the evaporator and the average air in the compartment
Δt_{df}	Defrost frequency/interval, in h, rounded to the 1 st decimal
ΔT_{ev}	Evaporator temperature difference (K) [r/f]

$\Delta T_{hot}, \Delta T_{cd}$
 η

Temperature difference between the ambient air temperature and the condenser
Efficiency

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Executive summary

This is the final 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 ended in January 2016 (final report, 1st version). Tasks 1 to 3 contain (minor) changes following the first stakeholder meeting 1 July 2015 compared to the interim report. Tasks 4 to 6 were 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 7 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)
- Scenarios (Task 7, Chapter 13)

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 was vital.

Industry association CECED has offered several preliminary analyses for discussion, including initial proposals, which were made available 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. Current average product life of approximately 16 years is adequate from a holistic point of view (energy versus non-energy conservation) but reparability can be improved to ensure that it does not diminish in the future. Meeting the WEEE-recycling rate of 80% is challenging and difficult to improve without jeopardizing energy-efficiency because the best and most-used insulation foam (poly-urethane) is difficult to recycle and typically makes up 20% of the product weight. . 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 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 and legally more 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 the adder for chillers are eliminated. Compensation factors for no-frost (stays at 1.2) and built-in (1.04 or 1.14 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 high temperature (energy saving) compartments.

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 (€56/unit). Total consumer expenditure is thus estimated at 27.4 billion euros (€1404/unit) in the EU 2014.

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.

Task 7 on policy options and scenarios was included after the 2nd stakeholder meeting. The preliminary analysis estimates that –in 2030-- the Least-Life-Cycle-Cost scenario will save an extra 10 TWh/a in electricity, 3.5 Mt CO₂ equivalent/a in greenhouse gases and around 1 billion Euro in consumer expenditure with respect of the BAU scenario. Total business revenue (all sectors) is projected to increase by 1.8 billion Euros.

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 appliances¹ 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 refrigeration² also requires, within four years after entry into force, to *'assess the verification tolerances in Annex VII'* and *'the possibilities to remove or 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 review⁴, 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.'*

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 Task 1-6 Report was 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 N° 4⁵)— 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).
- '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 study⁶.
- 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).

2 Consultation and data retrieval

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/>

2.1 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 N° 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.

2.2 Consultation

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

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 ran for 13 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 was received during and after 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 stakeholder meetings in **Annexes E and F**. They are also 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 empty⁹.

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) regulation of 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 a battery operated appliance needs to be electric mains-(AC) 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

Nonetheless, The reaction of the environmental NGOs was that the non-household appliances should remain included (see Minutes in Annex E). This applies to hotel minibars, but it was also made clear that professional chest freezers were explicitly exempted from the 2015 Ecodesign regulation for Professional Refrigeration¹¹ with the intention that they would be regulated under the current household refrigeration regulation (see Minutes in Annex E). The main manufacturer of minibars mentioned that the current formulation of the scope is in any case not adequately clear, as demonstrated by a ruling of a German court that interpreted that minibars are not included in the scope (see paragraph 4.2.1). The latter indicates that the definition of non-household appliances included in the scope should not be generic but very specific.

3.2 Article 2

It seems that Article 2 (Definitions) can 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'*¹²(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'*.

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

¹¹ Commission Regulation (EU) 2015/1095 of 5 May 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for professional refrigerated storage cabinets, blast cabinets, condensing units and process chillers (Text with EEA relevance) OJ L 177, 8.7.2015, p. 19–51

¹² 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.*

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':

- *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 Efficiency Index) to give a volume correction factor for built-in appliances (Table 6 of IV). Note that CECED, in its most recent proposal sets, also with respect of the new IEC standard, a more strict definition.¹³

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 II¹⁴, 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

¹³ Built-in appliance: Any appliance that is designed, tested and marketed exclusively (1) to be installed totally encased (top, bottom, sides and back) by cabinetry or panels that are attached during installation, (2) to be 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.

¹⁴ Requirement from 1 July 2013 (Annex II, Point 1)

the top-opening compartment exceeds 75% of the total gross volume. This definition is important to define, in Annex IV Categories 8 and 9, two different freezer types (chest and upright).

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

- **fresh food storage** for 'unfrozen foodstuffs';
- **cellar** for 'particular foodstuffs or beverages at a temperature warmer than that of a fresh food storage compartment';
- **chill** for 'highly perishable foodstuffs';
- **frozen-food storage** means a 'low-temperature compartment specifically for frozen foodstuffs and classified according to temperature as follows', using the star(*) designation: 0* < 0 °C but not intended for highly perishable foodstuffs; * ≤ 6 °C; ** ≤ 12 °C; *** ≤ 18 °C;**** or 'food freezer' ≤ 18 °C but with a defined food freezing capacity;
- **ice making** for 'freezing and storage of ice';
- **multi-use** for compartments where the end-user can set the storage temperature¹⁵;
- **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 storage of frozen foodstuffs;
- **frozen-freezer:** with one or more compartments suitable for freezing foodstuffs with temperatures ranging from ambient down to -18 °C, and which is also suitable for *** storage, possibly with a **section¹⁶;
- **wine storage appliances:** that has no compartment other than wine storage compartments;
- **multi-use appliances:** that has no compartment other than multi-use compartments;

¹⁵ 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.

¹⁶ 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.

- **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 **is** regulated in the current Ecodesign Regulation when the refrigerating appliance also has other compartments. Only in the case that the appliance has *'no compartment other than one or more wine storage compartments'* (citation Article 2, sub 7) it is a *'wine storage appliance'* and thus excluded from the Ecodesign requirements in Annex II. The wine storage appliances are not excluded from the *'Measurements'* in Annex III¹⁷ and the verification of the humidity performance is explicitly part of Annex V.

Considerations (stakeholder comments were 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.

¹⁷ 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 (*)	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;

(*) 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^{***}
$> + 14$	$+ 5 \leq twma \leq + 20$	$+ 8 \leq t_{cm} \leq + 14$	$0 \leq t_{1m}, t_{2m}, t_{3m} \leq + 8; t_{ma} \leq + 4$	$- 2 \leq t_{cc} \leq + 3$	$\leq - 6$	$\leq - 12$ (*)	$\leq - 18$ (*)

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

(*) 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 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 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 1st stakeholder meeting, environmental NGOs doubted the necessity of glass doors and thus the need for compensation, but in the 2nd meeting they conceded that a compensation factor might be used just for ecodesign requirements. 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 62552:2013¹⁸ published in the Official Journal in January 2014¹⁹. It is the legal basis for the current assessments for market surveillance. This standard is based on IEC 62552:2007²⁰ 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)²¹, 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 62552²², 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 153:2005²³.

For noise measurement (relevant for the energy label) the Communication mentions IEC60704-2-14²⁴, but this reference was corrected later on in 2010 and expanded with IEC 60704-1²⁵ and IEC 60704-3²⁶.

For power consumption in standby and off modes the reference is Commission Regulation (EC) No 1275/2008.²⁷

The measurement method for wine storage appliances, as well as the humidity measurement of wine storage compartments, was defined in the Communication, Part 2 and now included in EN 62552:2013.

¹⁸ EN 62552:2013 Household Refrigerating Appliances - Characteristics And Test Methods (IEC 62552:2007, Modified + Corrigendum Mar. 2008).

¹⁹ OJ C 22, 24.1.2014, p. 32–33

²⁰ 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)

²¹ 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.

²² Work Item (WI) of CENELEC TC 59 X, WG 8.

²³ 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.

²⁴ 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)

²⁵ 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.

²⁶ 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.

²⁷ 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 IEC 62552-1, 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.

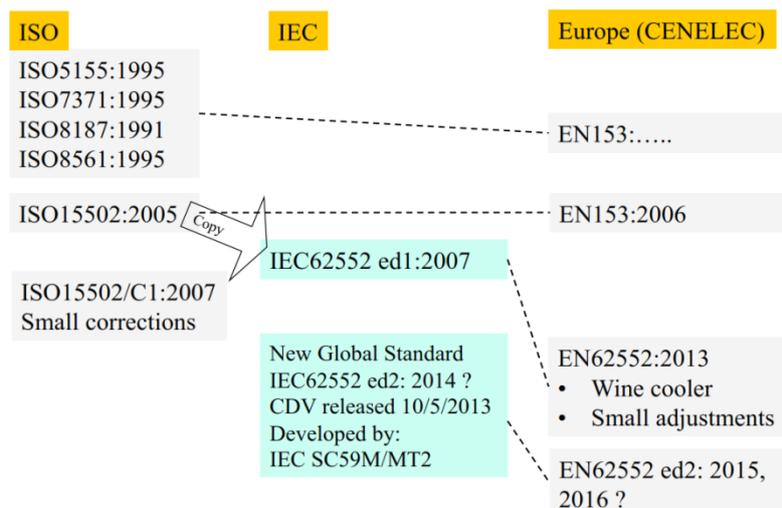


Figure 1. History of IEC 62552 (source: M. Janssen, 2013²⁸)

²⁸ 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

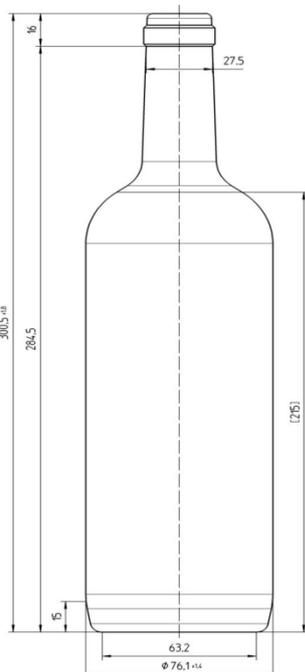
The IEC 62552:2015 standards and the draft EN 62552 are the most relevant for this study and will be the subject of the rest of this section.

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 changed from 5 to 4 °C and the chill target temperature increased from 0 to +2 °C (see also paragraph 9.3.9);
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 2), 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

According to Annex A, for thermoelectric and absorption appliances the energy consumption test is to continue to be done at 25 °C, unlike for the compressor driven appliances. As regards these appliances manufacturer Dometic also mentions that he

would like minibars to be included in the regulation of commercial refrigeration but if this is not deemed suitable to clearly mention and define that minibars are only included in the household refrigeration regulation, which at the moment is not clear.²⁹ Furthermore Dometic would like an indication on the label to indicate the design temperature, typically 'cellar (12 °C)' or 'pantry (17 °C)'. Finally, Dometic asks not to ban appliances with glass doors. Similar considerations apply to thermoelectric and absorption cooling boxes.

4.2.2 IEC 62552-2 (General performance tests)

Storage tests, at various ambient temperatures and with test packages, 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 will be present. The ambient temperature is 25 °C. The freezing capacity, in kg/12h, is tested with a predefined mass (3.5 kg per 100 l freezer volume) and a test load to be cooled from 25 °C to -18 °C. The cooling capacity is tested with a predefined mass (4.5 kg per 100 l refrigerator volume) and test load to be cooled from 25 °C to 10 °C.

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

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

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

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

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

Consideration (for stakeholder feedback): The temperature rise test is currently incorporated in EU regulations only for information. It 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 reaction 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

²⁹ There has been a dispute where the German court decided that minibars did not fall within the scope. Ref.: Landgericht Düsseldorf, 37 O 58/13, 20th February 2014.

specified ambient conditions. Note that this relates to the external surface and is probably less relevant in the more temperate EU climate conditions.

4.2.3 IEC 62552-3 (Energy efficiency tests)

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

- Steady state power consumption P , in W, at ambient temperatures of 16 °C and 32 °C (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:

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

Consideration (for stakeholder feedback):

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

The same goes for ΔE_{aux} , where the legislator may choose not to regulate, regulate separately or regulate as an integrated part of the daily energy. The determination of ΔE_{aux} does require, if it is regulated, the setting of some 'regional' EU parameters, e.g. for the amount of ice produced.³⁰

In the 1st stakeholder meeting there was no reaction to the above; 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,

³⁰ Note that energy use of anti-sweat heaters that do not have an ambient control as well as icemakers 'ready for action' is included in the normal test procedure. The term E_{aux} , in regions where it is prescribed (so far not the EU), would only relate to additional demands of a legislator.

- 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, 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 controlled anti-condensation heater or a working ice-maker) 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 $\Delta E_{processing}$, 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).³¹

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 EU³².

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.

In the 2nd stakeholder meeting the environmental NGOs indicated that the course of action when circumvention is discovered should not be entirely left to surveillance

³¹ Decided at the Frankfurt meeting of CENELEC TC 59X, WG8

³² While Japan has a warmer average climate than the EU.

authorities/ Member States but that the regulation should at least say that these products are by definition non-compliant.

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 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^{33 34}.

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.³⁵
- A linear calculation to achieve an ambient temperature of 25 °C, which would result in a factor $F=0.4375$ (rounded 0.438)³⁶ 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 temperatures³⁷, 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.

³³ Janssen, M., Ecodesign and labelling review Cold – Product categorisation and correction factors, Re/genT Note 15116/CE12/V5, April 2015.

³⁴ 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.

³⁵ $(16+32)/2=24$

³⁶ Average temperature = $0.4375*16 + (1-0.4375)*32 = 25$

³⁷ COP is Coefficient of Performance. The key formula is $COP_{\text{carnot}} = (T_{\text{cold}} + 273.15)/(T_{\text{hot}} - T_{\text{cold}})$

- 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 energy³⁸. Very small effect on volume (max. 5% of freezer volume).
- Category 7 (fridge-freezer), static (two thermostats): 7 % more energy (after elimination of one anomaly). Very small effect on volume (max. 5 % more freezer volume). Note that the negative impact of the lower fridge compartment is partially compensated by the positive impact of the new conditions for the freezer compartment.
- Category 7 (fridge-freezer), frost free (two thermostats): 9 % more energy, reflecting new defrost-cycle being more stringent and the relatively high impact of defrosting on the very efficient products in this group.³⁹ 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:

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

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

³⁸ 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.

³⁹ 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.

- 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).⁴⁰
- 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.⁴¹

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*⁴²).

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

$$COP(T_a 25^\circ\text{C}) \neq 0.438 \cdot COP(T_a 16^\circ\text{C}) + (1-0.438) \cdot COP(T_a 32^\circ\text{C})$$

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
- 2 % 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

⁴⁰ Here the CECED values are taken as a reference; depending on the heat transfer efficiency of the evaporator or condenser the values may change.

⁴¹ 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.

⁴² Latin, meaning 'other things being equal'. Abbreviation: cp or c.p.

study team finds, see Annex B, $F=0.6$ (22.4 °C). Note that according to 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.

Consideration (for stakeholder feedback): 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.

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°C	16 & 32°C	32°C	32.2°C	30°C	15 & 30°C
requirement	Fresh food	+4°C	+3°C	+7.2°C	+3°C	+4°C
	Freezer*	-6°C	-6°C	-9°C	-9.4°C	-6°C
	Freezer**	-12°C	-12°C	-15°C	-15°C	-12/-15°C
	Freezer***	-18°C	-18°C			-18°C
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).⁴³
- 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.
- 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.

⁴³ See also CECED informative papers on the Chinese measure published on the project website.

5 Legislation (Task 1.3)

5.1 EU-legislation overview

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

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

The energy label for household refrigerating appliances was also the first where it was necessary to update the energy label in 2003⁴⁴, 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.

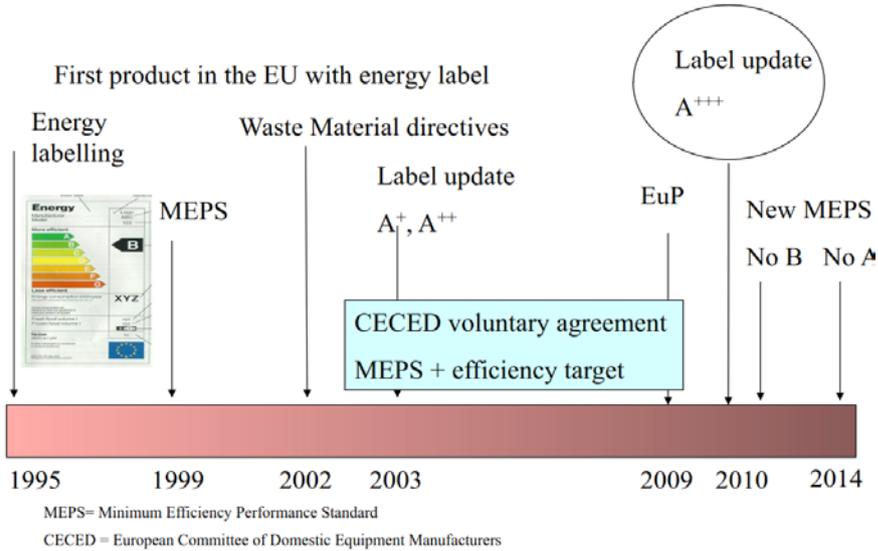


Figure 4. Short history of EU Energy Label and Ecodesign measures. (Source: M. Janssen, Refrigerator testing: IEC 62552 ed 2 development and AUS/NZ Round Robin testing, Presentation 13402 / RE24 / V2, Re/genT BV, 17/10/2013)

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

⁴⁴ Commission Decision 2003/66/EG

under the first Energy-using Products framework directive 2005/32/EC offered a more robust alternative.⁴⁵

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 %.⁴⁶

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 2037/2000⁴⁷ 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. 517/2004⁴⁸. As blowing agent cyclopentane, zero-ODP and GWP<25, is used.

As most other electrical and electronic equipment (EEE) refrigerators and freezers are subject to recovery and recycling targets under the Waste of Electrical and Electronic

⁴⁵ Note that CECEP actually preferred a mandatory regulation, because the voluntary agreement offered too much possibilities for non-complying 'free-riders'.

⁴⁶ According to the VHK EIA-study 2014, the 'BAU' (Business-as-Usual) scenario would have yielded an EEI of 78 in 2015.

⁴⁷ Regulation (EC) No 2037/2000 of the European Parliament and the Council of 29 June 2000 on substances that deplete the ozone layer.

⁴⁸ 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

Equipment (WEEE)-legislation, first introduced in 2002, but in this case separate collection is *'a matter of priority, for temperature exchange equipment (i.e. refrigerators, freezers, etc.) containing ozone-depleting substances and fluorinated greenhouse gases'* (Art. 5, WEEE-recast 2012⁴⁹). This means that special treatment facilities were set up to recover the refrigerant and —without significant emissions to outside air— to shred the foam (and cabinet).

From 2016 the minimum collection rate is set at 45 %⁵⁰ (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 impacts⁵¹ and attention of the legislator to 'nanosilver' under the Biocide Regulation.⁵²

As regards electrical safety household refrigerating appliances are subject to the Low Voltage Directive⁵³ and for electro-magnetic compatibility there is the EMC Directive⁵⁴. 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

⁴⁹ 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

⁵⁰ Or between 40 and 45% for several Eastern-European Member States

⁵¹ 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.

⁵² 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)

⁵³ 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

⁵⁴ Directive 2004/108/EC relating to electromagnetic compatibility and repealing Directive 89/336/EEC, OJ L 390 of 31 December 2004

aspects⁵⁵, 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’.⁵⁶

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.⁵⁷ 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.

⁵⁵ 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]

⁵⁶ http://ec.europa.eu/environment/consultations/closing_the_loop_en.htm (Consultation for all interested stakeholders from 28.5.2015 to 28.8.2015).

⁵⁷ European Commission Conference on Product Policy –Ecodesign & Energy Labelling, 20-21 Feb. 2014, misc. lectures.

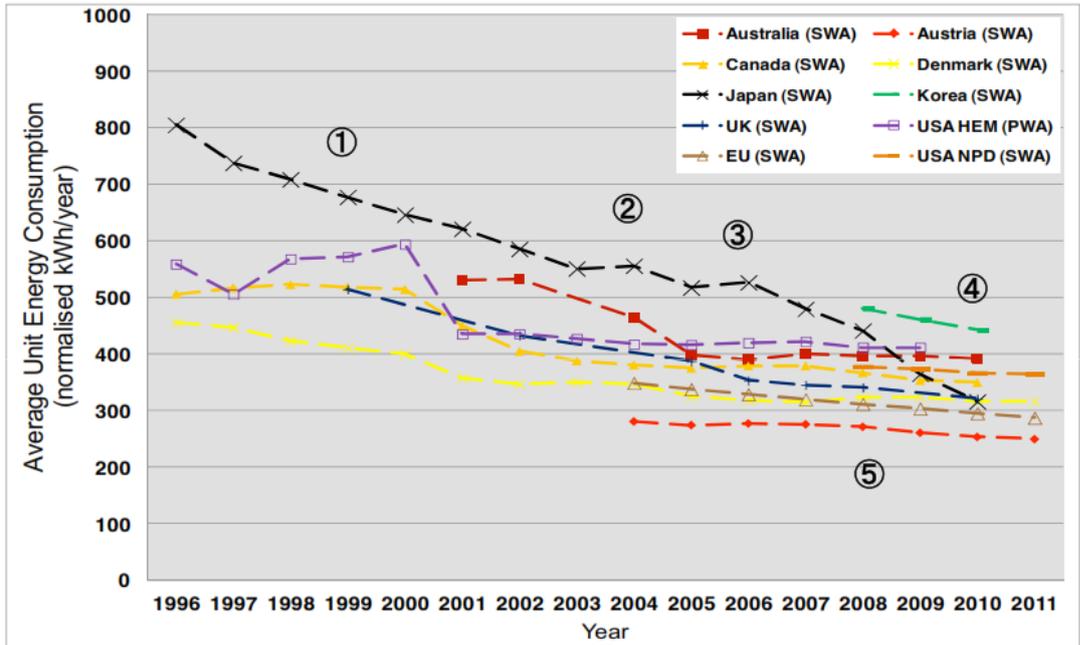


Figure 5. Average Unit Energy Consumption in selected countries and regions (Source: IEA 4E M&B, version 2014)

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.⁵⁸

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 according to IEA-4E.

⁵⁸ 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 $EEI = 100 \times AEC / SAEC$, meaning that SAEC is the line where $EEI = 100$. If you draw this line differently or with a different shape (e.g. curved) it will change the value of EEI.

5.3 Ecodesign metrics

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

$$EEI = AE/SAE$$

With: $AE = E_{24} \times 365$, 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

$$V_{eq} = \sum [V_c \times (25 - T_c) / 20 \times FF_c] \times CC \times BI$$

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. The most recent reports are included in Annex H.

An alternative proposal by ECOS-Topten was also presented during the first stakeholder meeting. The latest version of the proposal can be found in Annex H.

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: Prodcum, 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: Prodcum, Eurostat, 2015)

	2006	2007	2008	2009	2010	2011	2012	2013
Production								
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)⁵⁹.

⁵⁹ 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 countries⁶⁰, 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 eco-design 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 household⁶¹ and —including secondary and vacant homes— 1.3 refrigerating appliances per EU dwelling.⁶²

⁶⁰ Luxembourg, Cyprus, Malta, Bulgaria, Croatia

⁶¹ Assuming around 210 million households in 2015

⁶² 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)⁶³. 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 year⁶⁴. The estimated 'equivalent volume' (*Ve_q*), calculated according to the current regulations, is 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 V_{net}	litr	203	259	278	297	316	337	358	380	401	422
Equiv.vol. V_{eq}	litr	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	Mm ³ @ 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	Mm ³ @ -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 levies⁶⁵.

⁶³ VHK, EIA-study, 2014. This estimated product life figure does not only follow from specific sources (see Chapter 7 on durability) but is also consistent with known sales, penetration rates and population figures.

⁶⁴ See Omnibus study, Figure 5-5 (source CECED), showing a compound aggregate growth in net volume of 15% over the 2001-2012 period.

⁶⁵ 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.⁶⁶

6.3 Actors, jobs and trends

6.3.1 Actors

Important manufacturers with EU production facilities are Electrolux⁶⁷, Bosch-Siemens, Whirlpool⁶⁸, 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)⁶⁹ by Whirlpool, a US based firm with its EU-headquarters in Italy.⁷⁰

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 Eurocave⁷¹, 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.

⁶⁶ 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 température 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.'

⁶⁷ Brands: Electrolux, Zanussi, AEG, Rex, etc.

⁶⁸ Whirlpool brands: Whirlpool, Bauknecht, Ignis, Maytag, Laden, Polar and Privileg. Indesit brands: Indesit, Hotpoint / Hotpoint-Ariston and Scholtès.

⁶⁹ previously part of Merloni Elettrodomestici

⁷⁰ EC, 'Mergers: Commission approves acquisition of Italian domestic appliances producer Indesit by Whirlpool', http://europa.eu/rapid/press-release_IP-14-1133_en.htm

⁷¹ 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 CECED⁷². 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 based⁷³) 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 database⁷⁴, showing trends in energy efficiency related features.

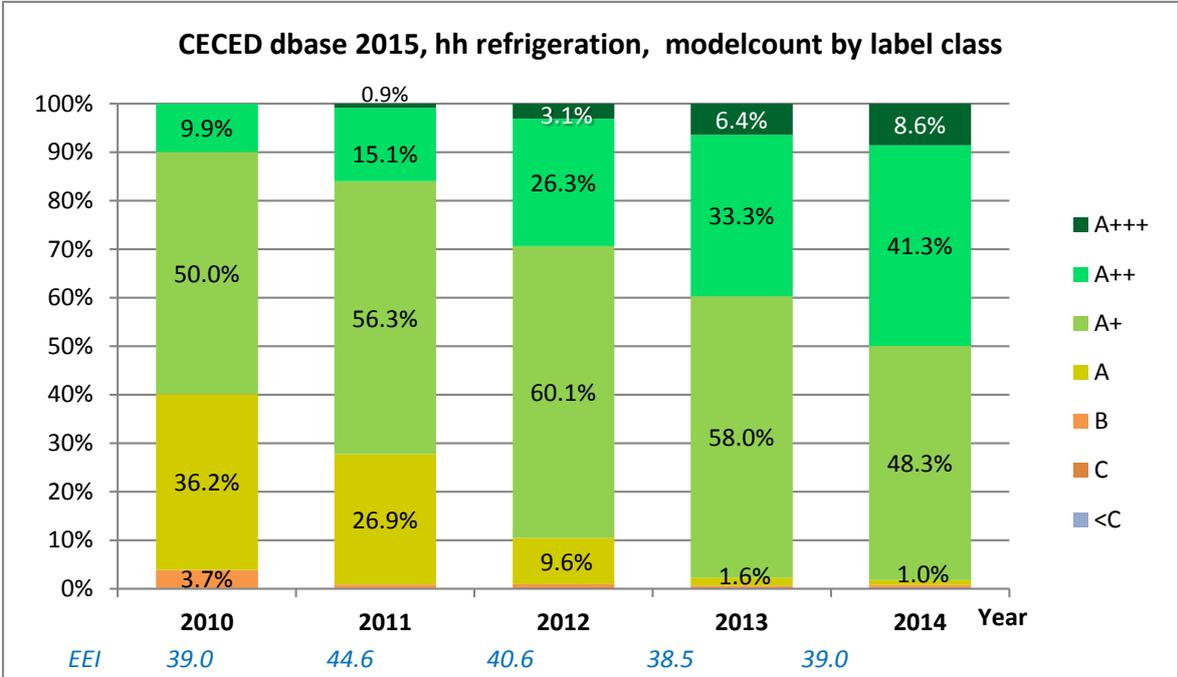


Figure 6. Counts by label class (source: VHK on basis of database CECED 2015)

⁷² www.ceced.eu
⁷³ EC Impact Assessment 2009, SEC(2009)1021
⁷⁴ 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 39.⁷⁵

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 model availability. Comments from NGOs signal this as a concern and strong reason to revise the energy label (see Annex H).

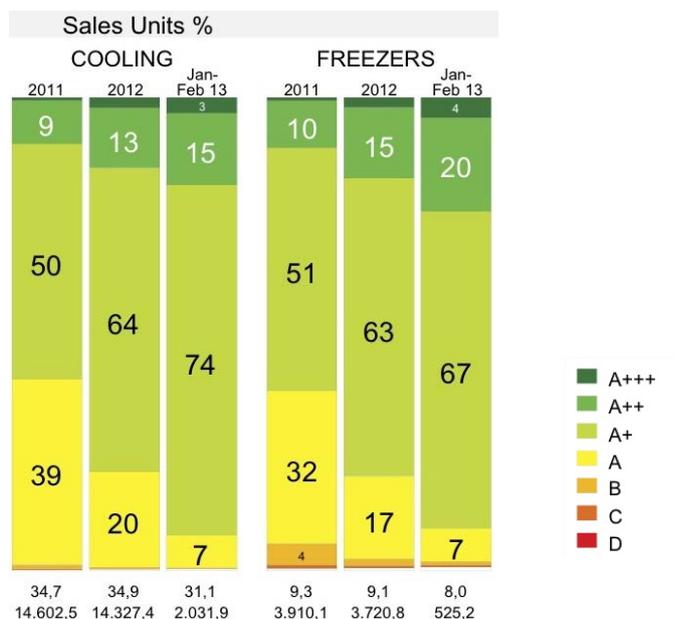


Figure 7. Sales data per label class (source: GfK for EU23, in TopTen 2013)

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		unit	1990	2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040	2045	2050
ECO																
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	0.50	0.41	0.41	0.40	0.40	0.40	0.39	0.38	0.36	0.34	0.32	0.30	0.28	0.26	
GWP	Mt CO ₂	69	42	41	39	37	35	34	27	22	17	13	10	8	7	

⁷⁵ 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.

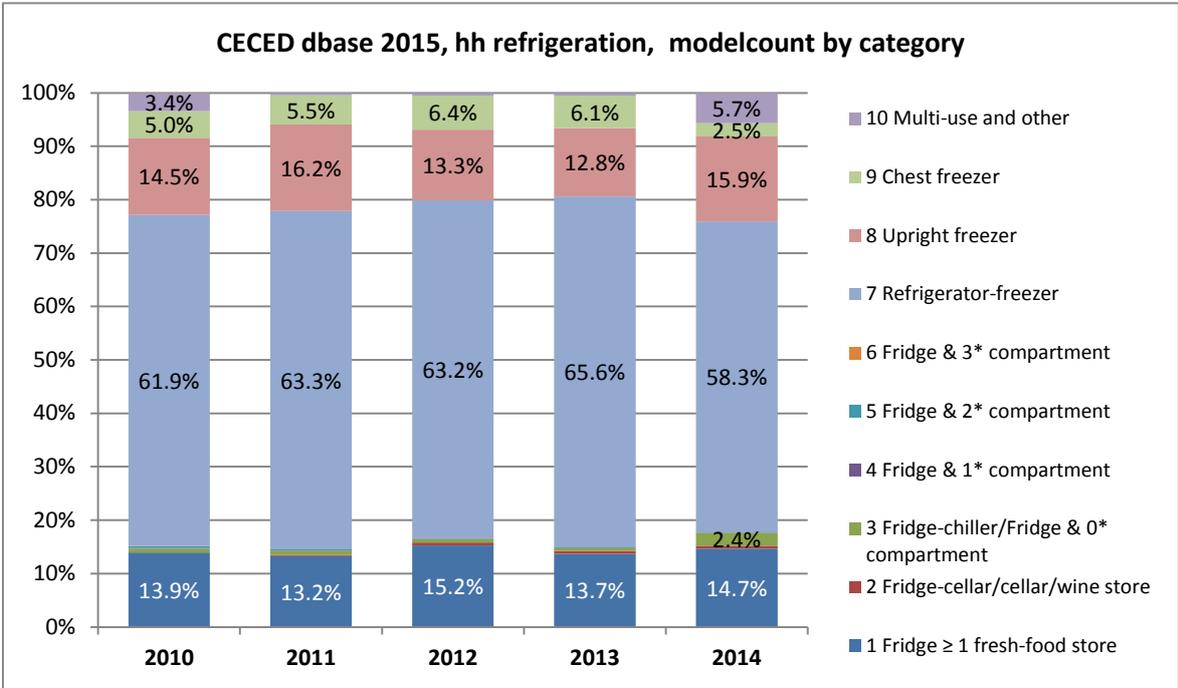


Figure 8. Counts by category (source: VHK on basis of database CECED 2015)

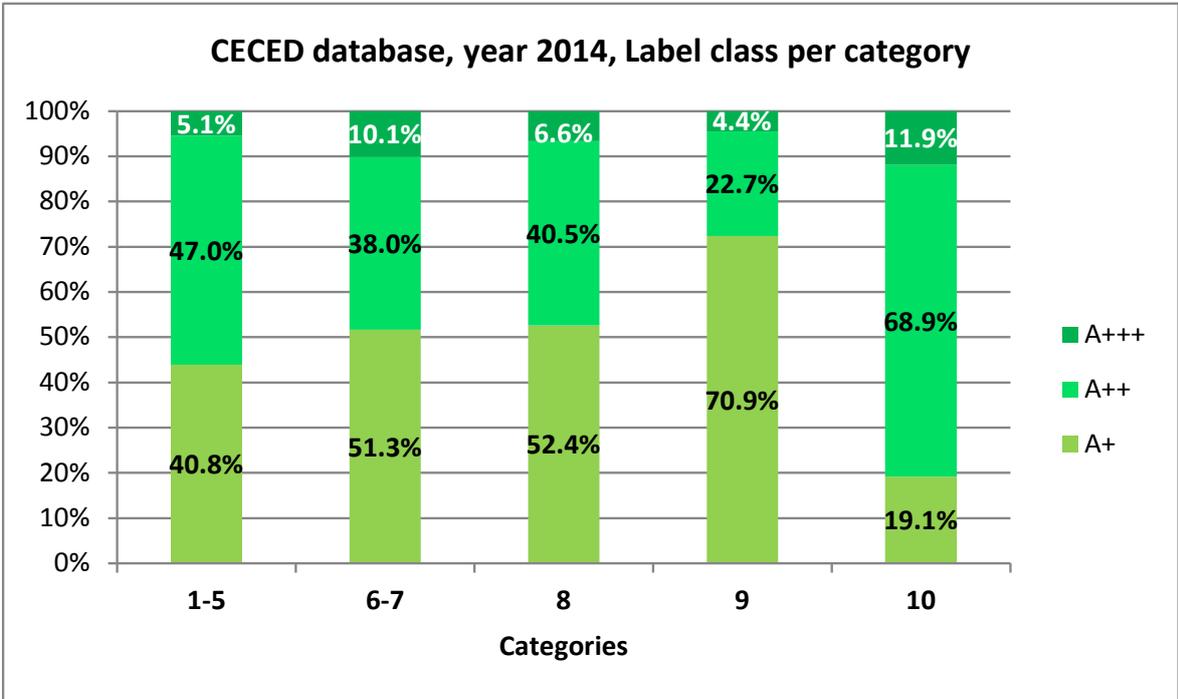


Figure 9. Counts by category and class (source: VHK on basis of database CECED 2015)

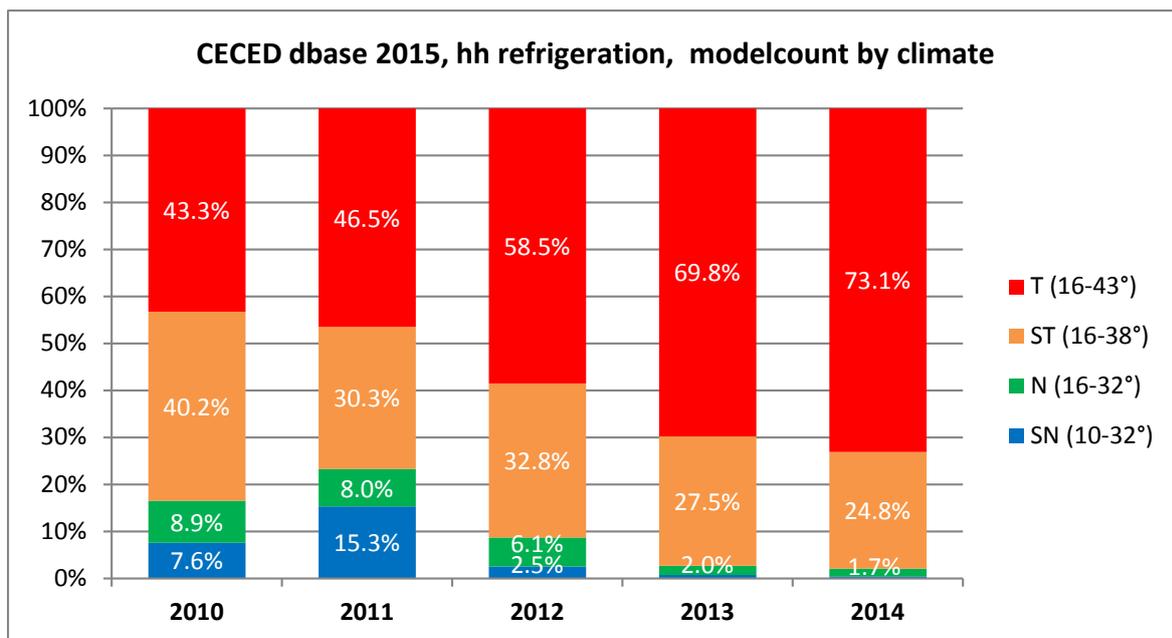


Figure 10. Count climate correction 2010-2014 (source: VHK on basis of database CECED 2015)

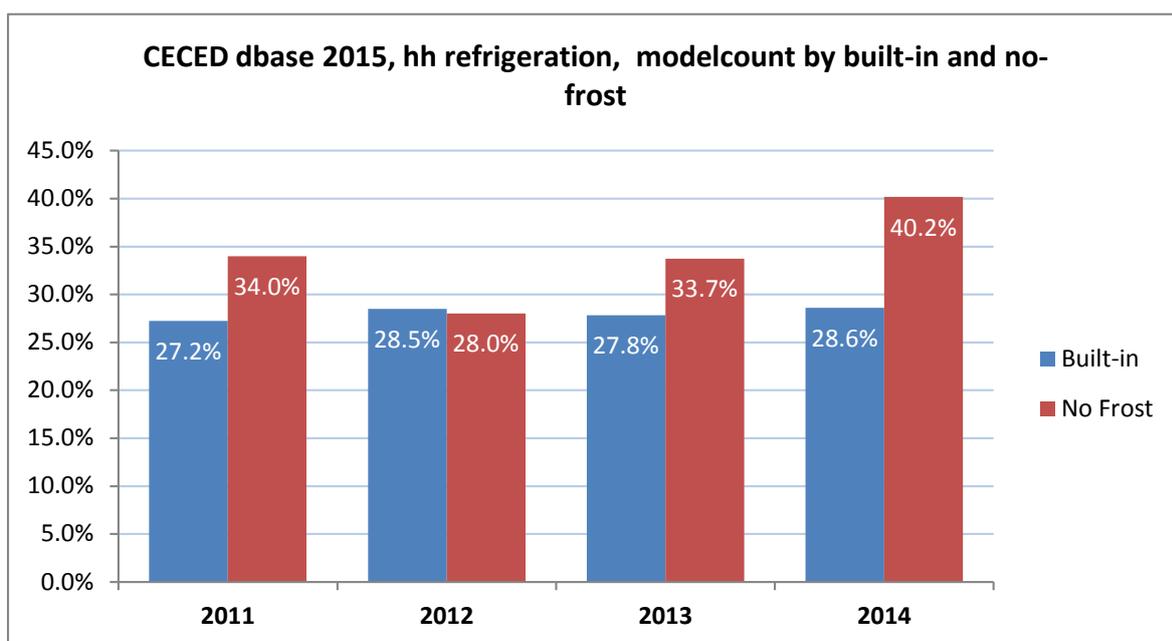


Figure 11. Count Built-In and No-frost appliances (source: VHK on basis of database CECED 2015)

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.

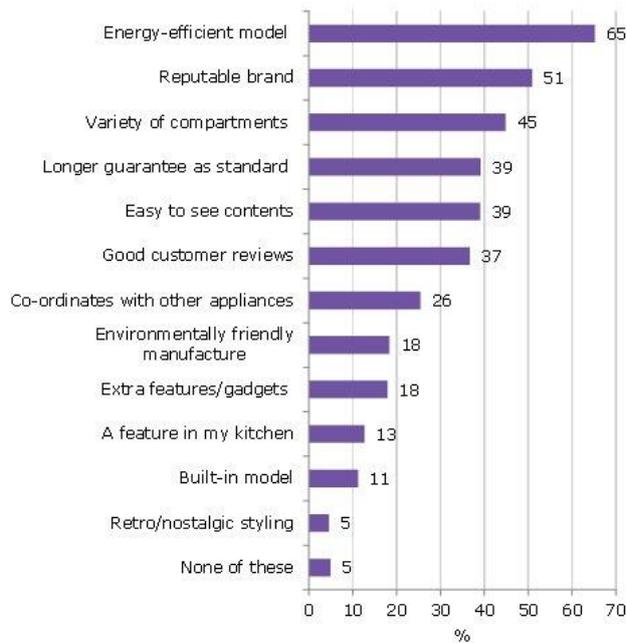


Figure 12. Factors influencing the choice of refrigeration appliances (source: GMI/Mintel "Fridges and freezers – UK", April 2014, in 'Energy efficient products – helping us cut energy use')

The trends in energy efficiency are a necessary input for Tasks 5, 6 and 7. 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 EU⁷⁶, 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.

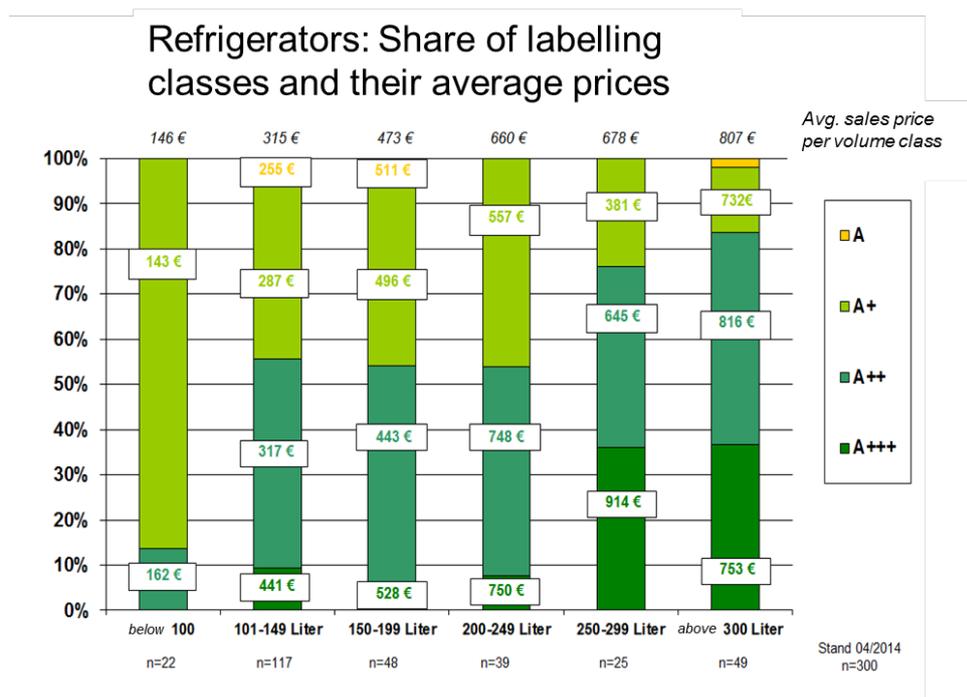


Figure 13. Refrigerator energy classification and prices, Germany 2014. (source: Verbraucherzentrale Rheinland Pfalz, 2014)⁷⁷

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.

⁷⁶ Comparison with the most recent figures in [TopTen, Topten.eu, Energy efficiency of White Goods in Europe: monitoring the market with sales data, June 2015] indicate that the average German refrigerator+fridge-freezer (sales-weighted 1:3) is considerably more expensive than average EU, but also much more efficient (high market-share of A+++).

⁷⁷ Elke Dünnhoff, Katrin Negatsch, Carmen Strüh, Ramona Wiese, Energieverbrauchskennzeichnung von elektrischen Geräten –Ergebnisse des dritten Marktchecks im Dezember 2013, Verbraucherzentrale, April 2014.

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

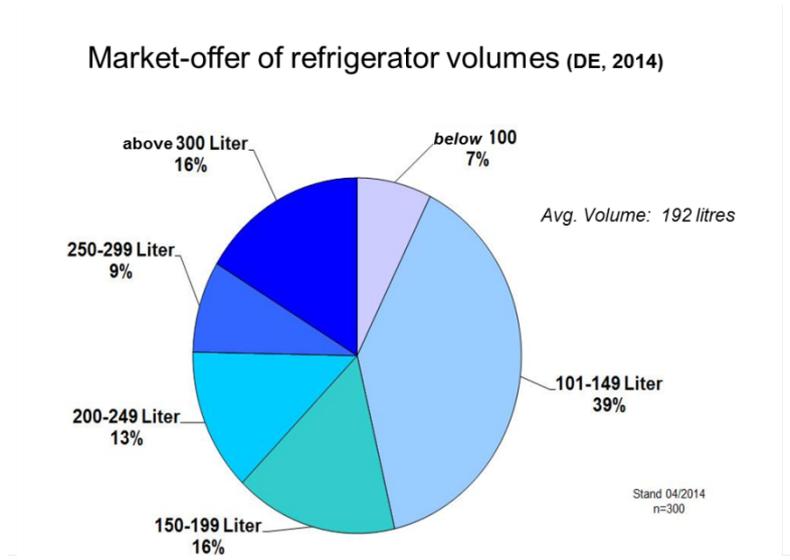


Figure 14. Refrigerator volumes on offer, Germany 2014.

(source: Verbraucherzentrale Rheinland Pfalz, 2014)

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

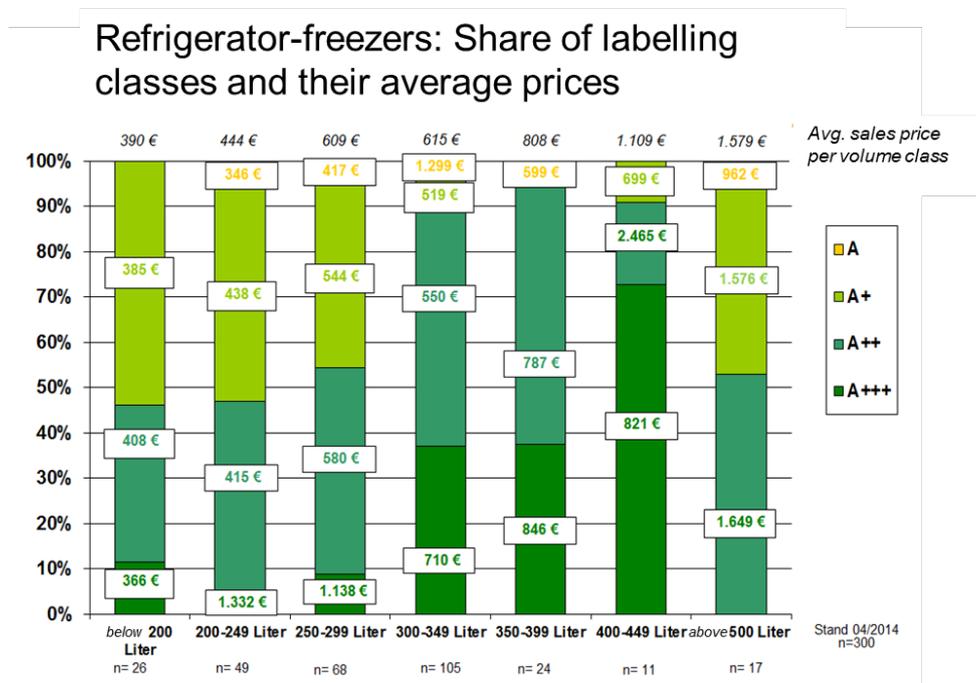


Figure 15. Refrigerator-freezers, energy classification and prices, Germany 2014.

(source: Verbraucherzentrale Rheinland Pfalz, 2014)

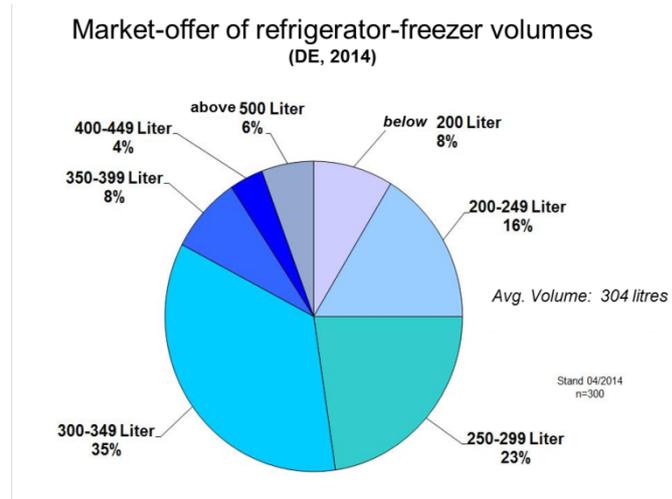


Figure 16. Refrigerator-freezer volumes on offer, Germany 2014.

(source: Verbraucherzentrale Rheinland Pfalz, 2014)

Figures above have been compared to the most recent trends from TopTen (based on GfK data)⁷⁸. Assuming the sales-weighted (1:3) average prices for refrigerators and fridge-freezers of the Verbraucherzentrale 2014 to be comparable to the average TopTen 'refrigerator' the price-difference between an A++ and A+++ is comparable. Both sources find a price difference of 24-27% or around €140-150.

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.

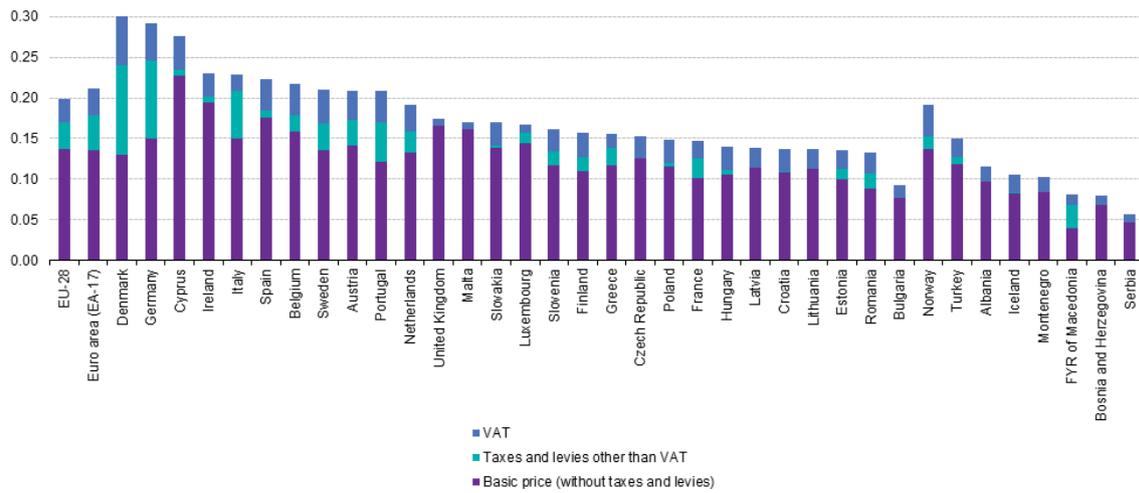
Table 13. REAL Electricity rates, residential (in 2010 euros, inflation corrected)

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

Inc. %/a
4%

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

⁷⁸ Ibid 76.



(1) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
 (*) 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.

A simple example:

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

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

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

Door openings

The fridge is assumed to be opened 20 times per day and the freezer 4 times per day, 365 days per year. This means there is 20 x 0.2 x 365=1460 m³ of fridge air and 4 x 0.1 x 365= 146 m³ of freezer air that needs to be reheated because of door openings.

At every door opening the air in the fridge has to be heated up by 15 K (20 °C-5 °C) and the freezer by 38 K (20 °C—18 °C). The energy demand for that is 1460 x 0.83 x 15= 18165 kJ for the fridge and 146 x 0.83 x 38= 4605 kJ for the freezer. In total this is 22770 kJ or 6325 Wh (1 Wh=3.6 kJ)= 6.325 kWh per year. The electricity needed to provide this 6.3 kWh is --assuming a (bad) COP of 2.5-- thus 2.53 kWh/year.

Warm load

No statistics could be found, but let us assume (VHK estimate on basis of FAU Food Balance), that the average European buys around 650 kg of food & beverages that go into the refrigerator or freezer. If we add some 40-50 % for food that was heated up during use (left on the table, leftovers, etc.) a ballpark estimate is the equivalent of 1000 kg per year per person. At a little less than 2.5 persons per household this means 2500 kg per fridge/freezer per year that needs to be heated up from shop-temperature to fridge/freezer temperature. Assume that this temperature differences is 15 °C (from 20 to 5 or for a freezer from -3 to -18 degrees)

The annual energy demand per fridge-freezer to (re)cool warm load is thus $2500 \times 15 \times 4.2 = 157500 \text{ kJ} = 158 \text{ MJ}$. This equals 43 kWh/year . The electricity use, at average $\text{COP}=2.5$ would be $43/2.5 = 17.2 \text{ kWh/year}$.

Conclusion

In total and in this worst-case example, our fridge-freezer would thus consume $6.3+17.2 = 23.5 \text{ kWh}$ 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 $5 \text{ }^\circ\text{C}$ extra high testing temperature. The test temperature of $25 \text{ }^\circ\text{C}$ versus a $20 \text{ }^\circ\text{C}$ 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 $16 \text{ }^\circ\text{C}$ and $32 \text{ }^\circ\text{C}$ ambient, but it might as well come from different inside loads (e.g. warm food, frequent and long door openings). The appliance has to perform 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 leads 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 condenser-unit 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 functional 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 FAO⁷⁹, 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.

⁷⁹ FAO, Global Food Losses and Food Waste - extent, causes and prevention. Food and Agriculture Organization of the United Nations, Rome, 2011.

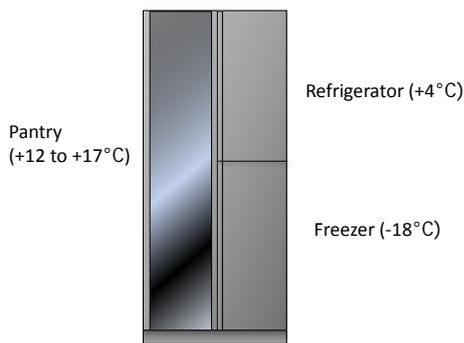


Figure 18. Illustration of a pantry/refrigerator/freezer
(source: VHK 2015)

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

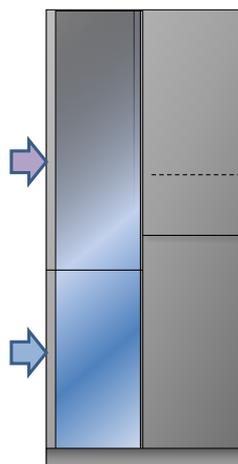
Food planning: Many people forget expiry dates, well-hidden left-overs, etc.. If the fridge had a scanner that could read bar- or QR codes of foodstuffs and a small display it could help to fight food waste. This might also help the fight against obesity or other eating disorders, both serving health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

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

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 (4 °C): Dairy 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>

defrost cool re-use

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.

Data on first-life of refrigeration appliances in the EU originate mostly, directly or indirectly, from market institute GfK that works with consumer panels or point-of-sales questionnaires. GfK data for the Netherlands and Germany show a first-life of around 14-15 years, whereas GfK in the UK⁸⁰ indicate a useful life of perhaps 11 years.

Second-life data of refrigerators are anecdotal, but plausible. Penetration rate of refrigerators is close to 1.5 refrigeration appliances per household. Assuming that a household either has a combi-appliance or a set of single refrigerator and single freezer, the penetration rate should be no more than 1.25. This means that in 25% of EU households there is a second combi or a second refrigerator or freezer. This is also plausible from a recent (interim-)report of Öko-institut and University of Bonn for the German environment ministry UBA (UmweltBundesAmt)⁸¹ showing that 43% of replacement sales for refrigerators, including combis, and 52% of freezers being replaced are in perfect working order, but the consumer wanted a 'better appliance'. Unfortunately, they were not being asked what they were doing with these still functioning old appliances, but for the whole population of EEE-appliances 15-20% answered that they were not replacing or buying for the first time, but wanted an additional appliance.

Government-supported consumer websites on environment, like MilieuCentraal in the Netherlands⁸², actively dissuade consumers to give old refrigerators/freezers a second life in the utility room, garage or garden shed to cool the odd bottle of beer for the barbecue; a function that the household previously could well manage with only their

⁸⁰ The 2008 EU Preparatory study by ISIS/ENEA indicated an average age of 5.1 years for the UK and 6.8 years in Sweden and Finland.

⁸¹ Prakash, S.; Dehoust, G.; Gsell, M.; Schleicher T. & Stamminger, R. (2015). Einfluss der Nutzungsdauer von Produkten auf ihre Umweltwirkung: Schaffung einer Informationsgrundlage und Entwicklung von Strategien gegen „Obsoleszenz“. (Öko-Institute with Bonn University for UmweltBundesAmt)

⁸² <https://www.milieucentraal.nl/energie-besparen/apparaten-en-verlichting/huishoudelijke-apparaten/koelkasten-en-vriezers/>

primary (efficient) kitchen appliance but which is now (more than) doubling their household refrigeration energy bill.

From the point of view of the environment the prolonged second or third-life of European refrigerators in Africa is seen as a negative development, e.g. under the Basel convention⁸³ and in the WEEE directive 2012/19/EU. Not only does it keep ozone depletion substances (freon) on the market and moves it to environments that are difficult to control 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. Studies for Ghana revealed that in 2009, around 70 % of all imports of electrical and electronic equipment (EEE) 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. In other words, 55% of all EEE sold in Ghana came from second-hand European EEE⁸⁴. Article 10 of the WEEE Directive 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, but –as the Basel Convention notes—illegal exports from the ports of Amsterdam and Antwerp are masked as “second-hand goods”, “private goods”, “for charities”, “for personal use”, “miscellaneous” and “effets personnels”.

A backwards-looking Japanese life cycle inventory 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 %.⁸⁵

Figure 19 gives a forward-looking calculation for the current EU situation by the study team. The result is not quite that spectacular, but it also shows that there is no energy gain (nor GWP-gain) in lifetime extension. The assumptions in this calculation are optimistic and, amongst others, entail that there is no deterioration of the refrigerator efficiency over its product life due to wear and tear or aging of materials. Calculations were made for the average consumer buying the current average combi (260 kWh/a, i.e. better than A+) and an average consumer buying the then average combi at a level of A+++ (see also scenario analysis in Chapter 13) after either 16 or 20 years. The latter would be using 240 kWh (4%) more. Calculations are also made for a high-income 'early adopter' that buys a A+++ combi today (150 kWh/a) and replaces it by a BAT-appliance (80 kWh/a) after 16 or 20 years. The latter would be using 80 kWh (2%), or roughly the same, over a 20 year period.

This outcome agrees with the findings of Gensch et al.⁸⁶ (Öko-Institut for Miele), which calculates an optimal product life of 15 years (from the point of view of GHG emissions/energy) for an A+++ combi (164 kWh in their case) that can be replaced by a product that uses 40% less energy, at a public power-mix of 2010.

According to some stakeholders the outcome seems not in line with studies from Ricardo-AEA (2015)⁸⁷ and Bakker et al. (2014).⁸⁸

⁸⁴ Where are WEee in Africa? Findings From the Basel Convention, e-waste Africa Programme. Basel Convention, 2011.

<http://basel.int/Implementation/TechnicalAssistance/EWaste/EwasteAfricaProject/tabid/2546/Default.aspx?overlyId=ArtId-468>

⁸⁵ 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

⁸⁶ Gensch, C. & Blepp, M.: Betrachtungen zu Produktlebensdauer und Ersatzstrategien von MieleHaushaltsgeräten. Im Auftrag der Miele & Cie.KG. 2015.

⁸⁷ 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.

⁸⁸ Bakker, C; Wang, F.; Huismana, J.; den Hollander, M.: Products that go round: exploring product life extension through design, Journal of Cleaner Production, Volume 69, 15 April 2014, p. 10-16

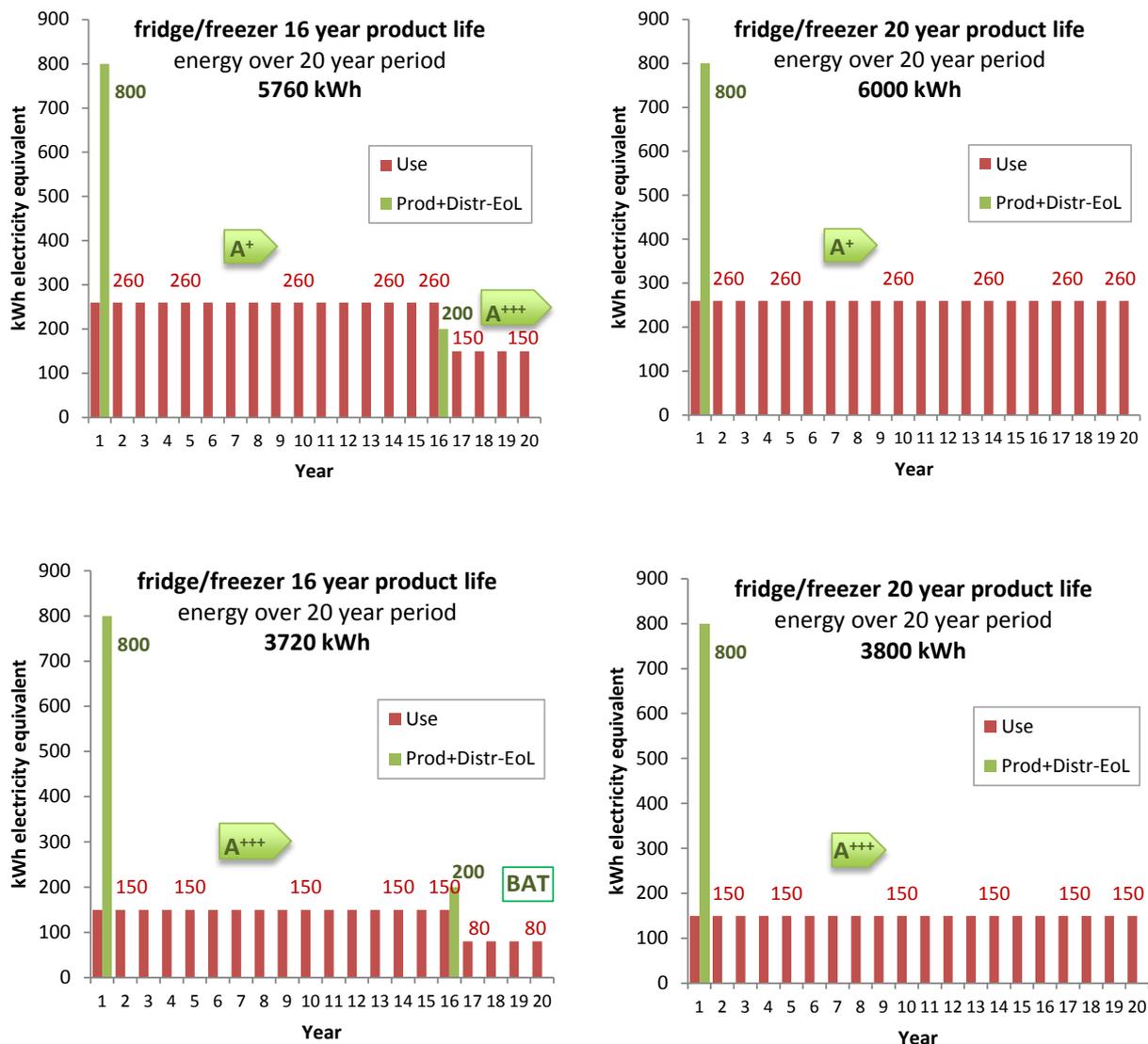


Figure 19. Energy scenarios of fridge-freezer (Cat. 7) lifetime extension (source VHK)

Top: A consumer replacing the current average (13% better than A+) after 16 years by the then average appliance (conservatively estimated at A+++), including proportional write-off for production+distribution-EoL and energy consumption for an extra 4 years of the A+++ appliance use [left graph] versus same consumer keeping the first appliance the full 20 years [right graph].

Bottom: Same situation but now for an A+++ appliance, being replaced by a BAT appliance after 16 years (see Chapter 12) versus one which is replaced after 20 years.

Note: The energy for production+distribution-EoL is derived from the LCA in Chapter 11 (Table 38 for COLD7 with primary energy recalculated into electricity equivalent at 40% power generation and distribution energy). It is assumed that a) the lifetime extension can be realised without extra production energy, b) production, distribution and recycling energy does not change, c) power generation efficiency is constant, d) the energy efficiency in use does not deteriorate in time.

Ricardo-AEA compares three products: two standard products –one average (285 kWh/a) and one efficient (156 kWh/a)—both with a lifetime of 10 years and one ‘durable’ product (285/kWh) with a lifetime of 15 years. It was found that the durable product had a lower impact over an equal lifetime, but it was also concluded that this advantage was much smaller than the replacement –after 10 years—of the standard average product by the standard efficient product. In fact, the efficient standard product didn’t need to be so much better than the standard average product; an efficiency improvement of only 5%

would have been enough. As a result, Ricardo-AEA concludes the following for refrigerators:

'...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...'

Bakker et al find that lifetime extension for 2011 refrigerators is worthwhile, using a similar methodology as the study team. However, they used UK MARKAL⁸⁹ data and manufacturer interviews as inputs for energy efficiency. On that basis they projected e.g. 256 kWh/a for an average 2020 appliance.⁹⁰ This expectation was plausible at the time, e.g. consistent with the findings from the 2008 Ecodesign preparatory study, which specified Best Available Technology (BAT) at 175 kWh/a and expected no large improvements for the future. But since then the industry has progressed considerably and the energy efficiency of the average and best available product on the market is now found to be much better than expected.

There are more refrigerator-related studies on durability in an EU-context.

Building on earlier work in 2011-2012⁹¹, a 2014 article by Ardente and Mathieux from JRC-IES gives an overview of the current state-of-the-art in thinking about product durability⁹². 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.

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'.

⁸⁹ UK MARKAL is/was a model/database managed by the University College of London (UCL). It is reportedly used in determining UK energy policy. Input data are retrieved from external sources.
<https://www.ucl.ac.uk/energy-models/models/uk-markal>

⁹⁰ Pers. comm. Conny Bakker (TU Delft), 22.1.2016.

⁹¹ 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

⁹² 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.

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'.⁹³

Regarding durability several stakeholders (UBA/BAM, ANEC/BEUC, ECOS/TopTen) had severe doubts on the outcome of this paragraph and have asked for several extensions in the course of this study. These requests have been accommodated by the study team, but the conclusion remains that extension of the current lifetime of refrigerators and freezers of 15-16 years does not contribute to energy or carbon emission savings.

7.3.2 Reparability

Reparability measures may be introduced to extend product life but may also ensure that current lifetimes are maintained and/or that the product keeps working as efficiently as possible throughout its life.

GfK 2012 data for the UK, first cited by WRAP⁹⁴ ('Switched on to value', 2014), which is then cited in the 2015 Ricardo-AEA durability study, mention that

- UK consumers expect refrigerators to last only 8 years,
- in reality 50% is replaced before that time and
- 77% of these replacements is reportedly due failure or unreliability of the 'old' appliance. this implies that 38% would fail within 8 years.

For Germany the 2012/2013 GfK-data used the 2015 Öko-Institut for UBA mention that 13% of refrigeration appliances fails in the first 5 years. This is a hefty increase from the past, which mentions only a 7% failure rate, albeit based on less reliable data. The same source also finds that the average lifetime is decreasing significantly. (see figure 20)

US-companies selling extended warranties, also signal decreasing lifetimes, especially by electronics failures.⁹⁵ US refrigerators/freezers are different from the EU types, i.e. larger and with more features, but a repair rate of 37% in the first 3-4 years for side-by-side fridge-freezers with icemaker and dispenser is very high. For a top/bottom fridge-freezer with icemaker the repair rate is 20% and for a fridge-freezer without icemaker it is 12% according to this source.

As regards the nature of the failure of refrigerators in the EU and especially the UK, the most extensive overview is given in the Ricardo-AEA report. It cites the 2008 Ecodesign preparatory study, which mentions thermostats/thermistors and electronics as most frequent components that fail. This is confirmed by rudimentary statistics of the UK repair trade, which mentions also re-gassing⁹⁶ as a fairly frequent repair, and by RREUSE-statistics⁹⁷, that add problematic door seal replacement⁹⁸ to the list. Compressor failure is relatively seldom (4% of repairs).

⁹³ 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.

⁹⁴ WRAP, 'Switched on to value', 2014

⁹⁵ https://www.squaretrade.com/html/pop/lm_failureRates.html

⁹⁶ Re-gassing means topping up the refrigerant as the consequence of (micro) leakage.

⁹⁷ RREUSE is a European umbrella for social enterprises with activities in reuse, repair and recycling

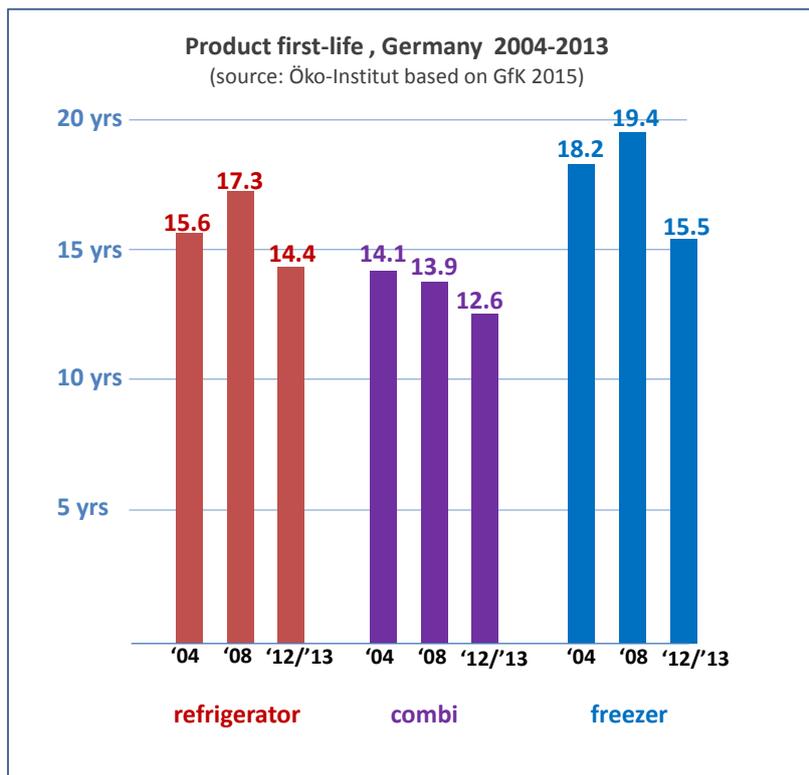


Figure 20. Product life of refrigeration appliances in Germany 2004-2013 (source: Öko-institut 2015 on the basis of GfK data)

The UK consumer organisation Which? mentions ice build-up in freezers (e.g. due to faulty door seal), blocked drains, broken interior elements, incorrect temperatures (e.g. faulty thermostat) as most frequent complaints.

Apart from repairs, also the decrease in efficiency over product life is relevant. Insulation foam material is subject to aging (diminished insulation value over time) and there is wear and tear of door gaskets (leading to ice build-up) and interior elements. Compressor bearings, axes and seals may also be subject to wear. Although there are no statistics, it can be expected that refrigerator/freezer efficiency diminishes by some 10% over a 15-16 year product life.

Policy measures suggested by stakeholders to improve reparability include extension of the warranty, setting minimum lifetime requirements and better availability of spare parts.

The legal minimum warranty for refrigeration appliances is 2 years. Most manufacturers and some larger retail chains offer the possibility of an extended warranty for an extra 3 years (2+3 formula) at fixed prices of € 90 or at a fixed price of € 50 and maximum of € 50 per repair. Manufacturer Miele offers a service contract for € 249 that extends the warranty to 10 years.

Apart from paid extended warranties, some manufacturers offer a standard longer warranty (meaning the possible costs are absorbed in the purchase price). Liebherr offers a standard 7 year guarantee for some models. Ricardo-AEA also signals that Gorenje, Siemens, Grundig and retailer IKEA give a 5 year warranty on some models. Retailer John Lewis gives a 3 year warranty. According to the same source, South-Korean manufacturers Samsung and LG give a 10 year warranty on (inverter and) compressor-failure for some models. Chinese manufacturer Haier gives a 12 year warranty on

⁹⁸In some new models gaskets cannot be replaced, but the whole door has to be replaced.

compressors of A++ models and a lifetime compressor-warranty for some specific models.

The above shows that manufacturers (and retailers) are using the extended warranty as a commercial feature. However, making e.g. a 5 year general warranty mandatory may not be in the best interest of both the consumer --who has to pay directly or indirectly e.g. € 100 for something that he/she may never use/appreciate—nor for the manufacturer that may make unpredictable moves to be competitive in low-priced market segments. E.g. it could well be that he/she increases the expected life of components by going back to using the old electromechanical thermostats with worse efficiency but higher reliability than the more failure-prone electronics. Also for the policy maker the refrigerator, with its reservations on the merit of lifetime extension, may not be most evident product to start with these long warranty periods. Finally, it is the question whether Ecodesign regulations are the proper place or whether this becomes more of a consumer rights issue (as it is today).

For setting minimum technical lifetime requirements the durability study by Ricardo-AEA identified several available EU test standards for components, including:

- IEC 60335-1:2010+A1:2013/EN 60335-1:2012 Household and similar electrical appliances — Safety, Part 1: General requirements
 - Tests referring to IEC 60730-1; number of cycles at least: thermostats 10 000, temperature limiters and thermal cut outs 300 to 1000 cycles
 - Endurance tests referring to IEC 60384-14 standard: Switches: at least 10 000 cycles
- EN 60335-2-24: 2010 Household And Similar Electrical Appliances - Safety; Part 2-24: Particular Requirements For Refrigerating Appliances, Ice-Cream Appliances and Ice Makers
 - Test of flexing of electrical conductors that are flexed in normal operation: 100 000 cycles;
 - Test: fan not reaching excessive temperatures if the motor locks or fails to start.
- EN 60335-2-34: 2010 Household And Similar Electrical Appliances - Safety; Part 2-34: Particular Requirements For Motor Compressors
 - Compressor Start Relay is tested to 100 000 operations.
 - Burst pressure test with only limited leakage allowed (R600a: one minute at 35/25 bar at 70/20 °C for high/low pressure side, which is 5/3 times the normal operating pressure)
- EN 62552 : 2013 Household refrigerating appliances - Characteristics and test methods
 - Door seal effectiveness test carried out before and after 100 000 (refrigerator) or 30 000 (freezer) door openings.
 - Durability of hinge, door and door handle after 100 000 (refrigerator) or 30 000 (freezer) door openings at a specific angle.
- DIN 8974 (Compressors): Switching test 500 000 cycles for hermetic compressors in refrigeration systems
- DIN 8978 (Compressors) Wear test: 1000 h uninterrupted running at specified coil temperature (R600a: 10.9 bar: 1.08 bar)
- DIN 8979 (Compressors) High temperature test: 2000 h uninterrupted running at specific coil temperature (R600a: 7.7 bar: 1.08 bar)

There is no lifetime testing of the appliance as a whole.

Some of the tests mentioned above are typical safety tests, e.g. 10 000 switches for thermostats hardly qualify as endurance test for a device that has to switch >100 000 cycles. Compressor testing would be suitable, but the current low compressor failure would not warrant to make such expensive testing mandatory. Compressors are usually designed to last for more than 20 years under normal operation. If they fail before, it is usually due to abnormal circumstances of operation (e.g. door seal leakage leading to iced freezer-evaporators leading to compressor high frequency switching and/or long running hours) . There are accelerated lifetime tests for compressors⁹⁹, but again the effort is not small. Testing door seal effectiveness in time is potentially the most useful test, given the complaints, but the development of minimum requirements will be time-consuming and may probably be best handled through a mandate to the ESOs.

Generally speaking lifetime testing is expensive, both for industry but certainly for market surveillance authorities, especially when the appliance is to be tested for a projected lifetime of 15-20 years.

Finally there is the option of requesting minimum availability of spare parts, also after the appliance is out of production. Given the failure rate and wear, a guaranteed availability of the thermostats/thermistors and door gaskets until 7 years after production of a model stops, seems to be the most useful. Also it must be possible to still replace just the door gaskets and not the whole door. It would be useful to also have modular electronics unit included in the list of spare parts, but it is difficult to imagine – given the rapid progress in electronics manufacture - how this could be implemented without keeping an uncertain number of these modules in stock for the full 7 years.

7.3.3 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.¹⁰⁰

End-of-life PUR can be recycled chemically (costly and potentially polluting) or mechanically (crushed and compressed to form wood-like blocks).¹⁰¹ Most end-of-life PUR comes from dismantled flexible PUR-parts of furniture (sofas), mattresses, carpet under-coverings or from hard PUR-panels (e.g. roof insulation).

⁹⁹ Seong-woo Woo, Michael Pecht, Dennis L. O'Neal, Reliability design and case study of a refrigerator compressor subjected to repetitive loads, International Journal of Refrigeration 32 (2009) 478–486.

¹⁰⁰ http://www.foam-tech.com/about_ft/environment.htm

¹⁰¹ <http://www.intcorecycling.com/How-to-recycle-pur.html>

In the case of refrigerating appliances, the PUR foam is stuck between the steel cabinet and the PS inner-liner and cannot be dismantled.¹⁰² 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, recover the steel parts through magnetic separation and incinerate (with heat recovery) the PUR-PS particles that remain.¹⁰³ This means that also the PS will not be recycled, but only used for heat recovery.

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

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. 517/2004¹⁰⁴.

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.¹⁰⁵

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.

¹⁰² 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.

¹⁰³ 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

¹⁰⁴ 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

¹⁰⁵ 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:

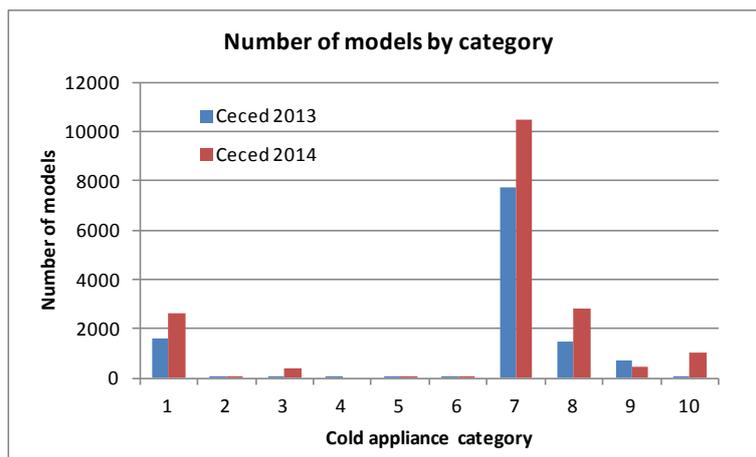


Figure 20. Toward base case definition

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 %¹⁰⁶ 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.

¹⁰⁶ 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.

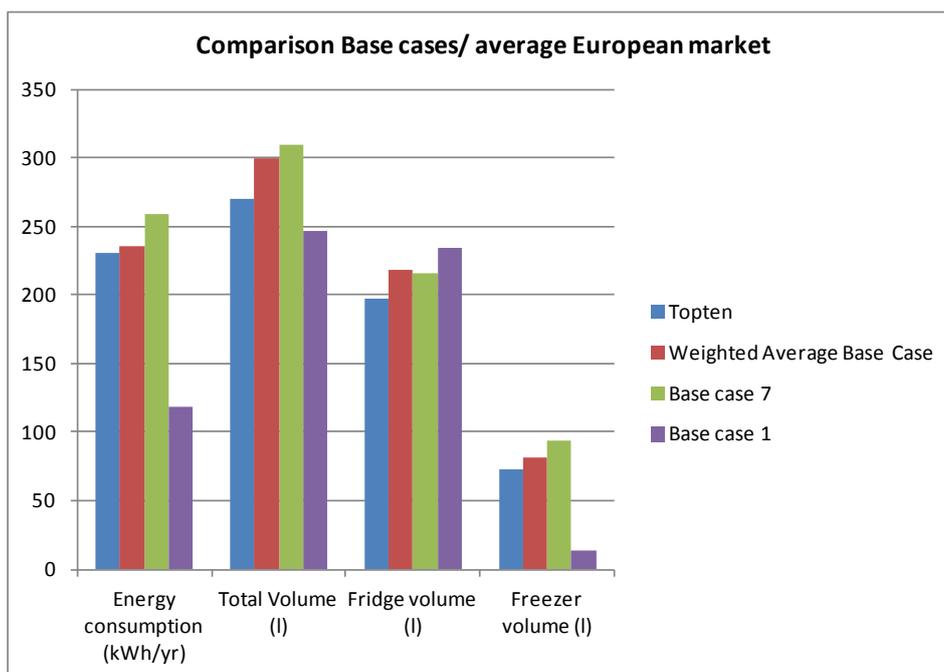


Figure 21. Comparison of base cases characteristics and average values on the European fridge market

The average characteristics by category are not representative of typical products. For instance, the EEL of real products stays close to the A+, A++ or A+++ lines, while average EELs 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 net volume in litres as the new net volume is unknown and is believed to be only 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 r_c -based on $T_a=24\text{ }^\circ\text{C}$ —was taken into account.¹⁰⁷

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.

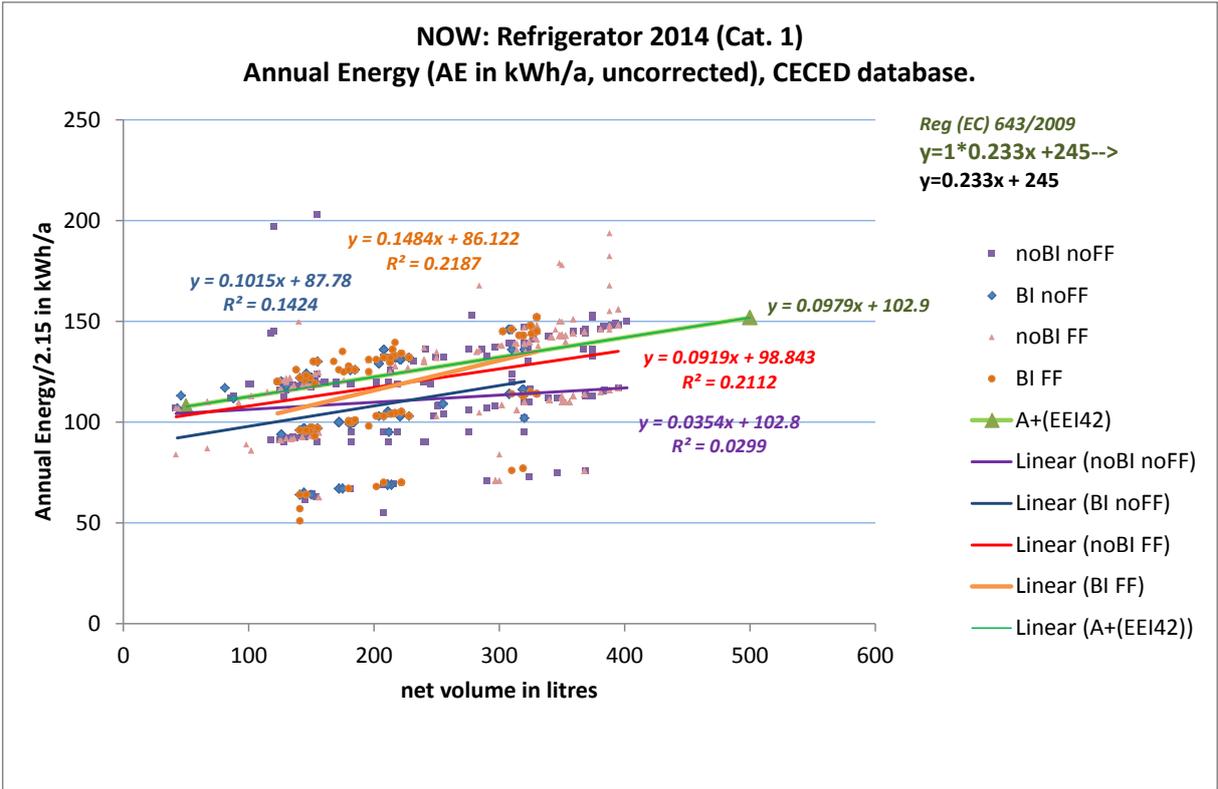


Figure 22. Refrigerator (category 1), regression of energy consumption in 2014 CECED database

¹⁰⁷ To ensure that $r_{c,old} * M_{old} = r_{c,new} * M_{new}$. With the new ambient temperature $T_a = 24\text{ }^\circ\text{C}$ the r_c value of all non-fresh food compartments will change, e.g. for a freezer it becomes 2.1 instead of 2.15.

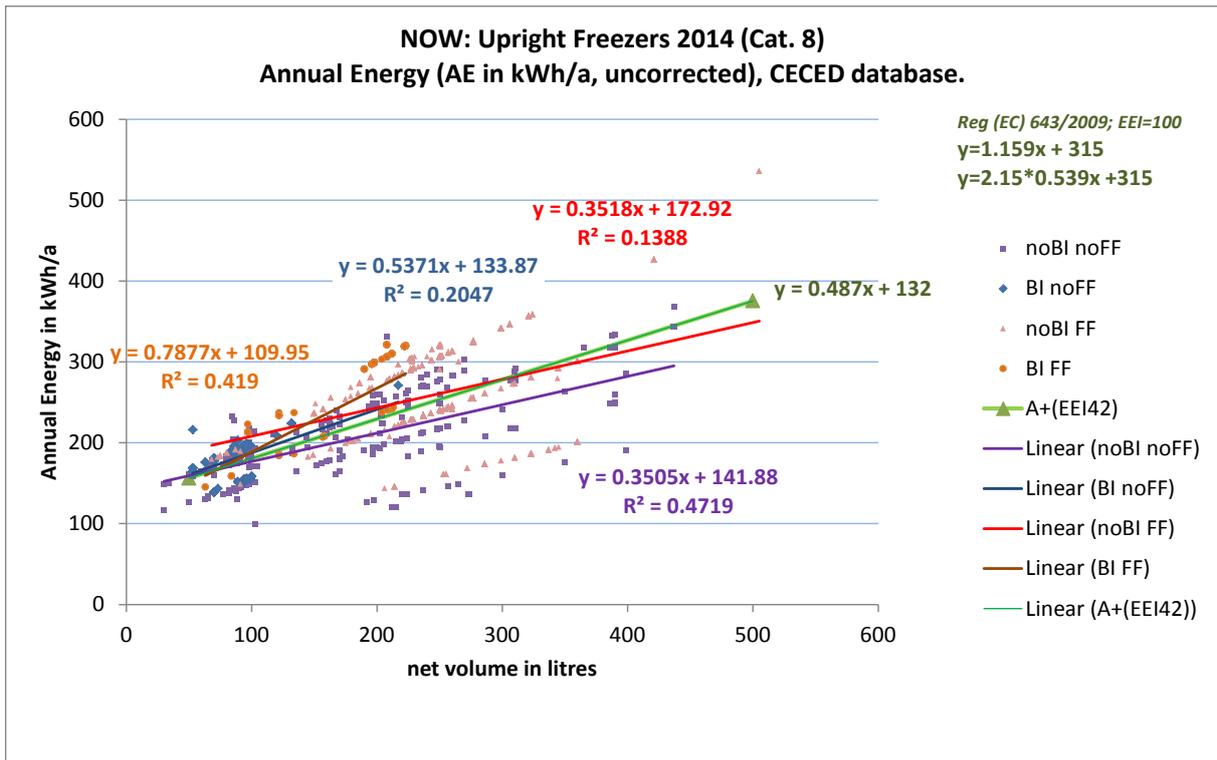


Figure 23. Upright freezer (category 8), regression of energy consumption in 2014 CECED database

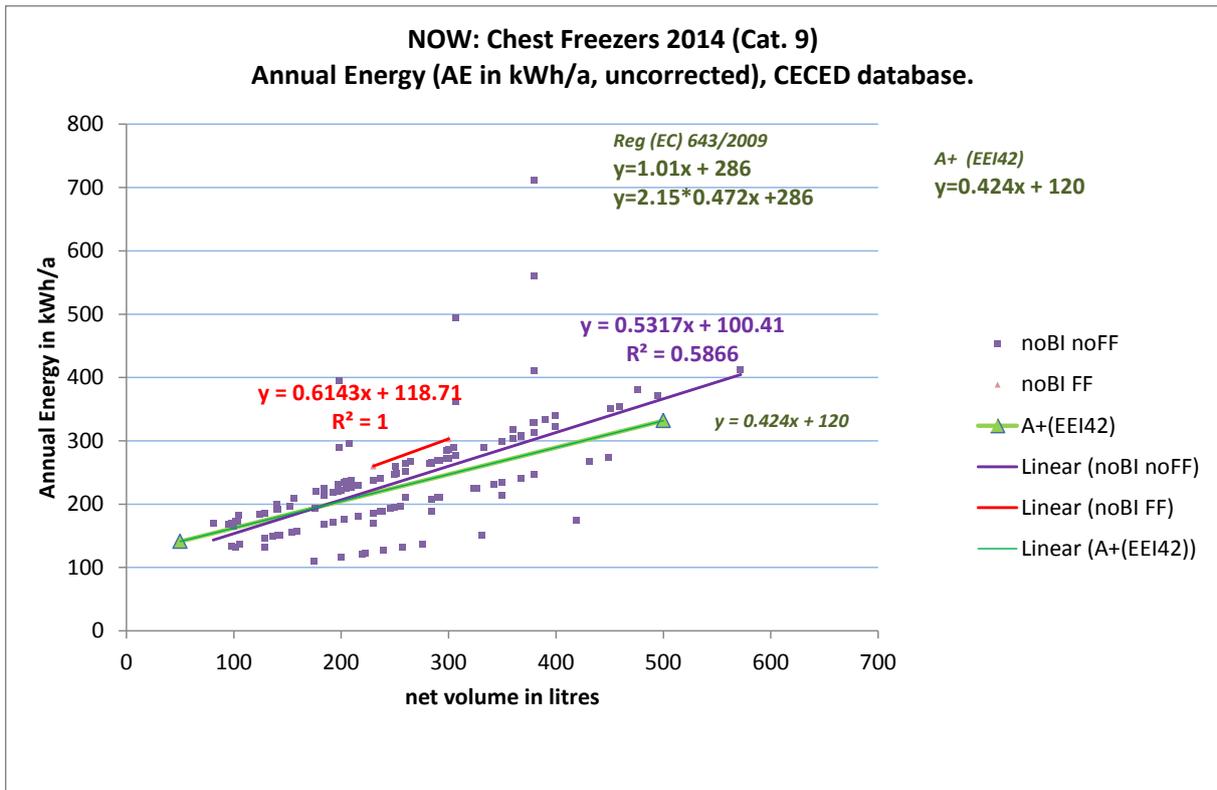


Figure 24. Chest freezer (category 9), regression of energy consumption in 2014 CECED database

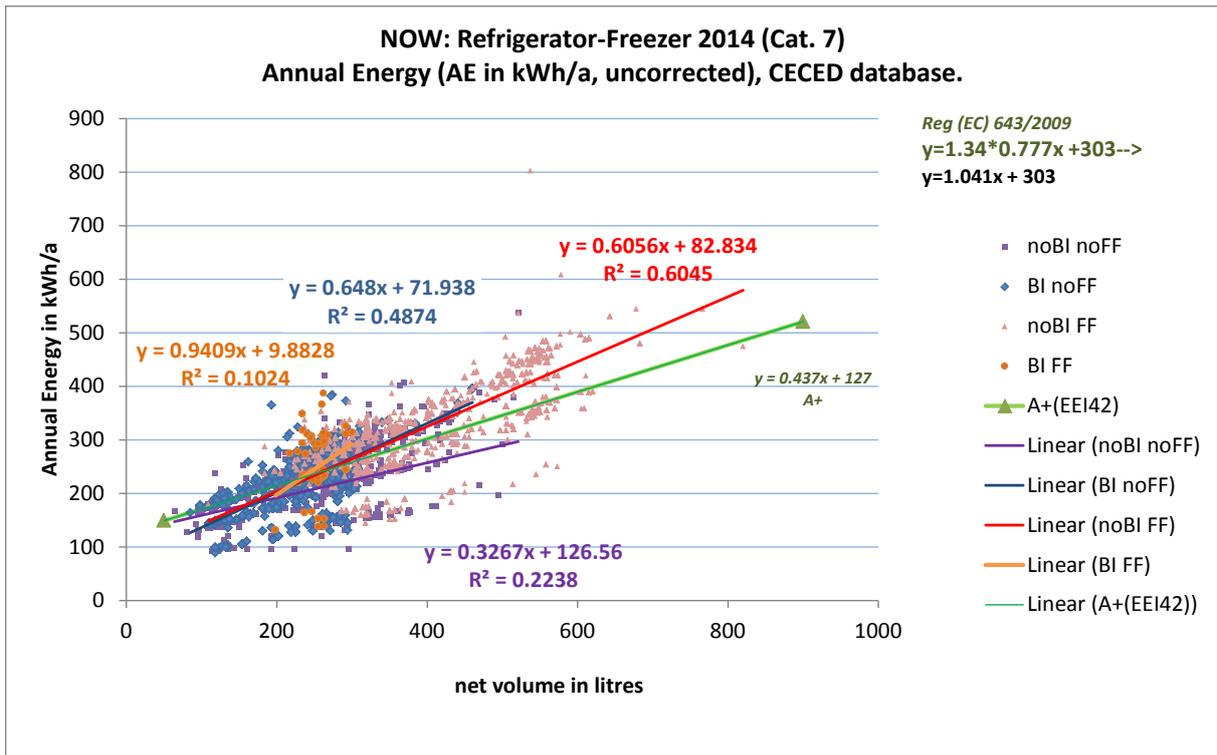


Figure 25. Refrigerator-freezer, all types (category 7), regression of energy consumption in 2014 CECEC database

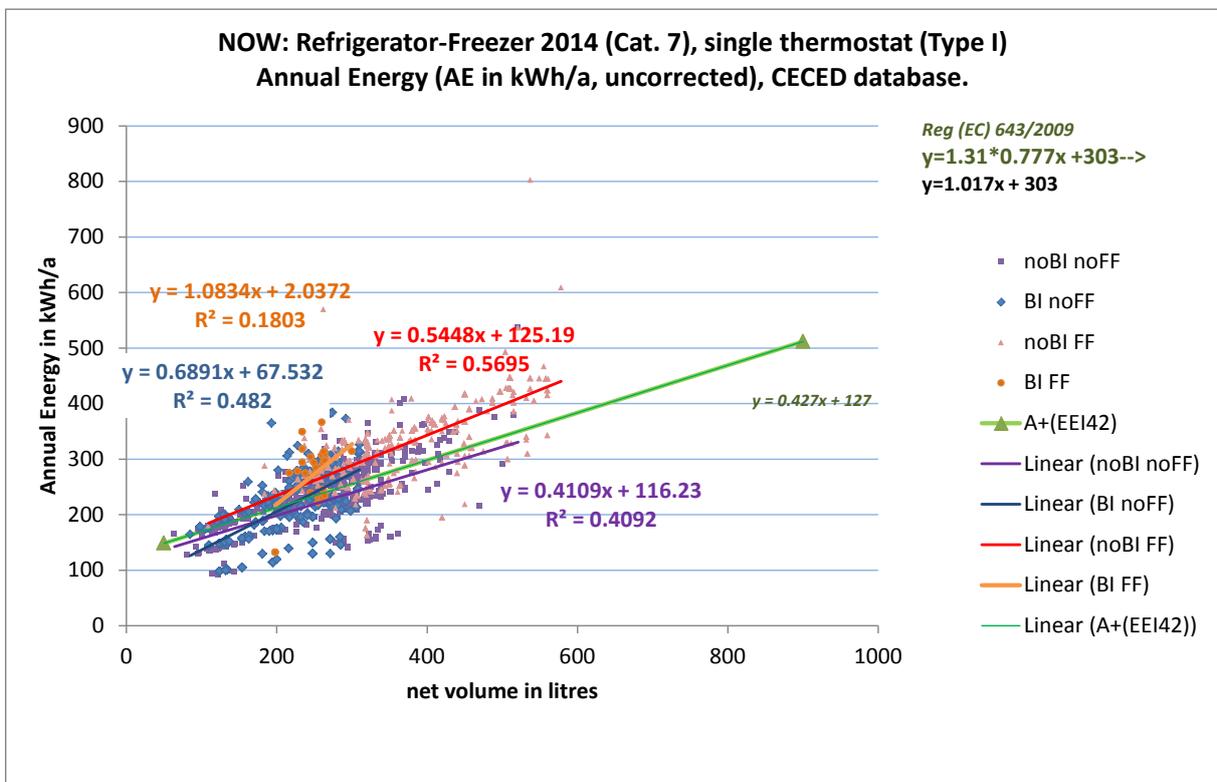


Figure 26. Refrigerator-freezer, all types (category 7), regression of energy consumption in 2014 CECEC database

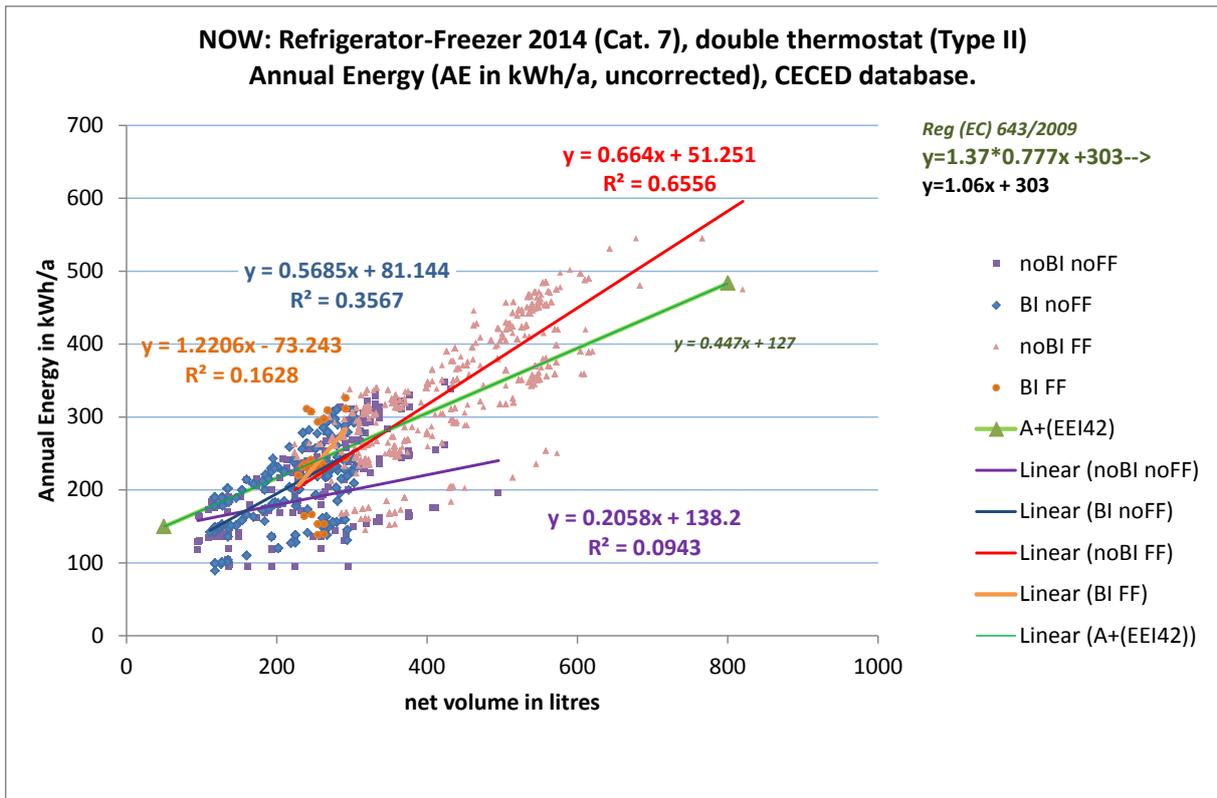


Figure 27. Refrigerator-freezer, Type II (category 7), regression of energy consumption in 2014 CECED database.

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

Category	No.	FF	BI	popul.	linear trend	r _c	Vgros	Vnet	Vfrz	Vother	Vfridge	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 (all)	8	n	n	3726	0.326x+126	1.28	289	275	71	1	203	216	6%	0.346	134	1.28	0.344	134
	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) single thermostat	13	n	n	2329	0.408x+112	1.29	288	276	73	2	202	229	10%	0.449	123	1.30	0.447	123
	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) double thermostat	18	n	n	1398	0.214x+134	1.27	284	274	69	1	204	194	3%	0.220	138	1.28	0.219	138
	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).

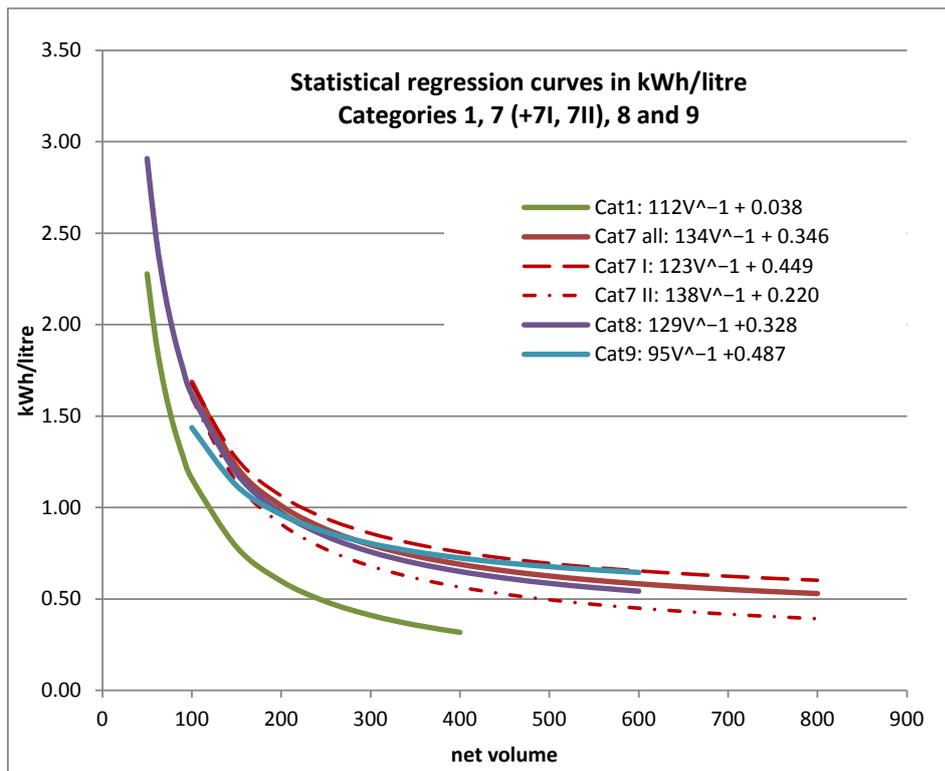


Figure 28. Statistical regression curves in kWh/litre for categories 1, 7, 8 and 9

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.

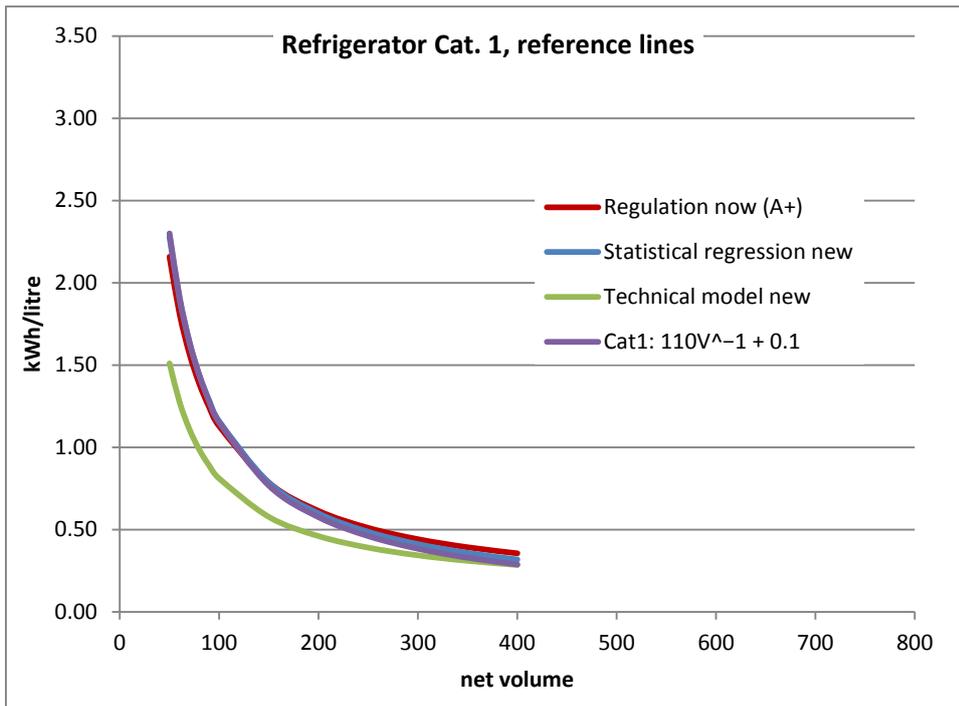


Figure 29. Refrigerator category 1, reference lines.

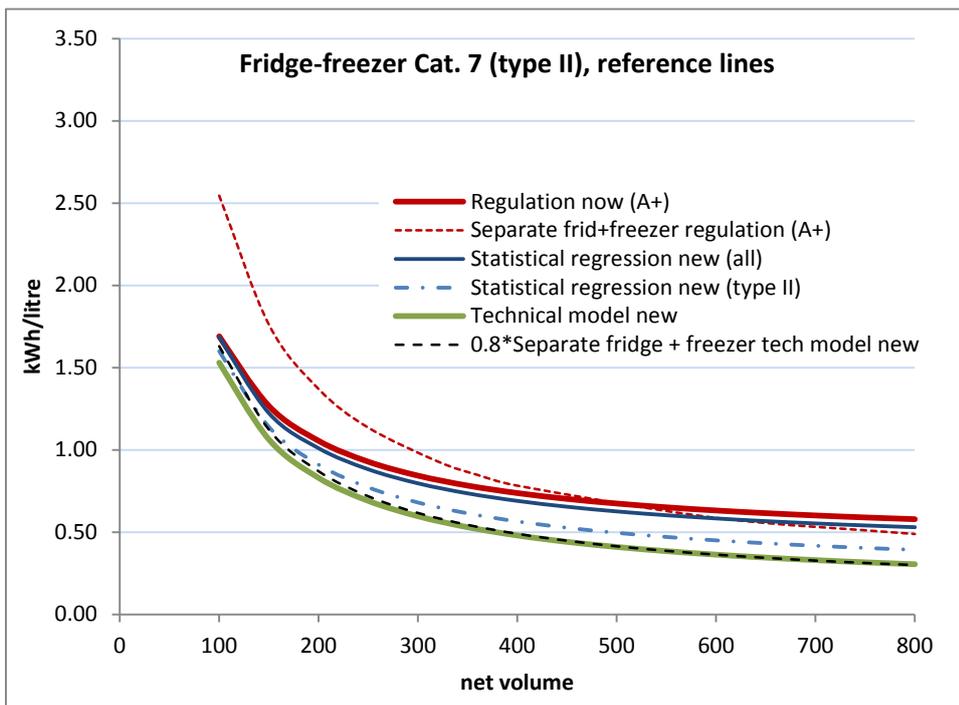


Figure 30. Refrigerator-freezer category 7, reference lines.

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).

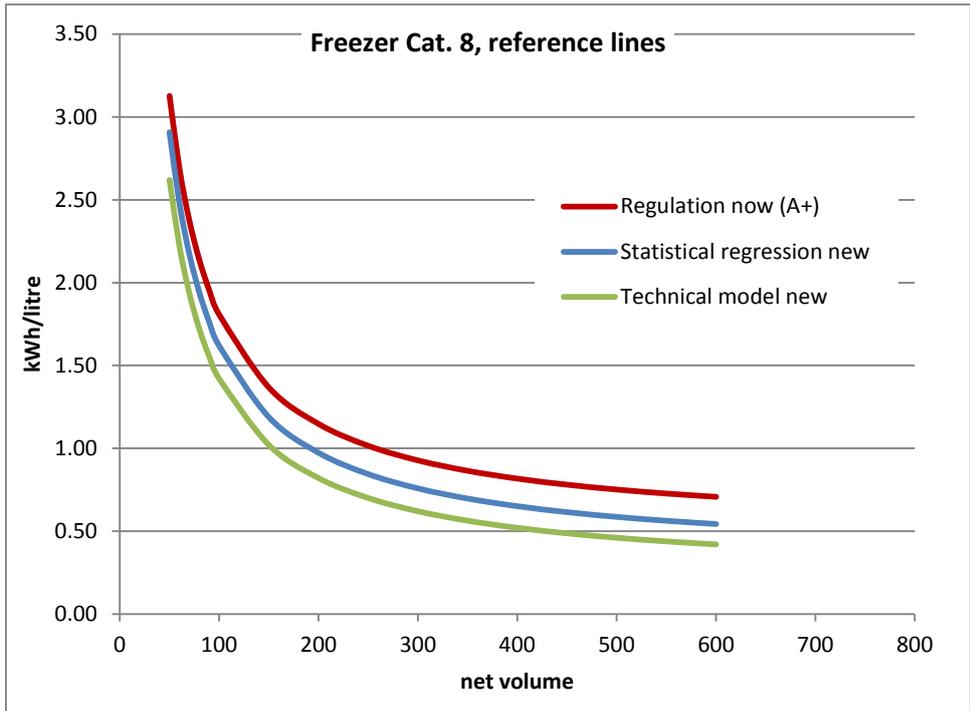


Figure 31. Upright Freezer category 8, reference lines.

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.

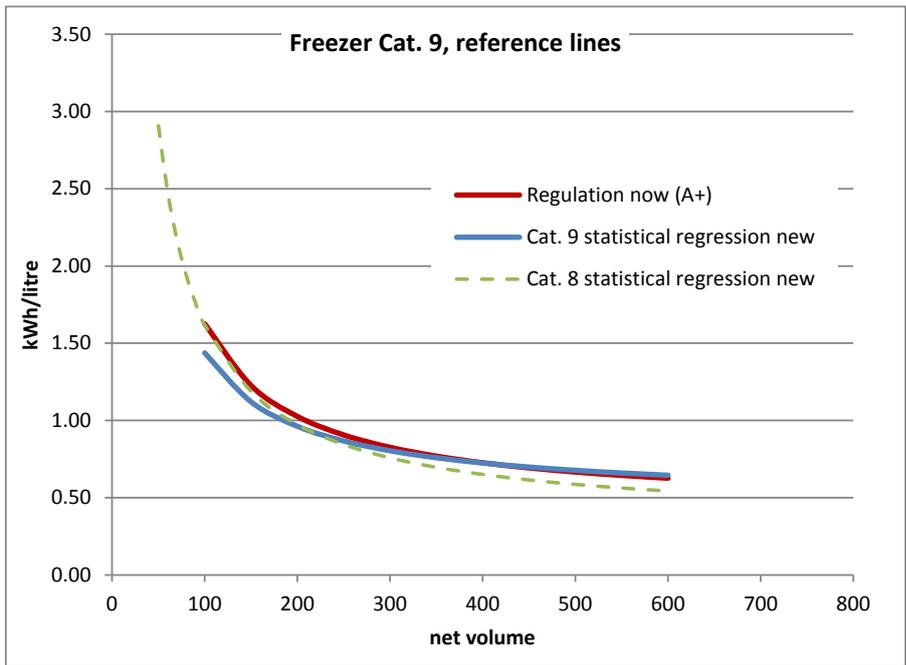


Figure 32. Chest Freezer category 9, reference lines.

8.2.3 No-Frost

The CECEC 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 be 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 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 .¹⁰⁸ 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.¹⁰⁹ 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 $EEI=AE/(V_{eq}\cdot M+N)$. In case of a refrigerator, with $V_{eq}=r\cdot V$, the index $EEI=AE/(r\cdot V\cdot M+N)$. 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 $EEI=(V\cdot q)/(r\cdot V\cdot M+N)$. For the baseline with $EEI=1$ the equation becomes $V\cdot q= r\cdot V\cdot M+N$ and thus $q=(r\cdot V\cdot M+N)/V$. 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. lumen/ W_{in} , W_{out}/W_{in} , $Wh_{in}/cycle$, etc.. More conventionally, given that the multiplier and variable V go first, the expression is $q=N/V+rM$ or $q=NV^{-1}+rM$.

¹⁰⁸ And a possible correction for the chiller CH.

¹⁰⁹ 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; $M=0.098$, $N=103$).

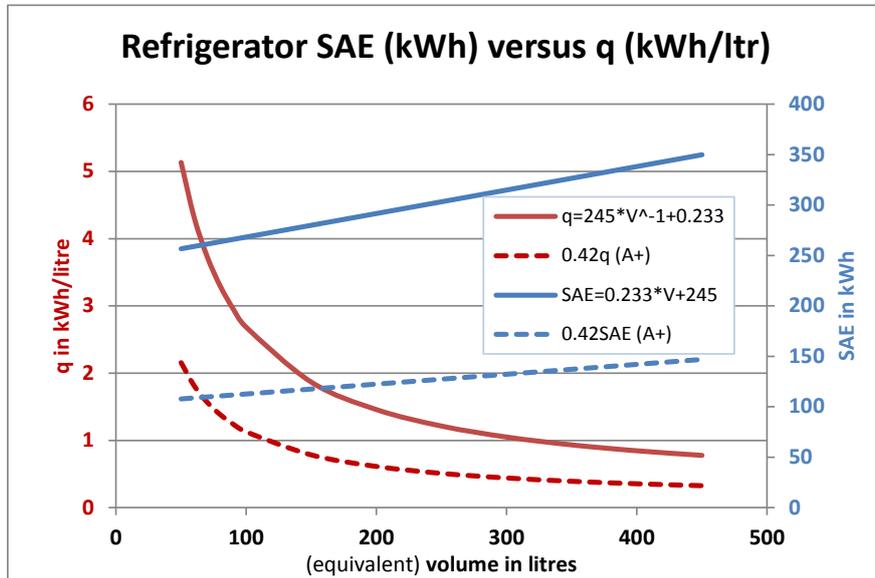


Figure 33. Standard Annual Energy (kWh) versus specific energy q (kWh/litre) for $EEI = 1$ and $EEI=0.42$ (A+) in the current legislation.

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 $q \leq 103 \cdot V^{-1} + 0.098$ 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, $T_c=-18^\circ\text{C}$; $M=0.539$, $N=315$) 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 $q \leq 132V^{-1} + 0.487$. For a similar chest freezer (Cat. 9; $M=0.472$, $N=286$) the limit at A+ is $q \leq 120V^{-1} + 0.426$.

In case of a fridge-freezer (Category 7, $M=0.777$, $N=303$), assuming actual freezer volume to be 25% of the total¹¹⁰ and thus $V_{eq}=0.25 \cdot 2.15 + 0.75 \cdot 1=1.29$, 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 $q \leq 127 \cdot V^{-1} + 0.420$.

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).

¹¹⁰ Average of the 2014 CECEd database is 25.8%.

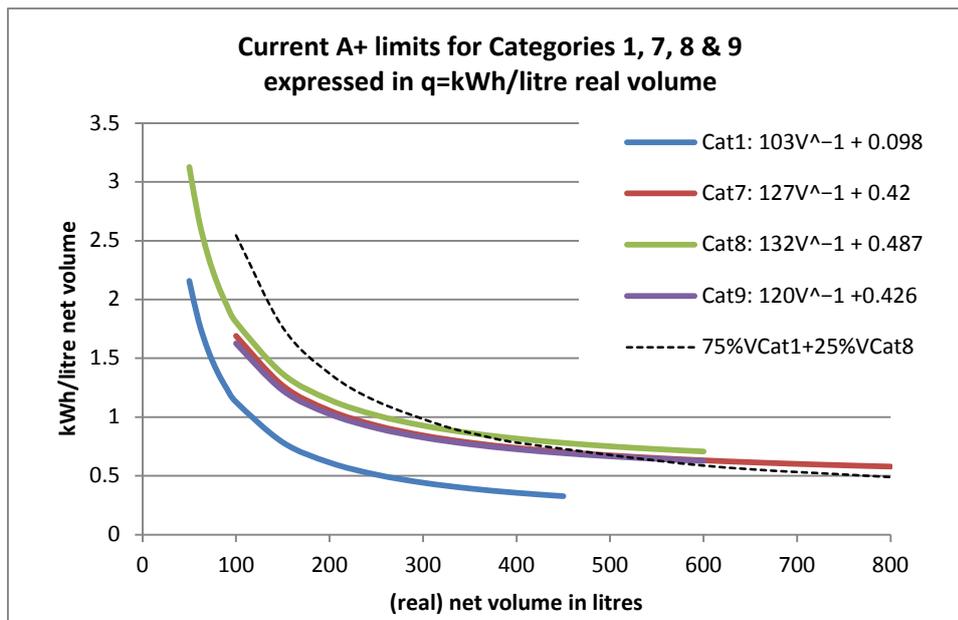


Figure 34. Overview of the A+ curves in kWh/litre for categories 1, 7, 8 and 9.

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, $r=2.15$, $T_c=-18\text{ °C}$) 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 m^3 (1000 dm^3), 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 m^2 (100 dm^2), 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 m^2), and the wall thickness t in m (10 dm). The transmission heat transfer coefficient U , in $\text{W/m}^2\text{K}$, 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.

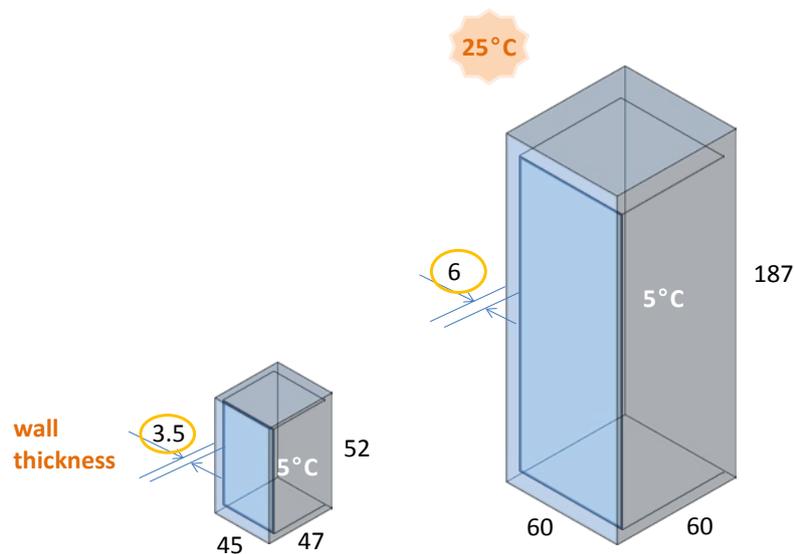


Figure 35. Smallest and largest refrigerators (Cat. 1) in CECED data base.

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.

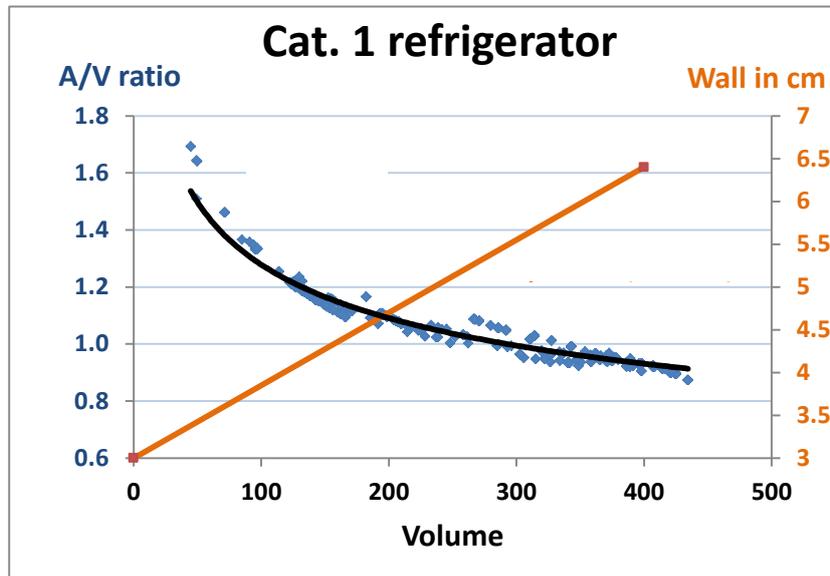


Figure 36. Calculated AV ratio and wall thickness versus net volume of a refrigerator (Category 1). Wall thickness is illustrative only (see Chapter 11)

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

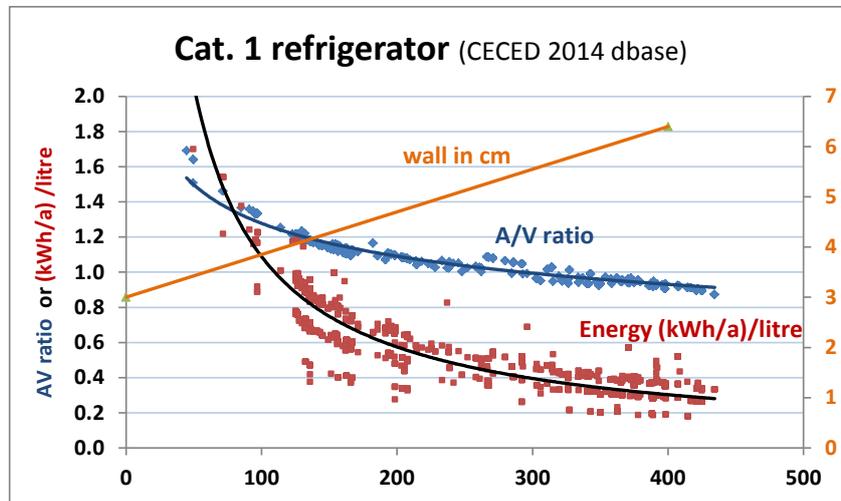


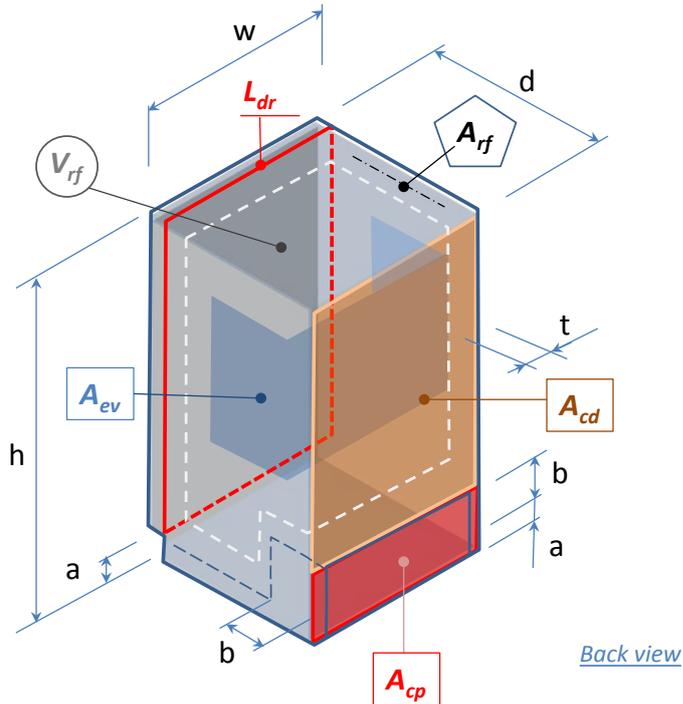
Figure 37. AV ratio, wall thickness (cm) and energy (kWh/a) per litre net volume

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 $b \times b \times w$. 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 $a \times w \times d$, 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.¹¹¹ 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 below¹¹²:

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

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

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

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

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

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.

¹¹¹ Guadalupe Huelsz et al., Evaluation of refrigerator/freezer gaskets thermal loads, HVAC&R Research, 17(2):133–143, 2011.

¹¹² CECED indicates that in the V_{rf} equation the term $b^2 \cdot w$ should be replaced by $b^2 \cdot (w-2t)$ and in the A_{rf} formula $(b+0.5t)^2$ should be replaced by b^2 . These changes, as well as other changes proposed by CECED on the technical model are well documented in the CECED reports, but have not been accommodated in the technical model. This is no value judgement on the proposals, but it is believed that they should be discussed with the metric, which will influence limit values, as a whole after the review study.

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 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.

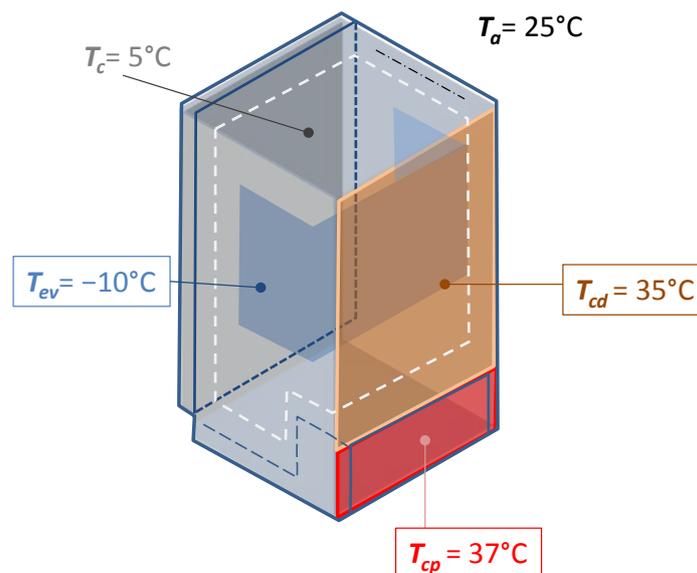


Figure 39. Basic refrigerator temperature map (illustrative)

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 (70/30% of area)	W/(m ² .K)	glass+frame
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'¹¹³) 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..

¹¹³ 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 ASHRAE¹¹⁴ LBP¹¹⁵ 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/CECOMAF¹¹⁶ standard conditions at -25 °C and +55 °C. Also there are COP test conditions from AHAM¹¹⁷ 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. 7¹¹⁸) 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.

¹¹⁴ ANSI/ASHRAE Standard 23-2005 'Methods of Testing for Rating Positive Displacement Refrigerant Compressors and Condensing Units'. (US standard)

¹¹⁵ LBP=Low Back Pressure

¹¹⁶ 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).

¹¹⁷ AHAM=Association of Home Appliance Manufacturers (US).

¹¹⁸ 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 $-25/+55\text{ °C}$ (T_{ev}/T_{cd} , CECOMAF) that can reach a COP of almost 3.4 at $-10/+35\text{ °C}$, which is a temperature pair typical of a refrigerator.¹¹⁹

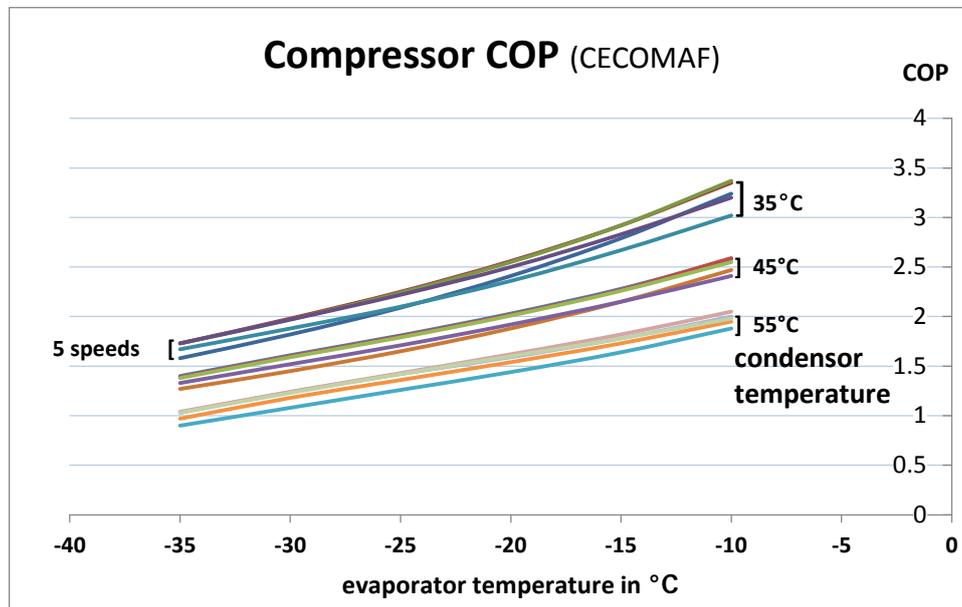


Figure 40. COP curves of low back pressure hermetic compressor EMBRACO VEM X7C at different speeds (1200/1600/2000/3000/4500 rpm), evaporator and condenser temperatures.

Note: COP ranges from 0.9 at 1200 rpm, $-35/+55\text{ °C}$ (cooling power 15 W) to 3.4 at 2000 rpm, $-10/+35\text{ °C}$ (cooling power 168 W). Maximum cooling power is 377 W at 4500 rpm, $-10/+35\text{ °C}$ and an electric power consumption of 147 W. Note that the VEM is an efficient compressor but not the latest generation.¹²⁰

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 optimisations¹²¹. For instance, the COP_{Carnot} at $-25/+55\text{ °C}$ is 3.21 and the COP_{Carnot} at $-10/+35\text{ °C}$ 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 2.¹²²

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 ($54.4-32.2=22.2\text{ K}$). 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.

¹¹⁹ 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.

¹²⁰ E.g. the EMBRACO EMD32 has a claimed COP above 2 at ASHRAE conditions.

¹²¹ E.g. ambient and suction temperatures, capacity setting (mass/volume flow rate), etc.

¹²² 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. 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 T_{cd} and T_{ev} and realistic cycle conditions (sub-cooling 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 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 freezers ($T_{ev} = -30$ °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.

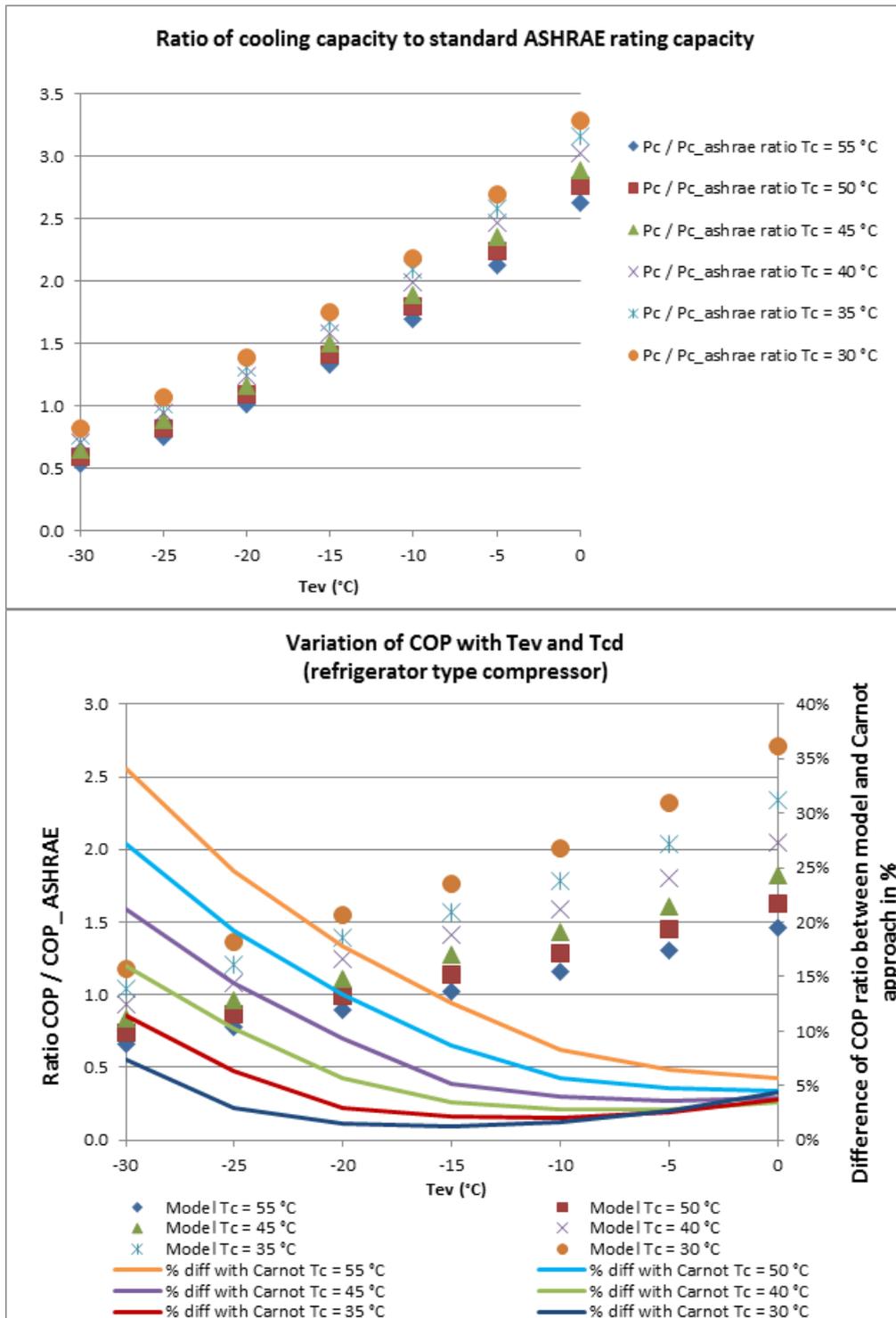


Figure 41. Model of relative capacity (a) and COP (b) as compared to ASHRAE standard rating conditions with varying T_{ev} and T_{cd} and comparison with Carnot COP.

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 T_{ev} and T_{cd} (in W)

The reference cycling study for refrigerators¹²³ 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 findings¹²⁴ 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 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.¹²⁵

¹²³ Coulter, W. H. and Bullard, C. W., An Experimental Analysis of Cycling Losses in Domestic Refrigerator-Freezers, ACRC TR-77, June 1995.

¹²⁴ Björk, E., Energy Efficiency Improvements in Household Refrigeration Cooling Systems, Doctoral Thesis, 2012.

¹²⁵ 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).

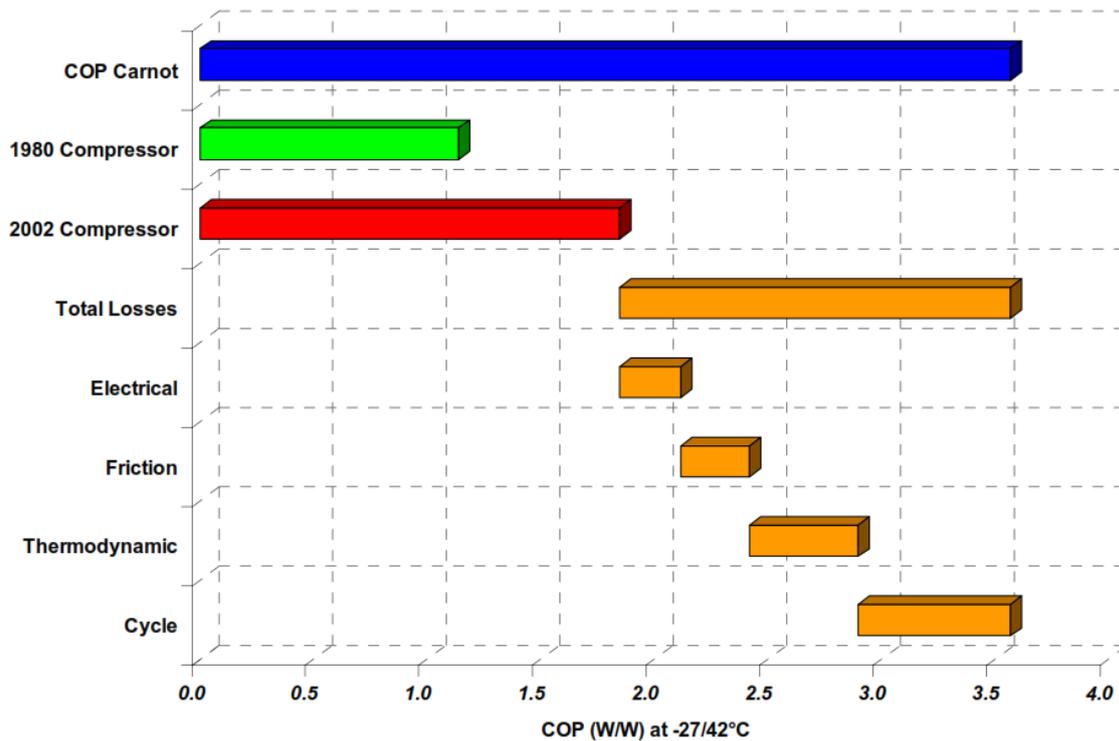


Figure 42. Efficiency of hermetic compressors (source: Possamai et al.¹²⁶)

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 m^2] and heat transfer coefficient of the heat exchanger U_{HE} [in W/m^2K] 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

¹²⁶ 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/m².K^{124,127} and decreases with increasing evaporating temperature. For freezer operating conditions, this value lies between 5 and 6 W/m².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 correlation¹²⁸ and optimal design parameters¹²⁹ have been used to assess the maximum heat exchange coefficient. U_{CD} is estimated to vary between 23 W/m².K and 29 W/m².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 m³/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.

¹²⁷ Fantini, M., Innovative techniques to reduce energy consumption of household refrigerators, M. Sc. Thesis, 2013.

¹²⁸ 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.

¹²⁹ 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.

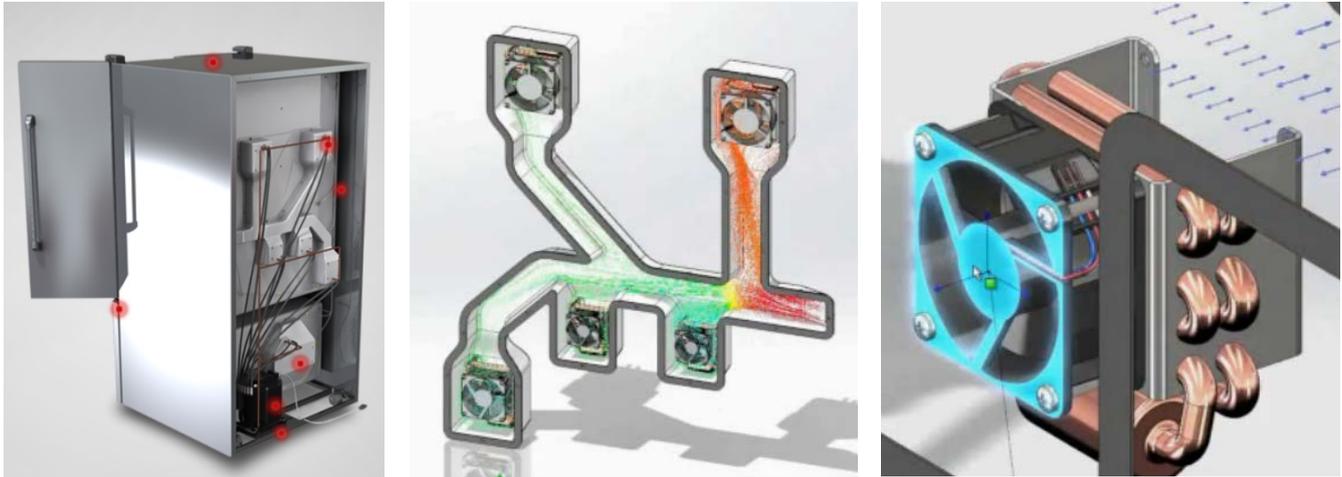


Figure 43. Frost free multi-duct fridge-freezer, using 5 fans and local finned coil evaporator heat exchangers (demonstration computer-model Solidworks¹³⁰).

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, 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

¹³⁰ 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 ($T_c = -18\text{ °C}$ and small volume) and the refrigerator space ($T_c = +4\text{ °C}$ and large volume).

- In practice, 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 most (smaller) combi-appliances is the regulation with a single compressor and solenoid valves that allow consecutive regulation of the loops. At the moment this solution involves alternating between a freezer-only loop and a freezer+refrigerator loop, which is still some sort of a compromise with respect to the two compressor solution, but it has the (often bigger) advantage of being able to use a more efficient big compressor instead of two inefficient small ones. 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} values¹³¹, 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.¹³²

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.

¹³¹ Ignoring specific industry values in this case.

¹³² Extra length of door perimeter is $2*w$. Volume lost is $(w-2t)*(d-2t)*t$. Extra heat loss from freezer to fridge ($\Delta T=23$) through the shared wall is modelled as extra envelope surface $(w-t)*(d-t)$, implicitly at $T_c=-1^\circ\text{C}$.

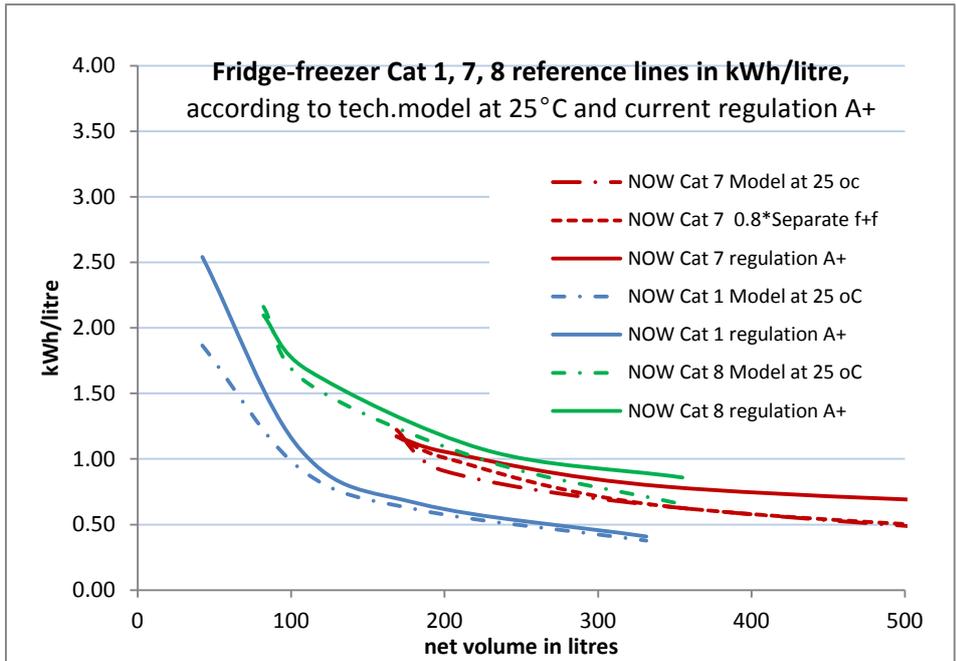


Figure 44. Reference lines from technical modelling (dot-dash line) versus the reference lines at A+ (EEl = 0.42) according to the current regulation. ¹³³

¹³³ 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 ² K)	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				
COP_{cyc}	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				
E_{aux}	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 $q\text{-A+}= 103/V + 0.098$.

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 $q\text{-A+}= 132/V + 2.15*0.487$ (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 $V_c=73\%$, $r_c=1$) and freezer ($V_c=27\%$, $r_c=2.15$) 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 current regulation uses $q\text{-A+}= 127/V + 0.42$ 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.¹³⁴ 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.¹³⁵

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).

¹³⁴ CECED calculates 11.9% higher. For combi and freezer the CECED numbers are comparable.

¹³⁵ For the calculation of individual M and N values the r_c value of freezers becomes 2.1 instead of 2.15 (2% lower). This, however, does not influence the r_c*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 the EU, with f-factor 0.5 the overall compensation from these numbers would be around 30 kWh/year. The average freezer compartment in a combi is around 70-100 litres. If it were a standalone freezer it would have an average energy use of approximately 150 kWh/year; in a combi it would be lower because of the combi-effect and 30 kWh would anyway add 20-25%. In a stand-alone freezer, which is a smaller market than the combi also in terms of freezer volume, the 30 kWh compensation would add 10-15%.

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 of e.g. 1.15. The statistical analysis in Chapter 8 suggests that a factor 1.2 would be more appropriate. This is definitely a subject for review in a few years when more data is available.

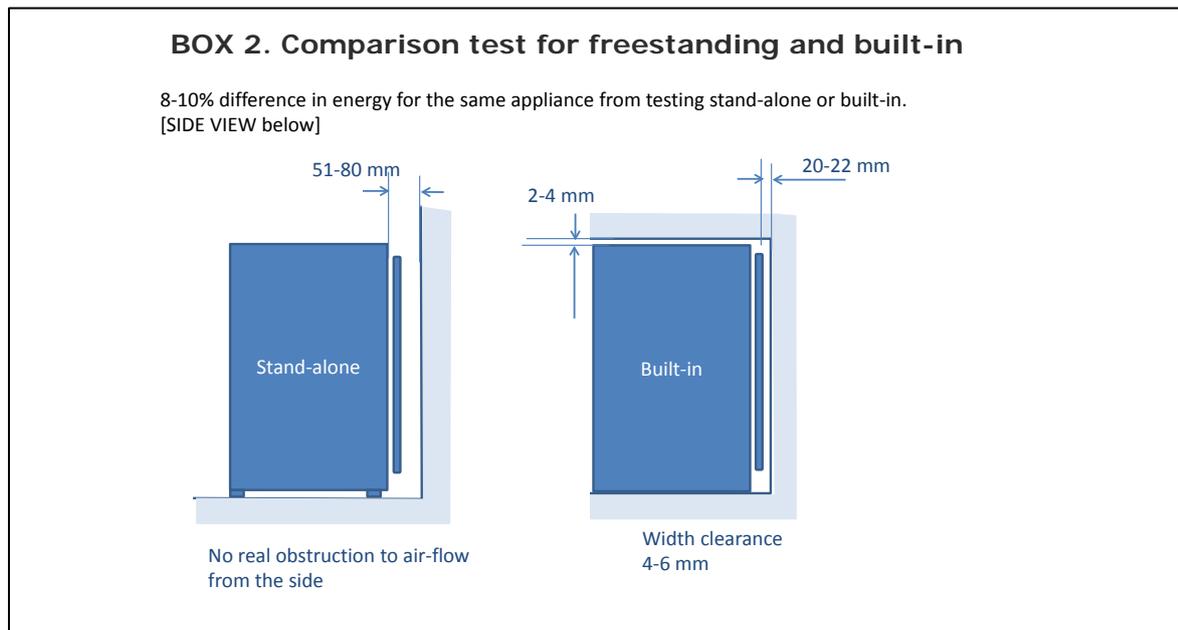
In reaction, Germany (UBA/BAM) agrees to a need for an auto-defrost compensation because of icing of the compartment, and the higher energy consumption that goes with it, are not part of the standard test. Other parties in the stakeholder meetings acknowledge the convenience benefit for the consumer.

ECOS/TopTen oppose defrosting compensation, but if it is deemed indispensable, then it should at least be reflected on the energy label. The annual extra energy consumption due to no-frost should be indicated on the label (as it is supposed to be measured under the new measurement standard). CLASP is also against and says that [an auto-defrost correction] 'could only be justified if proportional savings are demonstrated in real-life conditions. We could however not find sufficient data to defend this option.'

In that latter context it must be mentioned that also the study team did not find statistical data on frequency of manual defrosting in the EU-practice. As to the impact of not defrosting in time, there are several consumer sites that –without giving background information- mention a 30% higher energy consumption at an ice-layer of 5 mm. Also the ice-layer in the freezer might lead to early failure of temperature sensors.

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 $+2^\circ\text{C}$). 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.



In a reaction, Germany (UBA/BAM) could agree with a built-in factor to compensate for differences in testing. ECOS/Topten did not want any compensation factors, so also not for built-in. CLASP agrees with ECOS/Topten because the consumer should be made aware that "these [built-in] appliances consume more than their stand-alone counterparts."

9.3.9 Compensation for chiller

At the moment, for refrigeration appliances with a chiller volume of at least 15°C , there is a compensation of 50 kWh/year (currently 21 kWh/year at A+ level, 16 kWh/year at A++ level). This compensation/bonus comes on top of the temperature compensation r_c of 1.25 (25%) at a chiller target temperature T_c of 0°C , compared to a fresh food temperature of 5°C at 25°C ambient.

In the new IEC standard, the target temperature for a chiller has been raised to $+2^\circ\text{C}$ compared to the current EN-standard. At the same time, the difference between minimum and maximum instantaneous temperatures for the chiller compartment during the test, currently between -2°C and $+3^\circ\text{C}$, have been widened to -3°C and $+3^\circ\text{C}$. The fresh food temperature is now set at 4°C , which means that the temperature compensation r_c at a chiller target temperature T_c of $+2^\circ\text{C}$, compared to a fresh food temperature of 4°C at 24°C ambient, now becomes only 1.1 (10%).

The historical reasons for today's chiller compensation/bonus could not be traced. Also the reasons for the changed values in the new IEC standard are not given.

In its note (Annex H) CECED is giving technical and environmental reasons why the compensation/bonus for the chiller compartment should be maintained in their opinion. The environmental justification, longer preservation of especially meat and fish (much more environmental impact than e.g. salad), seems justified and backed by the research results. The only problem here is that the stakeholders that should be the first to promote this option, e.g. the environmental NGOs, are opposed to chiller bonus or rather, as UBA/BAM indicates, more detail would be needed (in the impact assessment study).

CECED's technical justification seems to be tuned to the situation with the new IEC standard, where the target temperature is +2°C whereas the upper instantaneous limit is +3°C. For optimal result this means that the temperature fluctuation, assuming symmetry around the average, must be within ± 1 K. This is indeed stringent. However, at the current target temperature of 0°C (best for meat/fish) and the permitted fluctuation of ± 3 K (instantaneous values) we are not far from what a good refrigerator can realise (± 4 K average values). In fact, from a cursory inspection of chiller-(sub)compartments in A++-models at hand there are solutions with no special fan or even temperature sensor; it appears enough to add an extra 2 cm insulation to the chiller part and probably some extra capacity of the evaporator/compressor.

There is no easy solution to the problem. Re-introducing a chiller bonus of e.g. 16 kWh is at the moment not supported by non-industry stakeholders and does not contribute to simplicity of the measure. Applying the N and M values of the freezer, i.e. effectively setting (as is the case with r_c) the limit between freezer and fresh food for the N and M factor at 2°C might be a non-obtrusive solution, but might result in overcompensation and industry-claims of the whole refrigerator being a chiller. Keeping the target temperature at 0°C, and thus a temperature compensation of 1.2 instead of 1.1, is another possibility that also makes sense from a point of view of avoiding foodwaste (0°C is optimal for meat and fish) but it would mean that the EU is no longer in line with the new IEC-standard and might be problematic from a WTO point of view. For that reason it might be an option to create an extra compartment-type, i.e. a 0°C chiller with also ± 3 K allowable deviation.

The issue needs to be further investigated in the impact assessment, possibly with more research on both the technical and environmental issues, before a final decision is made. For the moment we will use the fourth option, i.e. to create an extra 0°C chiller option, in our preliminary proposal.

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 ($T_c=0$ °C), the extra door losses add 3% to the total energy use of a large appliance¹³⁶, 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 ($T_c=12$ °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

¹³⁶ At constant external volume

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 with a solid door behave like a normal refrigerator, but with a $T_c=12$ °C instead of $T_c=4$ °C (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.

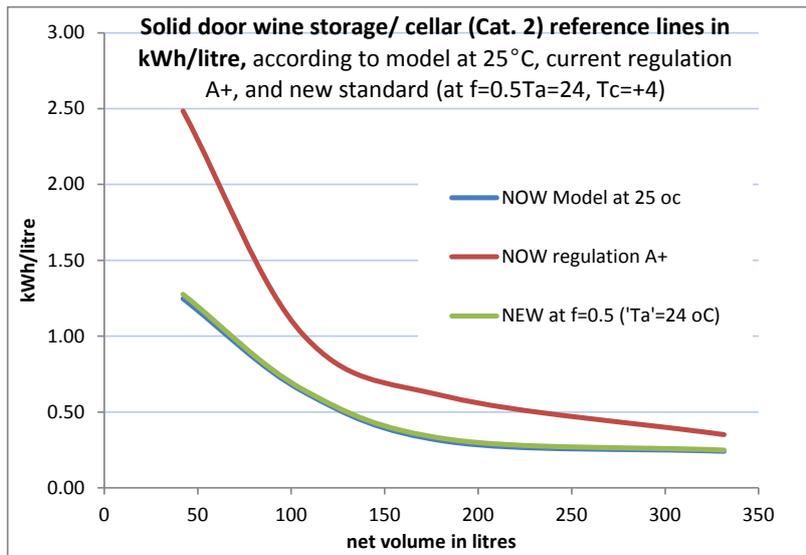


Figure 45. Solid door category 2 reference lines according to the technical model at 25 °C, current regulation A+ and the new standard at $T_a=24$ °C.

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.

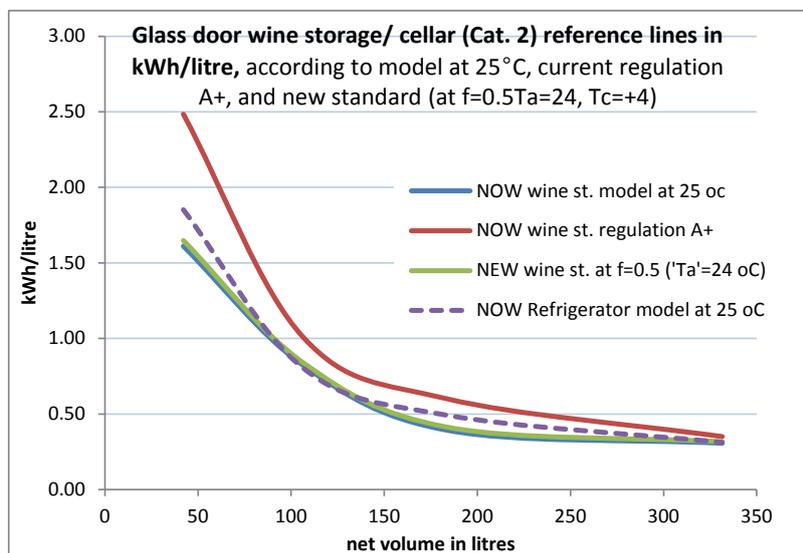


Figure 46. Glass door category 2 glass door reference lines according to the technical model at 25 °C, current regulation A+ and the new standard at $T_a=24$ °C.

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.

The reaction of most stakeholders, including NGOs, was that a glass door compensation factor of 1.2 can be considered in the Ecodesign requirements but not in the energy label rating. The Netherlands did not think it is a good idea to decouple Ecodesign and Energy Label and suggested that another way should be found, e.g. staged introduction of limits for wine storage appliances (more lenient). The latter is also supported by several NGOs (see Annex H)

9.4 Preliminary proposal for the metric

9.4.1 Introduction

The modality of the new metric has been a major topic of debate throughout the study and especially before, during and after the 2nd stakeholder meeting and 2nd interim report. It is a debate that will not be concluded within the time-frame of this review study but several major steps forward have been made.

As mentioned in the previous paragraphs, there appears to be a fair amount of consensus on compensation factors eliminating the current climate correction, giving a minimum compensation due to different testing with built-in appliances (factor ' B_c '), maintaining auto-defrost compensation for freezer compartments (factor ' A_c '), introducing a multi-door compensation (factor ' D ') that at least does not penalise the placing on the market of multi-door combi-appliances with high temperature compartments. Also there seem to be converging positions on a glass-door compensation for high temperature (wine) storage ($T_c \geq 12$) in the ecodesign measures, albeit not in the energy label.

Having said that, some environmental NGOs (ECOS, TopTen) are against any compensation factor for energy label rating, because they believe that it will misinform the consumer about the true electricity consumption, and other environmental NGOs want them to be lower (e.g. CLASP with regard the value of 1.2 for A_c). On the other hand, the industry is strongly advocating to maintain/re-introduce a compensation for the chiller compartment (temperature between -2 and +3°C), currently known as ' CH '.

For reasons of simplification and promoting flexibility in design, the review study tabled the concept of abandoning the current fixed appliance-categories in favour of a concept that would favour the combination of any type of compartments and would merely leave two sets of N and M coefficients. This is a major change and thus far no stakeholders objected to this new approach that would again promote incorporating high temperature compartments in combi-appliances, thus leading to energy saving and better food preservation (less food waste).

Nonetheless, there is continued concern with non-industry stakeholders that a new metric will not be stringent enough for large appliances, whereas industry —though in general agreeing with the principle—is providing arguments to keep the change to a minimum. All stakeholders seem content to pursue the discussion on the basis of the technical analysis/model and not (only) adhere to statistical curve-fitting.

In other words, there is still quite a challenge —both technically and politically—to realise the new, more flexible approach in an appropriate metric. In the 2nd interim report the study team made a first preliminary proposal.

The proposal was based on the notion that –contrary to what some stakeholders believe—the current metric, that appears linear (format $y=x$) when energy consumption is expressed ‘per appliance’, is in fact non-linear (format $y=1/x$, i.e. exponential) when expressed in the functional performance unit, i.e. per litre net volume of a certain temperature. This is demonstrated throughout this whole chapter 9, using not the current reference parameter SAE (in kWh/year per appliance) but the parameter q_{ref} (in kWh/year per litre). The latter parameter clearly reveals to be more stringent for large appliances than for small appliances and –in principle and after tweaking of the coefficients—could be used also in the new metric. This would be much less disruptive for all actors (industry, surveillance authorities, etc.) that are working with the current metric.

In that context it must also be noted that stakeholders were less than enthusiastic about the new notation in q_{ref} [kWh/ltr per year] and prefer to return to the familiar, equivalent formula with SAE [kWh/product per year]. In that notation the core formula, without compensation factors and applicable only to appliances with a single compartment (index c), is

$$SAE = N_c + V_c \cdot r_c \cdot M_c \quad [1]$$

where

- N_c, M_c are coefficients that are specific for compartments with a design temperature T_c either above 0°C (preliminary values $N_c = 75$, $M_c = 0.12$) or 0°C and lower (preliminary values $N_c = 100$, $M_c = 0.21$),
- V_c is the net volume of the compartment
- r_c is the equivalent volume coefficient with $r_c = (T_a - T_c)/20$ where T_a is the ambient temperature (now 24°C) and T_c is the design temperature of the compartment (e.g. $r_c = 1$ for a fresh food compartment, $r_c = 2.1$ for a 3 or 4-star frozen food compartment)

CECED is still proposing small changes to the above M and N factors for single appliances to make the SAE-curves steeper, mainly by challenging the relationship between wall thickness and size (net volume), but the biggest problem is still with finding the right metric for combi-appliances (e.g. fridge/freezer).

For the combi-metric there are a number of options that will be elaborated in the following sections.

9.4.2 Option 1: Current solution for combi-appliances

Option 1 is the current solution with a specific M and N factor for combi-appliances (in category 7 and indirectly in a part of category 10) in combination with equivalent volume V_{eq} . This is discussed e.g. in paragraph 5.3 and follows –without compensation factors—the format

$$SAE = M \cdot V_{eq} + N = M \cdot \sum_{c=1}^n V_c \cdot r_c + N$$

This solution looks simple and it has the advantage that market-actors are used to it. The simplicity implies a certain rigidity regarding variation compartment volume and temperature shares. This has obviously been acceptable over the past 20 years, probably mainly because the average combi-appliance is a fridge-freezer (little other compartment types) and there is little spread in the relative volume-share of freezers versus refrigerators. One might wonder if this is still acceptable if there is more variation in the number, relative volume and temperature of compartments.

But the bigger question is what the M and N coefficients should be. These coefficients were conceived on the basis of statistical curve-fitting 20 years ago when the combi-market mainly consisted of poorly-insulated appliances with smaller volumes and single-thermostat ('Type I') controlled, low-efficiency on-off compressors. This has led to curve which –for a fridge-freezer with a 27% freezer share—to a curve at A++ level (EEI=33) that is close to the energy limit of an upright-freezer (see figure), i.e. with $M=0.256$ and $N=100$ (+6-7% with the new IEC-standard and $F=0.5$). In the meanwhile, the market has moved and is still moving towards better-insulated appliances with higher volumes and double thermostat ('Type II') controlled, higher-efficiency variable speed compressors. Moreover the decision basis should be a technical analysis, with most stakeholders believing that the limits should be more stringent for larger appliances (meaning a significantly lower M value).

9.4.3 Option 2: Sum of individual compartments

A new solution, proposed in the 2nd interim-report, is to derive the energy limit of the combi from the limit-curves of the single compartments. The rationale is that a 'combi-limit' for fridge-freezer should be 'somewhere in between' the limits for single-appliances. In extreme (theoretical) cases a 'combi' could be a fridge-fridge or freezer-freezer, where the consumer has the possibility of different thermostat-settings between the compartments but where the test-temperatures between the compartments are the same and limits should not be different from those for the single appliances.

The simple approach would be to SUM the energy limits for individual compartments, i.e. a refrigerator with volume V_1 and freezer with volume V_2 , with formula (without $A_c B_c D$ compensation factors):

$$SAE = C \cdot \sum_{c=1}^n (N_c + V_c \cdot r_c \cdot M_c) \quad \text{where } N_c = 0 \text{ if } V_c = 0$$

This formula seems to work for the average 310 litre fridge-freezer combi and requires only a small correction C (0.87) to arrive at values that are in line with the technical model. This *combi-factor* C is necessary because of the scale-effect in compressor-efficiency (COP), whereby the efficiency of the two smaller (lower capacity) individual compartment compressors is significantly worse than the efficiency of the larger combi-compressor. Furthermore, the compartments in a combi have a shared wall, which means that the average 'ambient' temperature and thus the heat load of each compartment is lower than in the individual smaller compartments.

However, because of especially the scale-effect of the compressors, the curve is not realistic when applied over the whole volume range of the combi (see Figure 47) and might create loopholes.

9.4.4 Option 3: Volume weighted average of single full-size compartments

For that reason, an alternative approach was mentioned in the 2nd stakeholder meeting whereby the combi-limit is the VOLUME WEIGHTED AVERAGE of energy limits for each temperature level, i.e. refrigerator with volume V and freezer with volume V , formula (without $A_c B_c D$):

$$SAE = C \cdot \sum_{c=1}^n \left[\left(\frac{V_c}{V} \right) \cdot (N_c + V \cdot r_c \cdot M_c) \right]$$

This formula has the advantage over the previous formula that, it stays in line with the energy limits for the single refrigerator and the single freezer. However, in order to arrive at energy limits that are consistent with the technical model of the average fridge-freezer, a hefty correction factor is needed. CECE arrives, with a best regression, at a factor $C=1.35$ with $M=0.12$ and $N=72$ for the fresh food compartment and $M=0.15$ and $N=138$ for the freezer compartment. The regression analysis with the CECE-modified

technical model (12 models) shows reasonable agreement, with an average error <1% and peak deviation (for the largest combi in cat. 7) of +8.5%.

CECED is concerned that the coefficient 1.35 lacks a good physical meaning and that a combi constructed from e.g. two fresh food compartments (or two freezer compartments) would get a large bonus.

The study team thinks that the latter is relatively easily corrected by a temperature correction which incorporates the temperature-difference between highest and lowest T_c in the combi compared to the temperature-difference in a standard fridge-freezer (+4––18=22 °C). Furthermore, if the same regression error is acceptable as for the CECED formula (-3.6% average) then the basic correction factor could also be $C=1.3$.

The value for C would then be $C=1+0.3\cdot(T_{c,max}-T_{c,min})/22$. This makes the correction factor $C=1$ in case of a fridge or a freezer and $C=1.3$ in case of a fridge-freezer. The temperature correction could apply to only a part of the 0.3 correction, because even two refrigerators with two doors that are able to answer to two different thermostat settings are likely to be more inefficient than a single refrigerator with one door and only having to regulate one temperature. For instance, the formula could be $C=1.15+0.15\cdot(T_{c,max}-T_{c,min})/22$.

Technically, the factor can be explained by a number of issues:

- The formula weighs the efficiency on the basis of volume, e.g. a 27% freezer volume results in 27% of the freezer M and N value. If the weighting would have been done on the basis of the relative heat loads the freezer share would be higher and lead to a lower correction factor. For instance, weighting on the basis of equivalent volume, which is a rough approximation of the heat load, a combi with 27% freezer volume would have 41% of the freezer M and N values in the overall correction. And if the real heat load would have been taken into account, e.g. using the surface area and not the volume, the M and N values of the freezers (higher than the M and N values of the fridge) would even be more dominant. This effect can cause some 10% difference.
- The compressors of combi and single fridge or freezer may have comparable compressor efficiency, but the cooling system efficiency also depends on the control and in that sense a combi with (usually) one compressor regulating two different compartment heat loads is always a compromise with respect to a single compressor regulating a single compartment temperature. This was explained in a previous paragraph. Also in the technical model (Table 19) it can be seen that the volume-weighted compressor COP of the single appliances 330-351 litres is almost 15% higher than the COP of the combi of 344 litres.
- Finally, the door losses (infiltration, edge conduction losses, etc.) of a combi appliances are higher than with a single door appliance of the same size. Table 19 shows that the door perimeter length of the 344 litre combi is 20% more than that of single appliances in the range of 330-350 litres. With the single appliances the door heat loss accounts for 15% of total heat loss; with the combi for 23%.

9.4.5 Option 4 CECED formula

After the 2nd stakeholder meeting CECED looked at various options (see Annex H). They discarded option 2 for reasons mentioned. Their discussion of the volume-weighted approach (option 3) is given above. Subsequently CECED developed its own formula. The values of the wall thickness in the technical model were adjusted, considering amongst others a technological maximum for the PUR-insulation of 10 cm instead of 12 cm

mentioned in the report.¹³⁷ The wall thickness of the largest refrigerator in the technical model was decreased to 65 mm wall thickness (instead of 70 mm). Also they increased the freezer condenser temperature from the 6-11 K range in this report to 13-15 K.¹³⁸ With these adjustments CECED found *SAE*-curves that are slightly (category 1, refrigerator) to considerably (category 8, upright freezer) less ambitious than the ones calculated in this report. The compressor COP values are kept identical as in the report.

Then they adjusted the wall thickness of the upright freezer to have the same heat load (for the same equivalent volume) as the refrigerator and finally used the wall-thicknesses for single refrigerator and freezer in the respective refrigerator and freezer compartments of a combi. The intention is to compare appliances that CECED considers technically equivalent. The result is a core formula with a single *M* and *N* value (*M*=0.47, *N*=127) for all compartments (fridge, freezer, combi) representing the annual heat load.

This core formula is then multiplied with a factor (*1/COP*) where *COP*=0.00161*V*+2.05 (if fresh food is the coldest compartment in a combi) or *COP*= 0.001*V* + 1.36 (if the frozen food is the coldest compartment) to translate the heat load into energy consumption. The first term (multiplier of *V*) takes account of the scale-effect in compressor-efficiency. For instance, in case of a 300 litre fridge-freezer the *COP* would be 1.66 (0.001·300 + 1.36) and thus effectively *M*=0.28 (=0.47/1.66) and *N*=76 (=127/1.66).^{139 140}

The study team notes that the *N* coefficient is 25% lower than the current metric for an A++ appliance, but the *M* coefficient which impacts the *SAE*-slope (kWh/a versus volume) is slightly higher than today. It is only through the effect of the *V* term in the *COP*-formula that the slope works out less steep than the current slope. In fact, the CECED *SAE*-limit (versus net volume) is no longer a straight line, but actually a real curve.

On top of the above calculations and changes in wall thickness, CECED also proposes a combi-effect correction *C*, reportedly to show consumers that a combi is 80% more efficient than two separate appliances. This correction with a factor 1.2, only when the difference in design temperature between coldest and warmest compartment is higher than 20K, would then give the combi the same label-rating as the (smaller) separate appliances. The study team notes that such a correction to show that a combi is more efficient than two separate appliances is not done today and –given the large market share of around 60% for combis (or even 75% if one sets 1 combi versus 2 single appliances)—there is no proof that this has had any impact on the combi-market.

Without compensation factors *A_c*, *B_c*, *D* and the chiller compensation *CH* that CECED advocates, the formula becomes

$$SAE = C \cdot \frac{M \cdot V_{eq}}{COP} = C \cdot \frac{\sum_{c=1}^n (M \cdot r_c \cdot V_c + N \cdot \frac{V_c}{V})}{COP}$$

¹³⁷ However, they did not consider that for the largest and most expensive appliances vacuum insulation panels (VIPs) are used more and more, meaning that the equivalent of 12 cm PUR-insulation could also be realised through foamed-in VIP panels.

¹³⁸ CECED found these values ‘more realistic’.

¹³⁹ These values relate to the current EN-standard, i.e. without a correction for the new standard. Including such a correction, CECED calculates values of *M*=0.5, *N*=134, *COPFF*=0.0016*V*+1.93 (fresh food) and *COPFR*=0.00093*V*+1.47 (frozen food compartment being the coldest). For a 300 litre fridge-freezer this implies roughly the same effective *M* and *N* values (*M*=0.286 and *N*=76) but the curve over the volume range will be slightly different.

¹⁴⁰ To arrive at a value of *M*=0.18, which is roughly the overall *M*-value of a fridge-freezer with 27% freezer share in option 2 [1.35*(0.27*0.15+0.73*0.12)], one would need a total volume *V*=1250 litres. To arrive at *N*=82 [Option 2: 1.35*(0.27*100+0.73*75)] one needs a volume *V*=188 litres.

The average regression error with the results of the (adjusted) technical model is -3.6% for a fridge-freezer with 27% freezer volume share in a range of -10.8% and 6.7%.

9.4.6 Summary

The figure below shows the new SAE-curves according to the various combi-options. The green curves show the A+, A++, A+++ levels for option 1, i.e. the current N and M values but corrected for the new IEC standard (at F=0.5). This means for the (static) average combi in category 7 a correction of +6%. As mentioned, the current slopes are considered too steep, i.e. not stringent enough for larger appliances.

The orange line is option 2, which is strange in as much as the overall level is high but also because it is as flat as the line of a refrigerator.

The black line, using $C = 1.15 + 0.15 \cdot (T_{c,max} - T_{c,min})/22$ ($C=1.3$ for a fridge freezer), shows option 3. The two (bold) blue lines show option 4, both with $C=1$ (straight) and $C=1.2$ (dashed). The former ($C=1$) is close to the line of option 3, but more stringent for small appliances below $V=300$ litres; the latter ($C=1.2$) is comparable to –but sometimes less stringent than-- the option 1 A++ line.

Note that both in options 3 and 4 (at $C=1$, $V>300$ litres) the slope is considerably flatter than the A++-slope in the current situation (option 1) and follows more or less the current A+++ slope.

Options 3 or 4 (at $C=1$) seem to be the most likely candidates for the final regulation.

The final choice will follow from impact assessment and policy decision making after this review study.

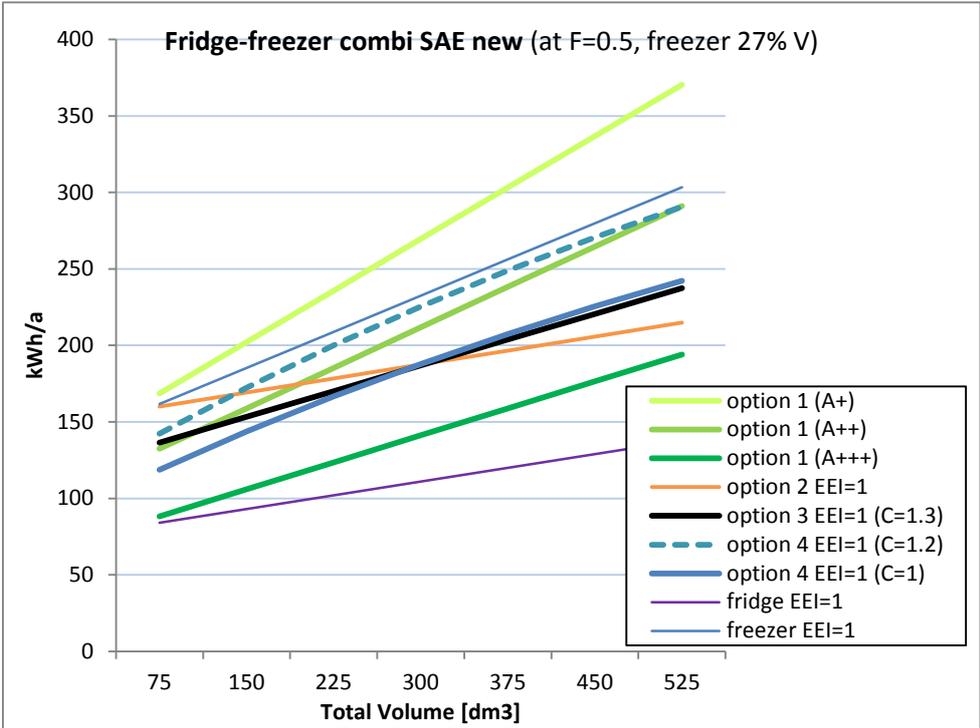


Figure 47. Comparison of options for the SAE of combi-appliances

The thin lines represent the new refrigerator (N=75, M=0.12) and freezer (N=138, M=0.15) SAE lines for comparison with various combi-options . These lines are also given

in the figure below, but now for comparison with the current A+, A++ and A+++ levels, corrected for IEC standard with +7% for refrigerator¹⁴¹ and -5% for freezers.

The SAE-line for refrigerators is at A++-level, but steeper than the A++ (comparable to A+). This is in line with the fact that the current slope is unrealistically flat, as is shown from the technical model.

The SAE-line for freezers is above A++ level but more flat than the current A++ lines, actually it is situated between A+ (small volumes) and A++ (large volumes). The slightly more relaxed reference, compared to current refrigerator and combi SAE-lines, not only follows from the industry-adjusted technical model but is also confirmed by the IEA 4E study that mentions the EU-freezer limits to be the most stringent in the world (see Chapter 5, paragraph 2). Furthermore, it also follows from Task 2 where there are considerably less A+++ models for freezers than for e.g. combis (see Fig. 9 in Chapter 6, combi-category 7 versus freezer-categories 8 and 9).

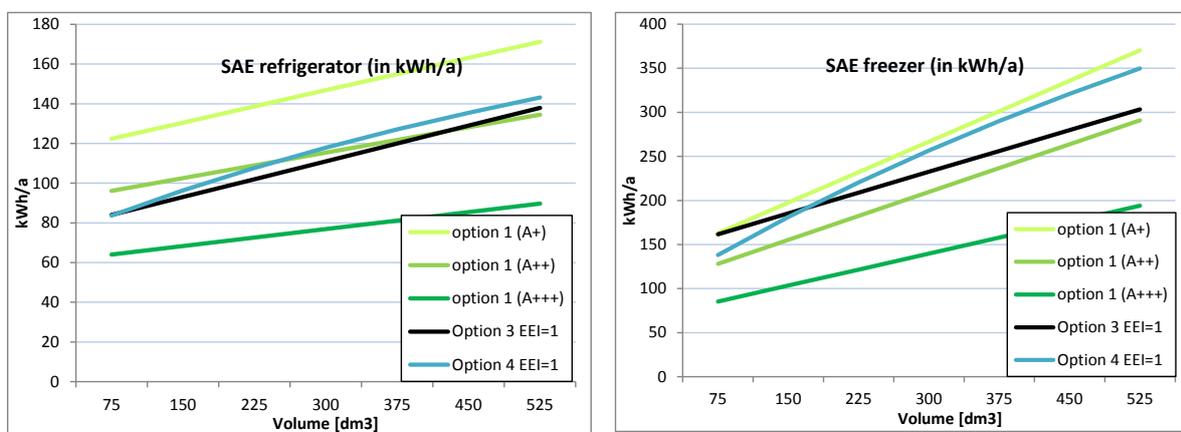


Figure 48. Proposed SAE lines for refrigerators (left) and freezers (right) in option 3.

To conclude, the SAE-formula below gives the full formula including compensation factors, using option 3 as an example.

$$SAE = C \cdot D \cdot \sum_{c=1}^n A_c \cdot B_c \cdot \frac{V_c}{V} \cdot (N_c + V \cdot r_c \cdot M_c) \quad \text{in kWh/year}$$

where

- SAE is reference electricity consumption in kWh/year,
- 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 $T_c < 0^\circ\text{C}$, 1.04 for compartments with $T_c \geq 0^\circ\text{C}$),
- C is combi-factor, expressing synergy effect when different compartment types are combined in one appliance, with formula C_c to be decided for multi-compartment 'combi' appliances¹⁴² and $C_c = 1$ for single-compartment appliances,

¹⁴¹ CECED calculates a correction of 11.9% for fridges in its technical notes

¹⁴² For instance, following option 3, $C = 1.15 + 0.15 \cdot (T_{c,max} - T_{c,min})/22$.

- 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); for ecodesign limits –not for the energy label-- a glass-door compensation of 1.2 is applied ¹⁴³,
- 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 chiller $N_c = 138, M_c = 0.15$, for refrigerators and compartment types with higher temperatures $N_c = 75, M_c = 0.12$; see also table),
- V is total net volume of the appliance,
- V_c is compartment net volume,
- r_c is temperature correction, with

$$r_c = (T_a - T_c)/20$$
 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	75	0.12	1.04
Wine storage ^[1]	+5	+20	+12	0.60			
Cellar	+8	+14	+12	0.60			
Fresh food	+4	+8	+4	1.00			
Chill ^[2]	-3	+3	0 or 2	1.2 or 1.1			
0-star & ice-making	<i>n.a.</i>	0	0	1.20	138	0.15	1.1
1-star	<i>n.a.</i>	-6	-6	1.50			
2-star	<i>n.a.</i>	-12	-12	1.80			
Food freezer & 3-star	<i>n.a.</i>	-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);

^[2]= for the moment it is assumed that both temperatures may be chosen, depending on whether The manufacturer wants to create a 'salad-chiller' (2°C) or a 'fish & meat chiller' (0°C). To be revisited in the impact assessment

The equivalent formula for specific energy q_{ref} , in kWh/litre/year, is the *SAE*-formula divided by V :

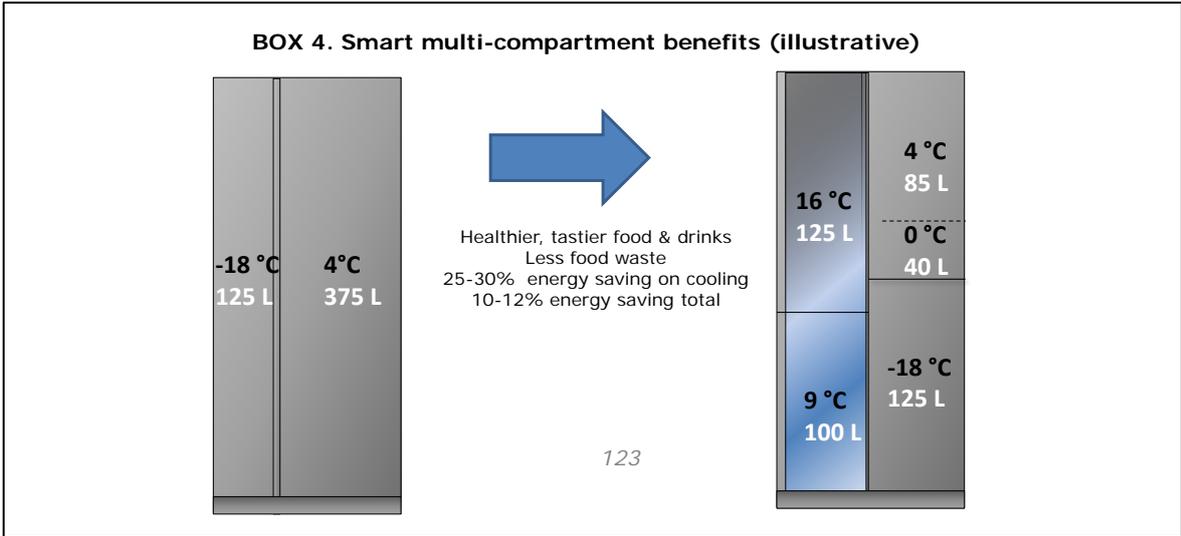
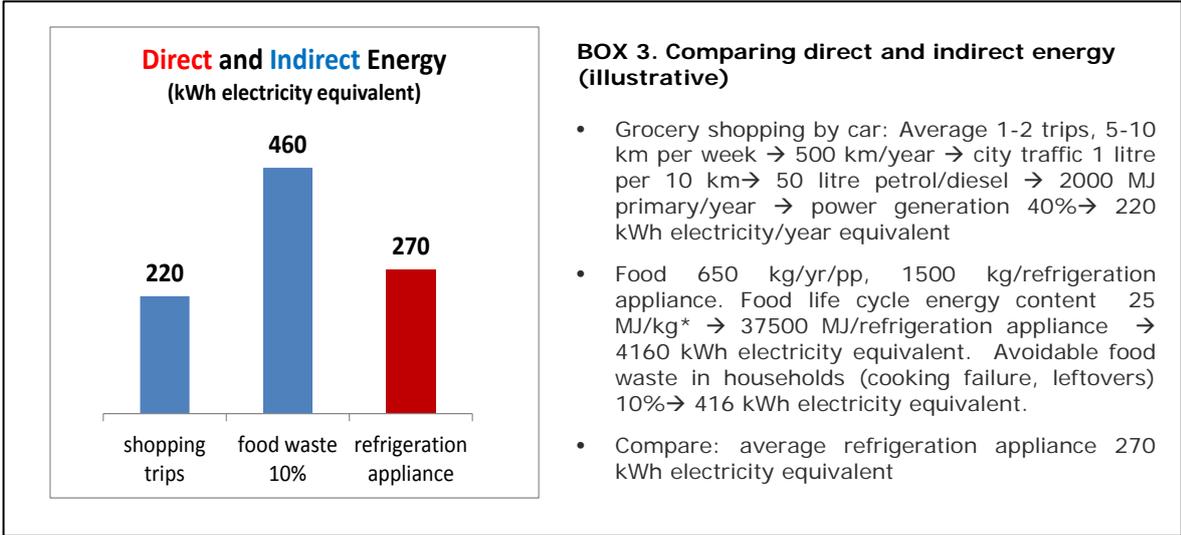
$$q_{ref} = C \cdot D \cdot \sum_{c=1}^n A_c \cdot B_c \cdot \frac{V_c}{V} \cdot \left(\frac{N_c}{V} + r_c \cdot M_c \right) \quad \text{in kWh/litre/year}$$

¹⁴³ This is roughly the compensation factor also used in e.g. California efficiency regulation for commercial refrigerators with glass door.

Final details, including an evaluation of the impacts of options 3 and 4 in relation to the assessment of limit values, still have to be revisited and analysed during the Commission’s impact assessment study. However, it is clear that the metric is potentially simpler (all captured in one formula) 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.



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 (V_{net})	gross internal volume (V_{gross})	external height h	external width w	external depth d	external volume (V_{ext})	packaged volume (+8 cm overall)	rounded packaged volume (V_{pack})
	<i>unit</i>	<i>kg</i>	<i>dm³</i>	<i>dm³</i>	<i>cm</i>	<i>cm</i>	<i>cm</i>	<i>dm³</i>	<i>dm³</i>	<i>m³</i>
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.

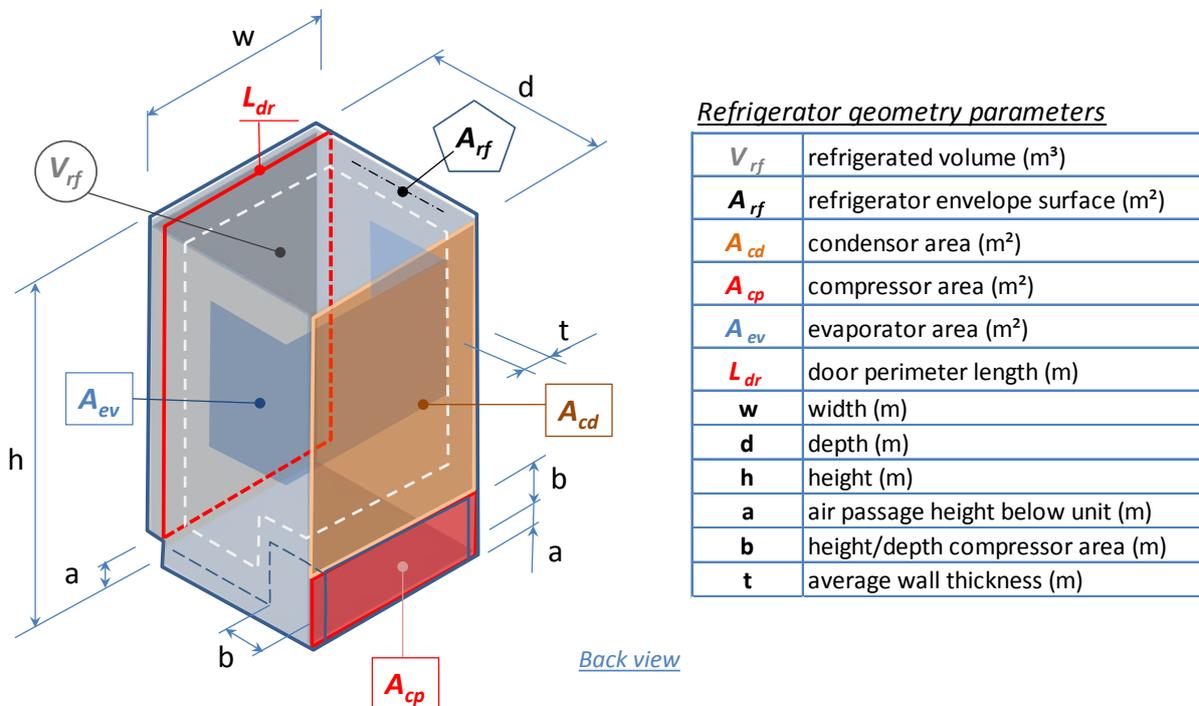


Figure 49. Refrigerator dimensions and other relevant geometry parameters. (VHK 2015)

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)

		average wall thickness t	ext volume (V_{ext})	ext. volume minus wall (V_{gross})	external component 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})
Category	Unit	cm	dm^3	dm^3	dm^3	dm^3	dm^3	dm^3	dm^3	dm^3
	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 $t=4$ cm 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 parameters¹⁴⁴ the Bills-of-Material in Table 31 are established. Figure 50 gives some more detail on the typical materials mix from of hermetic compressors.

¹⁴⁴ 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.

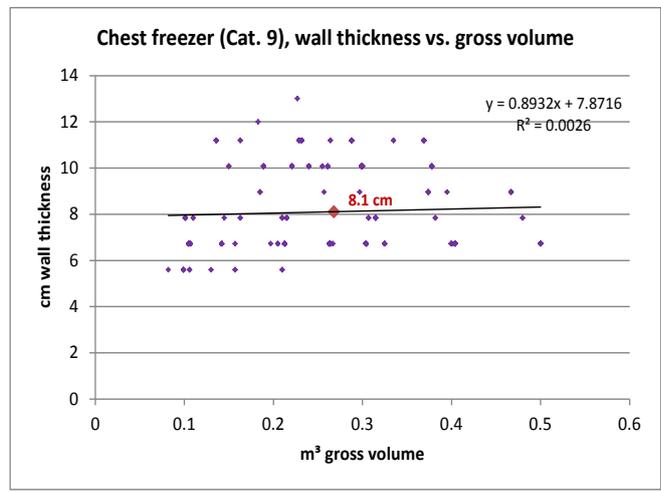
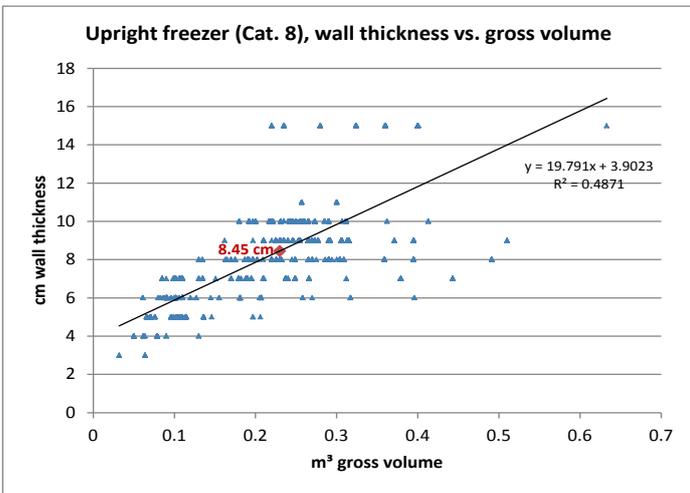
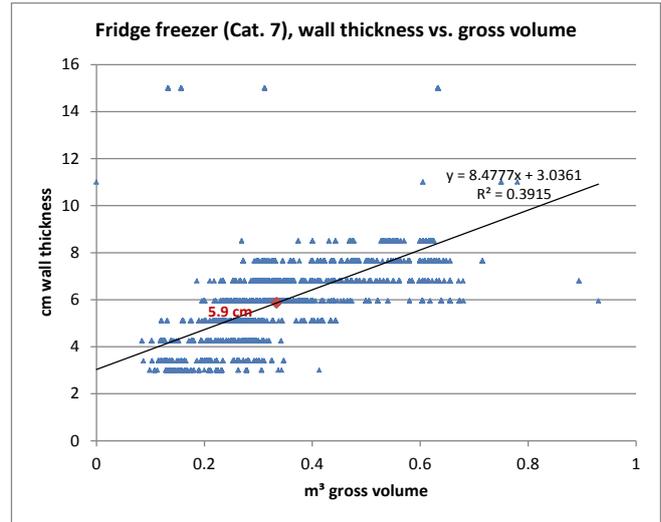
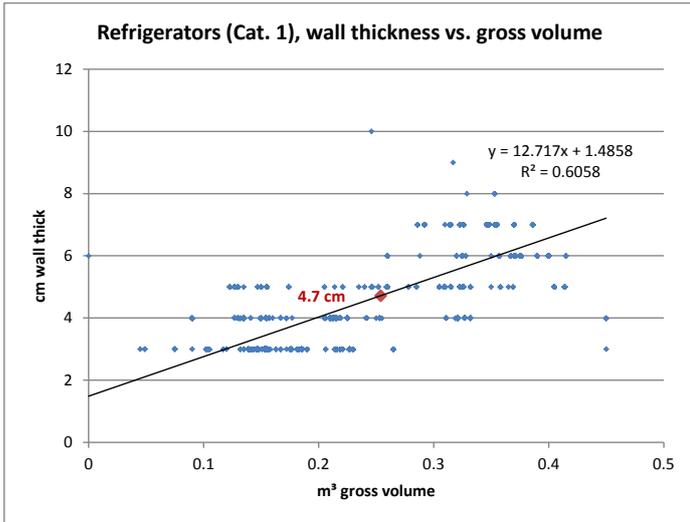


Figure 50. Distribution of approximated wall thickness versus gross volume for categories 1, 7, 8 and 9 in the CECED 2014 database. (source: VHK 2015)

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

		Neutral envelope surface (A_{rf})	condenser surface (A_{cd})	Door gasket length (L_{dr})
	Category			
	Unit	dm ²	dm ²	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:

- $A_{rf} = 2 \cdot (w-t) \cdot (d-t) + 2 \cdot [(h-t-a) \cdot (d-t) - (b+0.5t)^2] + 2 \cdot (w-t) \cdot (h-t-a)$; '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.
- $A_{cd} = w \cdot (h-a-b)$
- $L_{dr} = 2 \cdot (w+(h-a))$; 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	<i>EcoReport Category</i>
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)

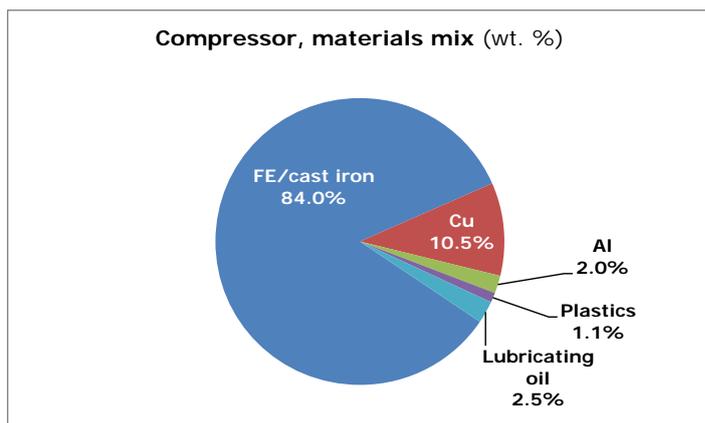


Figure 51. Hermetic compressor, typical materials mix (source: ENEA/ ISIS, Preparatory Study Ecodesign Lot 13: Domestic Refrigerators & Freezers, Task 5, final report, October 2007)

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 52. 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)

Base Case	sold 16 years ago (L=16)*			2015					
	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

Base Case	2005	avg. stock: 8 years old (2006)*			2014					New / Stock
	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	495	202	2.5	3.6	420
	A++	1228	105	257	50%	7%	€ 514	€ 2.23	2.00					
	A+++	158	71	271	36%	6%	€ 623	€ 3.21	2.30					
COLD2	B	28	206	198	0%	0%	€ 792	€ 7.82	4.00	1344	336	4.0	0.3	792
	A	27	150	193	0%	0%	€ 1 448	€ 11.71	7.50					
	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	557	231	2.4	11.5	466
	A++	3984	226	296	32%	38%	€ 574	€ 0.72	1.94					
	A+++	1057	154	310	32%	26%	€ 682	€ 1.50	2.20					
COLD8	A+	1498	253	183	33%	48%	€ 366	ref	2.00	439	217	2.0	1.4	320
	A++	1159	218	219	16%	66%	€ 482	€ 3.31	2.20					
	A+++	189	168	289	0%	71%	€ 751	€ 5.39	2.60					
COLD9	A+	322	256	264	0%	1%	€ 343	ref	1.30	356	215	1.7	2.6	343
	A++	103	194	255	0%	0%	€ 370	€ 0.43	1.45					
	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	unit	COLD1			COLD2			COLD7			COLD8			COLD9			TOTAL		
		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			
		Prod	Dstr	Use	EoL	Prod	Dstr	Use	EoL												
Other Resources & Waste																					
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)	m ³	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)	m ³	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.

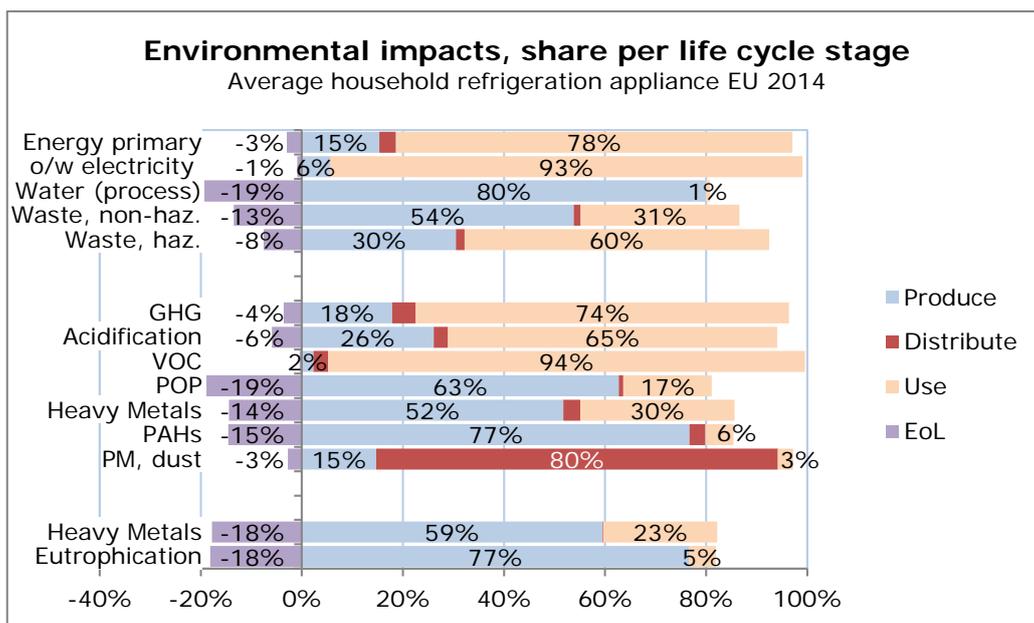


Figure 53. Environmental impacts, share per life cycle stage

Figure 53 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.¹⁴⁵

Figure 54 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 $0.36 \times 3.14\% = 1.2\%$ 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).

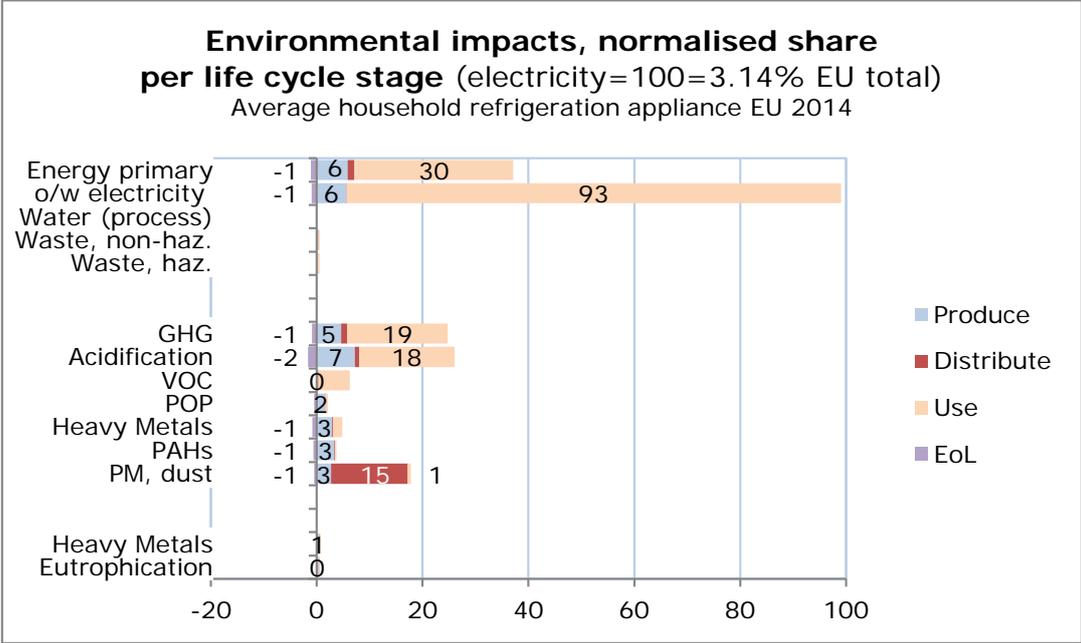


Figure 54. Environmental impacts, share per life cycle stage (electricity=100=3.14% of EU total)

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.

¹⁴⁵ 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 price¹⁴⁶.

External damages ('Societal life cycle costs')¹⁴⁷ 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 in the year 2014, respectively per base case and for the EU total. As far as production, distribution and end-of life are concerned, the impacts relate to the products sold, distributed and discarded in 2014. The impacts during product-use relate to the electricity consumption of the total stock of installed in 2014. Table 42 also shows the shares of the impacts in the EU totals (as illustrated in figure 36).

¹⁴⁶ 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.

¹⁴⁷ 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 emission 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%

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.

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. The only exception is for COLD2 unit for which a B class unit with consumption 177 kWh per year instead of 237 kWh per year was kept. In that case, priority was given to the available price information given in Table 35, so as to keep matching price and energy consumption available information.

Table 44. Main characteristics of the base cases

Basecase	Energy label class (indicative)	energy	net volume
		<i>kWh/a</i>	<i>litre</i>
COLD1	A+	119	248
COLD2	B	177	207
COLD7	A+	258	309
COLD8	A+	232	203
COLD9	A+	236	261

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.

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, 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 size	1,2,7,8,9
I1	Increased insulation thickness	+ 1 cm	Available for all appliances	1,2,7,8,9

I2	Increased insulation thickness	+ 2 cm	May not be applicable to built-in appliances	1,2,7,8,9
I3	Increased insulation thickness	+ 3 cm	May not be applicable to built-in appliances.	1,2,7
I3+	Increased insulation thickness	Increased insulation thickness up to 10 cm	Not applicable to built-in appliances.	1,2,7
I4	Use of vacuum insulated panels, 70 % of door are covered	Panels 2 cm thickness, conductivity $0.0035 \text{ Wm}^{-1} \cdot \text{K}^{-1}$	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 2 cm thickness, conductivity $0.0035 \text{ Wm}^{-1} \cdot \text{K}^{-1}$		1,2,7,8,9
D1	Glass triple glazing E-coating, argon fill	Uvalue = $1.1 \text{ W} \cdot \text{m}^2 \cdot \text{K}^{-1}$	Applied to wine cooler with glass only	2
D2	Glass door triple glazing E-coating, krypton fill (heavy door)	Uvalue = $0.8 \text{ W} \cdot \text{m}^2 \cdot \text{K}^{-1}$	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		1,2,7,8,9
F1	Improved convection heat transfer with indoor fan and multiflow	0.8 W fan, +40 % increase of the convection coefficient	Applied to static evaporators only	1,2,8,9
F2	Improved condenser heat transfer with outdoor fan	0.68 W fan, +40 % increase of the convection coefficient	Applied to static wire-and-tube condensers only	1,2,7,8

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.

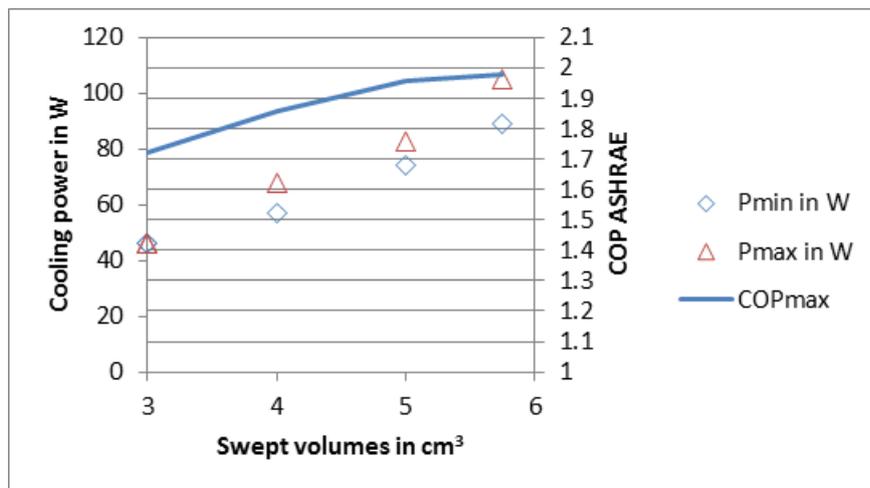


Figure 37. Best available compressor COP and capacity range (ASHRAE conditions) versus size (swept volume in cm^3), LBP, R600a

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.

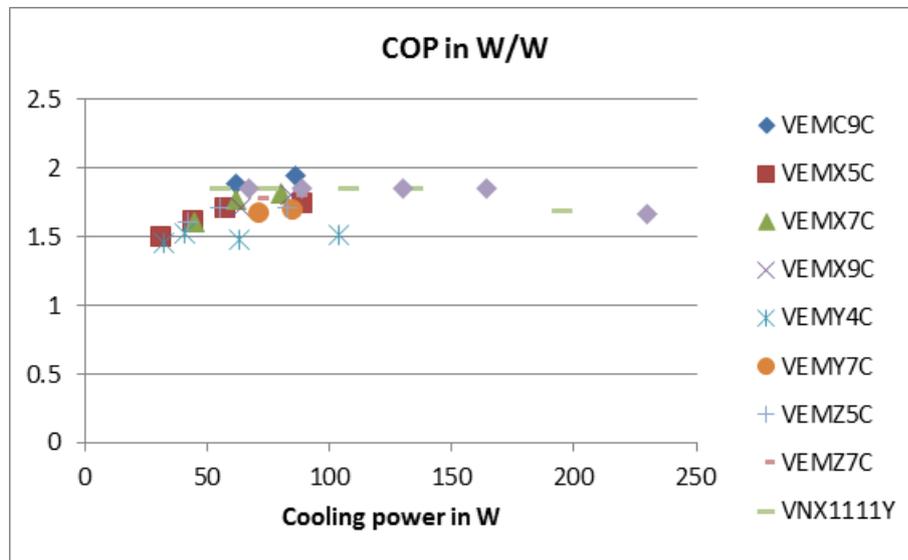


Figure 38. Variable speed compressor efficiency

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 category 2 refrigerators have a much lower average insulation thickness, each increase I1, I2 and I3 corresponds to 20 mm added insulation. As in task 4, polyurethane cyclopentane foam is used as the reference insulation. Its thermal conductivity is fixed at $0.020 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$.

According to M. Janssen¹⁴⁸, 100 mm thickness is a technical limit to insulation because of the foaming process. As a consequence, category 1 and 2 refrigerators can be further improved over I3 and a fourth option I3+ is added that shows the maximum potential with available industry tools. For freezers of category 8 and 9 that are already well insulated, I3 option cannot be applied and for category 9 freezer, the I2 option is limited to 15 mm increase (as average insulation is already 85 mm thick).

Regarding combined appliances (category 7), the refrigerator and freezer insulation thickness are supposed to be different^{148,149} in order to optimize the base case. With increasing insulation level however, this difference decreases because the 100 mm limit prevents to increase the freezer already large insulation level. A I3+ option is added which corresponds to the maximum feasible technology, with 100 mm insulation thickness for both refrigerator and freezer compartments.

Thickness insulation is supposed to increase width, depth and height of the appliances; according to M. Janssen¹⁴⁹, industry practice would rather be to increase only the height of the unit, because of standard width and length of manufacturing lines, but he also notes the impact can be neglected.

¹⁴⁸ M. Janssen, CECED Comments to Interim report (14.11.2015); Topic: technical model chapter 9, Re/genT Note:15423 / CE15 / V2, 8/12/2015.

¹⁴⁹ M. Janssen, CECED Comments to Interim report (14.11.2015) Topic: Design options and LCC (chapter 12), Re/genT Note1:15424 / CE16 / V1, 11/12/2015.

VIP integration: vacuum insulation panels 2 cm thick, with thermal conductivity of $0.0035 \text{ W.m}^2.\text{K}^{-1}$ are considered¹⁵⁰. 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 study¹⁵¹ 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). For category 2 refrigerators with only 2 mm thick insulation, replacing foam by 2 cm VIP panels is not realistic. However, as the VIP option are less cost-effective than standard insulation, this does not happen in the scenario of combined option. This only leads VIP single option to appear slightly more cost-effective as individual option that they would be in reality as probably no or less foam would be displaced.

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 triple glazing (argon fill). A second option is to use a triple glazing, krypton fill. Respective U values are, according to the Ecodesign Windows study, 1.7, 1.1 and $0.8 \text{ W.m}^2.\text{K}^{-1}$.

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 frequency of the compressor is divided by roughly 2^{152} , 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 products¹⁵³.

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).

¹⁵⁰ Greenblatt, Jeffery B.. Technical Support Document for the Final Rule on Residential Refrigerators, Refrigerator-Freezers and Freezers. U.S. Department of Energy, 2011.

¹⁵¹ 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.

¹⁵² Y. Yusufoglu, T. Apaydin, S. Yilmaz, H.O. Paksoy, Improving Performance of Household refrigerators by Incorporating Phase Change Materials, International Journal of Refrigeration, 2015.

¹⁵³ Janssen, M., Impact of the new IEC 62552-1,2,3:2015 global appliance energy consumption rating (second study), Re/genT Report number: 15127/CE40/V1, 13 April 2015.

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: Regarding natural-convection evaporators, forced convection heat exchangers could also offer substantial gains. The Fantini¹⁵⁴ 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 %. The F1 option is not used for COLD7 base case as the evaporating temperature is fixed at the level of the freezer one. This option would thus incur supplementary energy losses and no gain.

F2: 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)¹⁵⁵. 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). The F2 option is not used for COLD9 appliance as it is not clear how far the specific condenser design would benefit from this option.

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. For base case 7, the model has been modified to properly address the different insulation thickness of the refrigerator and freezer compartments. New variables introduced and changes in calculations are described below. The same notations as in Task 4 (Chapter 9) 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 E_{aux} 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 (U_{wall}), which explains the high heat load for the walls (U_{wall}). The heat conductivity of the door has been assumed to be of $1.7 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$. In order to have a compressor with a COP close to 1.5, the insulation level

¹⁵⁴ Fantini, M. Innovative techniques to reduce energy consumption of household refrigerators, Politecnico Di Milano, Thesis 2013.

¹⁵⁵ Hofmanas, I., Researches 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 (O6T), 2014, Kaunas

(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 (depending on the respective refrigerator and freezer load, it may be necessary to alternate freezer and freezer plus evaporator in order to maintain an adequate temperature in both compartments). It is supposed accordingly that the evaporating temperature can be maintained at the same level in both circuits. Maintaining two distinct temperatures in refrigerator and freezer evaporators is not thought to be feasible nowadays because of refrigerant migration that tends to equalize both temperature levels¹⁵⁴.

In order to check the feasibility of the temperature differences across the heat exchangers for the specific base case compressor capacity, 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 A_{ev} and A_{ev_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. A_{ev_max} is the sum of the areas of the inner cooled volume (minus the door area). Comparing the $P_{cond_required}$ and P_{cond_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.

For base cases COLD1, COLD2 and COLD8, the condenser area required to extract the heat is close to the maximum feasible. This indicates that ΔT_{cd} cannot be reduced further by increasing the area of the condenser. For the base case COLD9, this is not the case. Although it seems feasible to further increase the condenser size to reduce ΔT_{cd} , it was not done (proposed industry values were kept) because of the different condenser architecture of this type of refrigerator for which the correlation used may overestimate the heat transfer coefficient.

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

<i>Base case</i>		COLD 1	COLD 2	COLD 8	COLD 9
Vrf	refrigerated volume (m ³)	0,248	0,207	0,203	0,261
	refrigerated volume (litres dm ³)	248	207	203	261
Arf	refrigerator envelope surface (m ²)	3,111	2,443	3,220	3,280
Acd	condenser area (m ²)	0,648	0,449	0,743	1,244
Acp	compressor area (m ²)	0,135	0,132	0,138	0,236
Ldr	door perimeter length (m)	3,88	3,156	4,2	3,19
w	width (m)	0,54	0,528	0,55	0,945
d	depth (m)	0,55	0,5	0,587	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)	0,047	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 ² K)	0,426	1,000	0,235	0,250
Ptrans	transmission heat loss (W)	26	36	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)	33	40	40	41
Eloss_tot	annual heat energy loss (kWht/a)	286	348	348	361
ΔTev	evaporator temperature difference (K)	17	25	10	10
ΔTcd	condenser temperature difference K	10	13	12	12
Tev	evaporator temperature (°C)	-12	-13	-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	1,636	1,47	1,617	1,651
Pnom	Nominal compressor cooling power (W)	63	63	129	141
P	Cool power (W)	120	111	96	104
Cool. Load Ratio	Ratio of heat load to cool power	27%	36%	42%	40%
Cycling losses	Part load performance degradation losses (in % COP)	9%	8%	7%	8%
COP	COP value with actual Tev and Tcd temperatures	2,8	2,2	1,7	1,7
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	2,5	2,1	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)	119	177	232	236
EVAP REALITY CHECK					
h_{evap}	Evaporator convective heat transfer coefficient W/m ² .K	6,8	7,3	5,5	4,8
A_{ev}	Evaporator surface of the unit (m ²)	1,03	0,60	1,73	2,19
A_{evap max}	Evaporator surface available (m ²)	1,50	1,59	1,75	2,74
COND REALITY CHECK					
P_{cond required}	Heat to be extracted at condenser (W)	157	153	145	157
P_{cond max}	Max heat the condenser can extracted on refrigerator back surface (W)	175	163	148	207

Regarding the combined appliance COLD7, the following modifications to the Task 4 (Chapter 9) model, suggested by M. Janssen¹⁴⁸, have been implemented:

- the volume of the separator (V_s) is accounted for; its thickness equals the average wall thickness;
- the height of the separator (h_s) defines the respective refrigerator and freezer volumes; the ratio of the refrigerator to total volume ($R_{f/rtf}$) of the base case is close to 0.74; it is maintained at this value when insulation thickness is changing by adjusting the separator height.
- the insulation thickness differs in the refrigerator and in the freezer compartments; the thickness wall ratio (t_{wr}) gives the relative insulation thickness of the refrigerator compartment compared to the average wall thickness. The freezer insulation thickness is deducted by conservation of the total volume of foam for an insulation thickness equal to the average wall thickness. This parameter is set to minimize the total heat load, all other geometrical parameters being fixed.
- in addition, for the door gasket and miscellaneous loads, different U coefficients are computed, following the general hypothesis that these losses decrease with larger insulation from 0.08 W/mK to 0.04 W/mK for an insulation level increasing from 0.06 to 0.1 m;
- the average compartment temperature T_c is only indicative and not included in the calculations;
- although both refrigerator and freezer compressor capacity and efficiency appear in Table 48 below, they are supposed equal as the refrigerator compartment evaporating temperature equals the one of the freezer evaporator.

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

<i>Base case</i>		COLD 7
V_{rf}	refrigerated volume (m ³)	0,309
	refrigerated volume (litres dm ³)	309
V_s	Volume separator [m3]	0,013
V_f	Volume fresh food [m3]	0,229
V_r	Volume frozen food [m3]	0,080
$R_{f/rf}$	Ratio Vref / Vrf	0,741
A_{rf}	refrigerator envelope surface (m ²)	3,863
A_r	Area fresh food compartment [m2]	2,59
A_f	Area frozen food compartment [m2]	1,27
A_{cd}	condenser area (m ²)	0,856
A_{cp}	compressor area (m ²)	0,148
A_{ev}	evaporator area (m ²)	na
$L_{dr,r}$	refrigerator door perimeter length (m)	3,36
$L_{dr,f}$	freezer door perimeter length (m)	2,30
w	width (m)	0,59
d	depth (m)	0,59
h	height (m)	1,7
h_s	height level separator (mid position) [m]	0,583
a	air passage height below unit (m)	0,05
b	height & depth compressor area (m)	0,2
t	average wall thickness (m)	0,059
t_{wr}	t wall ratio	0,761
t_r	wall thickness fresh food [m]	0,045
t_f	wall thickness frozen food [m]	0,088
T_r	refrigerator temperature (°C)	5
T_f	freezer temperature (°C)	-20
T_c	Average compartment temperature (°C)	-2,6
T_a	ambient temperature (°C)	25
k	heat conductivity (W/mK)	0,020
U_{wall}	heat transfer coefficient wall (W/m ² K)	0,339
P_{trans}	transmission heat loss (W)	36
$U_{misc,r}$	refrigerator heat transfer coefficient door gasket and misc loads (W/mK)	0,080
$U_{misc,f}$	freezer heat transfer coefficient door gasket and misc loads (W/mK)	0,042
P_{misc}	door and misc heat loss (W)	10
$P_{loss,tot}$	total heat power loss $P_{trans} + P_{misc}$ (W)	46
$P_{loss,tot,r}$	Total heat loss refrigerator (W)	28
$P_{loss,tot,f}$	Total heat loss freezer (W)	17
$E_{loss,tot}$	annual heat energy loss (kWh_{th}/a)	402
ΔT_{ev}	refrigerator evaporator temperature difference (K)	33,0
ΔT_{fr}	freezer evaporator temperature difference (K)	8,0
$\Delta T_{cd,r}$	refrigerator condenser temperature difference (K)	10,0
$\Delta T_{cd,f}$	freezer condenser temperature difference (K)	10,0
$T_{ev,r}$	refrigerator evaporator temperature (°C)	-28,0
$T_{ev,f}$	freezer evaporator temperature (°C)	-28,0
$T_{cd,r}$	refrigerator condenser temperature (°C)	35,0
$T_{cd,f}$	freezer condenser temperature (°C)	35,0
P_{nom}	Nominal compressor cooling power (W)	141
COP_{nom}	nominal at -23.3/54.4°C, sub-cooling 32.2°C (-)	1,57
$P_{refrigerator}$	Refrigerator cool power (W)	121
$P_{freezer}$	Freezer cool power (W)	121
COP_{ref}	Refrigerator COP (-)	1,75
$COP_{freezer}$	Freezer COP (-)	1,75
COP_{global}	Average COP	1,75
$Cool. Load Ratio$	Ratio of Demand (Tamb) to P	38%
$Cycling losses$	Part load performance	7,7%
COP_{real}	With cycling correction	1,6
E_{aux}	<i>electricity CPU and possible fan (kWh/a)</i>	9
AE	annual electricity consumption (kWh_{el}/a)	258
EVAP REALITY CHECK		
$h_{evap,r}$	Evaporator convective heat transfer coefficient W/m ² .K	6,9
$A_{ev,r}$	Evaporator surface of the unit (m ²)	0,33
$A_{evap,max,r}$	Evaporator surface available (m ²)	2,30
$h_{evap,f}$	Evaporator convective heat transfer coefficient W/m ² .K	5,3
$A_{ev,f}$	Evaporator surface of the unit (m ²)	1,08
$A_{evap,max,f}$	Evaporator surface available (m ²)	1,29
COND REALITY CHECK		
$P_{cond,required,r}$	Heat to be extracted at condenser (W) (refrigerator operation)	179
$P_{cond,required,r}$	Max heat the condenser can extracted on refrigerator back surface (W) (refrigerator operation)	231
$P_{cond,max,f}$	Heat to be extracted at condenser (W) (freezer operation)	179
$P_{cond,max,f}$	Max heat the condenser can extracted on refrigerator back surface (W) (freezer operation)	231

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 varies (for instance, it tends to increase in case of oversizing of the compressor or increased evaporating temperature), the temperature difference across the heat exchanger needs to increase until an equilibrium is reached: the capacity variation of the compressor with varying evaporating temperature needs to match the evaporator capacity; this is done by adjusting the evaporation temperature. 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).

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 design 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 heat exchanger area shown before, which do not change for the design options.

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

<i>Base case</i>		COLD1	C1	C2	C3	VSD	I1	I2	I3	I3+	I4	I5	PCM	F1	F2
Vrf	refrigerated volume (m ³)	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248	0,248
	refrigerated volume (litres dm ³)	248	248	248	248	248	248	248	248	248	248	248	248	248	248
Arf	refrigerator envelope surface (m ²)	3,111	3,111	3,111	3,111	3,111	3,206	3,301	3,398	3,626	3,111	3,111	3,111	3,111	3,111
Acd	condenser area (m ²)	0,648	0,648	0,648	0,648	0,648	0,683	0,719	0,756	0,844	0,648	0,648	0,648	0,648	0,648
Acp	compressor area (m ²)	0,135	0,135	0,135	0,135	0,135	0,140	0,145	0,150	0,162	0,135	0,135	0,135	0,135	0,135
Ldr	door perimeter length (m)	3,88	3,88	3,88	3,88	3,88	3,96	4,04	4,12	4,304	3,88	3,88	3,88	3,88	3,88
w	width (m)	0,54	0,54	0,54	0,54	0,54	0,56	0,58	0,6	0,646	0,54	0,54	0,54	0,54	0,54
d	depth (m)	0,55	0,55	0,55	0,55	0,55	0,57	0,59	0,61	0,656	0,55	0,55	0,55	0,55	0,55
h	height (m)	1,45	1,45	1,45	1,45	1,45	1,47	1,49	1,51	1,556	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	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)	0,047	0,047	0,047	0,047	0,047	0,057	0,067	0,077	0,100	0,047	0,047	0,047	0,047	0,047
Tc	compartment temperature (°C)	5	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	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 ² K)	0,43	0,43	0,43	0,43	0,43	0,35	0,30	0,26	0,20	0,38	0,34	0,43	0,43	0,43
Ptrans	transmission heat loss (W)	26	26	26	26	26	22	20	18	15	24	21	26	26	26
Umisc	heat transfer coefficient door gasket and misc. load (W/mK)	0,080	0,080	0,080	0,080	0,080	0,080	0,063	0,053	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	4	6	6	6	6	6
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	33	33	33	33	33	29	25	22	19	30	27	33	33	33
Eloss_tot	annual heat energy loss (kWh/a)	286	286	286	286	286	253	217	193	165	263	238	286	288	286
ΔTev	evaporator temperature difference (K)	17,0	17,0	17,0	19,9	11,4	17,0	17,0	17,0	17,0	17,0	17,0	17,0	13,9	17,2
ΔTcd	condenser temperature difference K	10,0	9,9	9,8	11,4	6,8	10,0	10,0	10,0	10,0	10,0	10,0	10,0	11,0	7,5
Tev	evaporator temperature (°C)	-12,0	-12,0	-12,0	-14,9	-6,4	-12,0	-12,0	-12,0	-12,0	-12,0	-12,0	-12,0	-8,9	-12,2
Tcd	condenser temperature (°C)	35,0	34,9	34,8	36,4	31,8	35,0	35,0	35,0	35,0	35,0	35,0	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	1,64
Pnom	Nominal compressor cooling power (W)	63	63	63	86	31	63	63	63	63	63	63	63	63	63
P	Cool power (W)	120	120	120	142	78	120	120	120	120	120	120	120	136	122
Cool. Load Ratio	Ratio of heat load to cool power	27%	27%	27%	23%	42%	24%	21%	18%	16%	25%	23%	27%	24%	27%
Cycling losses	Part load performance degradation losses (in % COP)	9%	9%	9%	10%	7%	9%	10%	10%	11%	9%	10%	5%	9%	9%
COP	COP value with actual Tev and Tcd temperatures	2,8	2,9	3,1	3,0	3,2	2,8	2,8	2,8	2,8	2,8	2,8	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	2,5	2,5	2,5	2,5	2,5	2,5	2,6	2,6	2,6
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	4,4	6,2	6,1
AE	annual electricity consumption (kWhel/a)	119	113	105	111	105	106	92	82	71	110	100	113	115	114
REDUCTION IN CONSUMPTION (%)			5%	12%	7%	11%	11%	23%	31%	40%	8%	16%	5%	3%	4%

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

<i>Base case</i>		COLD2	C1	C2	C3	VSD	I1	I2	I3	I3+	I5	PCM	F1	F2	D1	D2
Vrf	refrigerated volume (m ³)	0,207	0,207	0,207	0,207	0,207	0,207	0,207	0,207	0,207	0,207	0,207	0,207	0,207	0,207	0,207
	refrigerated volume (litres dm ³)	207	207	207	207	207	207	207	207	207	207	207	207	207	207	207
Arf	refrigerator envelope surface (m ²)	2,443	2,443	2,443	2,443	2,443	2,524	2,691	2,862	3,127	2,443	2,443	2,443	2,443	2,443	2,443
Acd	condenser area (m ²)	0,449	0,449	0,449	0,449	0,449	0,477	0,535	0,597	0,695	0,449	0,449	0,449	0,449	0,449	0,449
Acp	compressor area (m ²)	0,132	0,132	0,132	0,132	0,132	0,137	0,147	0,157	0,172	0,132	0,132	0,132	0,132	0,132	0,132
Ldr	door perimeter length (m)	3,156	3,156	3,156	3,156	3,156	3,236	3,396	3,556	3,796	3,156	3,156	3,156	3,156	3,156	3,156
w	width (m)	0,528	0,528	0,528	0,528	0,528	0,548	0,588	0,628	0,688	0,528	0,528	0,528	0,528	0,528	0,528
d	depth (m)	0,5	0,5	0,5	0,5	0,5	0,52	0,56	0,6	0,66	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	1,26	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	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	0,2
t	average wall thickness (m)	0,020	0,020	0,020	0,020	0,020	0,030	0,050	0,070	0,100	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	12
Ta	ambient temperature (°C)	25	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	0,020
Uwall	heat transfer coefficient wall (W/m ² K)	1,00	1,00	1,00	1,00	1,00	0,67	0,40	0,29	0,20	0,76	1,00	1,00	1,00	1,00	1,00
Ptrans	transmission heat loss (W)	36	36	36	36	36	29	24	22	21	30	36	36	36	32	30
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	0,030	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	1	3	3	3	3	3	3
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	40	40	40	40	40	32	27	24	22	34	40	40	40	36	34
Eloss_tot	annual heat energy loss (kWh/a)	348	348	348	348	348	284	237	213	195	295	348	350	348	312	294
ΔTev	evaporator temperature difference (K)	25,0	25,1	25,1	28,6	18,0	25,0	25,0	25,0	25,0	25,0	25,0	21,1	25,4	25,0	25,0
ΔTcd	condenser temperature difference K	13,0	12,5	12,3	14,1	8,9	13,0	13,0	13,0	13,0	13,0	13,0	14,8	9,6	13,0	13,0
Tev	evaporator temperature (°C)	-13,0	-13,1	-13,1	-16,6	-6,0	-13,0	-13,0	-13,0	-13,0	-13,0	-13,0	-9,1	-13,4	-13,0	-13,0
Tcd	condenser temperature (°C)	38,0	37,5	37,3	39,1	33,9	38,0	38,0	38,0	38,0	38,0	38,0	39,8	34,6	38,0	38,0
COPnom	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1,47	1,73	1,85	1,98	1,50	1,47	1,47	1,47	1,47	1,47	1,47	1,47	1,47	1,47	1,47
Pnom	Nominal compressor cooling power (W)	63	63	63	86	31	63	63	63	63	63	63	63	63	63	63
P	Cool power (W)	111	111	111	128	78	111	111	111	111	111	111	130	113	111	111
Cool. Load Ratio	Ratio of heat load to cool power	36%	36%	36%	31%	51%	29%	24%	22%	20%	30%	36%	31%	35%	32%	30%
Cycling losses	Part load performance degradation losses (in % COP)	8%	8%	8%	9%	6%	9%	9%	10%	10%	9%	4%	9%	8%	8%	9%
COP	COP value with actual Tev and Tcd temperatures	2,2	2,7	2,9	2,7	3,1	2,2	2,2	2,2	2,2	2,2	2,2	2,4	2,4	2,2	2,2
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	2,1	2,4	2,6	2,5	2,9	2,0	2,0	2,0	2,0	2,1	2,2	2,2	2,2	2,1	2,1
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	11,1	11,0	8,8	8,8
AE	annual electricity consumption (kWhel/a)	177	151	141	150	134	147	125	114	105	153	170	172	168	160	152
REDUCTION IN CONSUMPTION (%)			15%	20%	15%	24%	17%	29%	36%	41%	14%	4%	3%	5%	9%	14%

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

<i>Base case</i>		VSD +												
		COLD7	C1	C2	C3	C2	I1	I2	I3	I3+	I4	I5	PCM	F2
V_{rf}	refrigerated volume (m ³)	0,309	0,309	0,309	0,309	0,309	0,309	0,310	0,310	0,310	0,309	0,309	0,309	0,309
	refrigerated volume (litres dm ³)	309	309	309	309	309	309	310	310	310	309	309	309	309
V_s	Volume separator [m3]	0,013	0,013	0,013	0,013	0,013	0,015	0,018	0,020	0,023	0,013	0,013	0,013	0,013
V_r	Volume fresh food [m3]	0,229	0,229	0,229	0,229	0,229	0,229	0,229	0,229	0,229	0,230	0,230	0,230	0,230
V_f	Volume frozen food [m3]	0,080	0,080	0,080	0,080	0,080	0,080	0,080	0,080	0,080	0,079	0,079	0,079	0,079
$R_{f/rf}$	Ratio Vref / Vrf	0,741	0,741	0,741	0,741	0,741	0,741	0,741	0,741	0,741	0,744	0,744	0,744	0,744
A_{rf}	refrigerator envelope surface (m ²)	3,863	3,863	3,863	3,863	3,863	3,986	4,110	4,236	4,377	3,863	3,863	3,863	3,863
A_r	Area fresh food compartment [m2]	2,59	2,59	2,59	2,59	2,59	2,66	2,73	2,81	2,89	2,60	2,60	2,60	2,60
A_f	Area frozen food compartment [m2]	1,27	1,27	1,27	1,27	1,27	1,32	1,38	1,43	1,49	1,26	1,26	1,26	1,26
A_{cd}	condenser area (m ²)	0,856	0,856	0,856	0,856	0,856	0,900	0,945	0,991	1,043	0,856	0,856	0,856	0,856
A_{cp}	compressor area (m ²)	0,148	0,148	0,148	0,148	0,148	0,153	0,158	0,164	0,170	0,148	0,148	0,148	0,148
A_{ev}	evaporator area (m ²)	na												
$L_{dr,r}$	refrigerator door perimeter length (m)	3,36	3,36	3,36	3,36	3,36	3,43	3,49	3,55	3,61	3,37	3,37	3,37	3,37
$L_{dr,f}$	freezer door perimeter length (m)	2,30	2,30	2,30	2,30	2,30	2,36	2,43	2,50	2,57	2,29	2,29	2,29	2,29
w	width (m)	0,59	0,59	0,59	0,59	0,59	0,61	0,63	0,65	0,68	0,59	0,59	0,59	0,59
d	depth (m)									0,6781				
h	height (m)									1,7881				
h_s	height level separator (mid position) [m]	1,7	1,7	1,7	1,7	1,7	1,7215	1,743	1,7645	5	1,7	1,7	1,7	1,7
a	air passage height below unit (m)	0,583	0,583	0,583	0,583	0,583	0,595	0,608	0,620	0,634	0,578	0,578	0,578	0,578
b	height & depth compressor area (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
t	average wall thickness (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_{wr}	t wall ratio	0,059	0,059	0,059	0,059	0,059	0,069	0,079	0,089	0,100	0,059	0,059	0,059	0,059
t_r	wall thickness fresh food [m]	0,761	0,761	0,761	0,761	0,761	0,780	0,865	0,935	1,000	0,761	0,761	0,761	0,761
t_f	wall thickness frozen food [m]	0,045	0,045	0,045	0,045	0,045	0,054	0,068	0,083	0,100	0,045	0,045	0,045	0,045
T_r	refrigerator temperature (°C)	0,088	0,088	0,088	0,088	0,088	0,100	0,100	0,100	0,100	0,088	0,088	0,088	0,088
T_f	freezer temperature (°C)	5	5	5	5	5	5	5	5	5	5	5	5	5
T_c	Average compartment temperature (°C)	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
T_a	ambient temperature (°C)	-2,6	-2,6	-2,6	-2,6	-2,6	-2,5	-2,3	-2,6	-3,5	-2,5	-2,5	-2,5	-2,5
k	heat conductivity (W/mK)	25	25	25	25	25	25	25	25	25	25	25	25	25
U_{wall}	heat transfer coefficient wall (W/m ² K)	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
P_{trans}	transmission heat loss (W)	0,339	0,339	0,339	0,339	0,339	0,290	0,253	0,225	0,200	0,307	0,273	0,339	0,339
$U_{misc,r}$	refrigerator heat transfer coefficient door gasket and misc loads (W/mK)	36	36	36	36	36	32	28	26	25	33	29	36	36
$U_{misc,f}$	freezer heat transfer coefficient door gasket and misc loads (W/mK)	0,080	0,080	0,080	0,080	0,080	0,080	0,062	0,047	0,030	0,080	0,080	0,080	0,080
P_{misc}	door and misc heat loss (W)	0,042	0,042	0,042	0,042	0,042	0,030	0,030	0,030	0,030	0,042	0,042	0,042	0,042
$P_{loss,tot}$	total heat power loss $P_{trans} + P_{misc}$ (W)	10	10	10	10	10	9	8	7	6	10	10	10	10
$P_{loss,tot,r}$	Total heat loss refrigerator (W)	46	46	46	46	46	40	36	33	31	42	39	46	46
$P_{loss,tot,f}$	Total heat loss freezer (W)	28	28	28	28	28	25	20	17	14	29	29	29	29
$E_{loss,tot}$	annual heat energy loss (kWh _{th} /a)	17	17	17	17	17	15	16	16	17	17	17	17	17
	annual heat energy loss (kWh_{th}/a)	402	402	402	402	402	354	315	289	268	371	339	401	401

ΔT_{ev}	refrigerator evaporator temperature difference (K)	33,0	33,0	33,0	33,0	30,1	32,9	33,7	34,4	35,2	33,4	33,9	33,0	33,1
ΔT_{fr}	freezer evaporator temperature difference (K)	8,0	8,0	8,0	8,0	5,1	7,9	8,7	9,4	10,2	8,4	8,9	8,0	8,1
$\Delta T_{cd r}$	refrigerator condenser temperature difference (K)	10,0	9,8	9,6	9,4	6,2	10,0	9,7	9,4	9,2	9,9	9,7	10,0	7,6
$\Delta T_{cd f}$	freezer condenser temperature difference (K)	10,0	9,8	9,6	9,4	6,2	10,0	9,7	9,4	9,2	9,9	9,7	10,0	7,6
T_{ev_r}	refrigerator evaporator temperature (°C)	-28,0	-28,0	-28,0	-28,0	-25,1	-27,9	-28,7	-29,4	-30,2	-28,4	-28,9	-28,0	-28,1
T_{ev_f}	freezer evaporator temperature (°C)	-28,0	-28,0	-28,0	-28,0	-25,1	-27,9	-28,7	-29,4	-30,2	-28,4	-28,9	-28,0	-28,1
$T_{cd r}$	refrigerator condenser temperature (°C)	35,0	34,8	34,6	34,4	31,2	35,0	34,7	34,4	34,2	34,9	34,7	35,0	32,6
$T_{cd f}$	freezer condenser temperature (°C)	35,0	34,8	34,6	34,4	31,2	35,0	34,7	34,4	34,2	34,9	34,7	35,0	32,6
P_{nom}	Nominal compressor cooling power (W)	141	141	141	141	71	141	141	141	141	141	141	141	141
COP_{nom}	nominal at -23.3/54.4°C, sub-cooling 32.2°C (-)	1,57	1,725	1,85	1,98	1,85	1,57	1,57	1,57	1,57	1,57	1,57	1,57	1,57
$P_{refrigerator}$	Refrigerator cool power (W)	121	121	121	121	74	121	116	112	108	118	115	121	124
$P_{freezer}$	Freezer cool power (W)	121	121	121	121	74	121	116	112	108	118	115	121	124
COP_{Pref}	Refrigerator COP (-)	1,75	1,93	2,08	2,23	2,42	1,75	1,72	1,70	1,68	1,74	1,72	1,75	1,84
$COP_{freezer}$	Freezer COP (-)	1,75	1,93	2,08	2,23	2,42	1,75	1,72	1,70	1,68	1,74	1,72	1,75	1,84
COP_{global}	Average COP	1,75	1,93	2,08	2,23	2,42	1,75	1,72	1,70	1,68	1,74	1,72	1,75	1,84
Cool. Load Ratio	Ratio of Demand (Tamb) to P	38%	38%	38%	38%	62%	33%	31%	29%	28%	36%	34%	38%	37%
Cycling losses	Part load performance	7,7%	7,8%	7,8%	7,8%	4,8%	8,3%	8,6%	8,8%	8,9%	8,0%	8,3%	3,9%	7,9%
COP_{real}	With cycling correction	1,6	1,8	1,9	2,1	2,3	1,6	1,6	1,6	1,5	1,6	1,6	1,7	1,7
E_{aux}	electricity CPU and possible fan (kWh/a)	9	9	9	9	13	9	9	9	9	9	9	9	11
AE	annual electricity consumption (kWh _e /a)	258	235	219	204	188	230	209	195	184	241	224	247	248
	REDUCTION IN CONSUMPTION (%)		9%	15%	21%	27%	11%	19%	24%	29%	7%	13%	4%	4%

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

<i>Base case</i>		COLD8	C1	C2	C3	VSD (+C2)	I1	I2	I4	I5	PCM	F1	F2
Vrf	refrigerated volume (m ³)	0,203	0,203	0,203	0,203	0,203	0,203	0,203	0,203	0,203	0,203	0,203	0,203
	refrigerated volume (litres dm ³)	203	203	203	203	203	203	203	203	203	203	203	203
Arf	refrigerator envelope surface (m ²)	3,220	3,220	3,220	3,220	3,220	3,318	3,367	3,220	3,220	3,220	3,220	3,220
Acd	condenser area (m ²)	0,743	0,743	0,743	0,743	0,743	0,781	0,800	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	0,145	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	4,32	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	0,58	0,55	0,55	0,55	0,55	0,55
d	depth (m)	0,587	0,587	0,587	0,587	0,587	0,607	0,617	0,587	0,587	0,587	0,587	0,587
h	height (m)	1,6	1,6	1,6	1,6	1,6	1,62	1,63	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
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)	0,085	0,085	0,085	0,085	0,085	0,095	0,100	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
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/m ² K)	0,24	0,24	0,24	0,24	0,24	0,21	0,20	0,22	0,20	0,24	0,24	0,24
Ptrans	transmission heat loss (W)	34	34	34	34	34	31	30	31	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
Pmisc	door and misc. heat loss Ldr*Udoor (W)	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	36	37	34	40	40	40
Eloss_tot	annual heat energy loss (kWh/a)	348	348	348	348	348	326	317	325	299	348	351	348
ΔTev	evaporator temperature difference (K)	10,0	10,0	10,0	10,1	6,7	10,0	10,0	10,0	10,0	10,0	8,1	10,3
ΔTcd	condenser temperature difference K	12,0	11,8	11,6	11,4	7,6	12,0	12,0	12,0	12,0	12,0	13,0	9,0
Tev	evaporator temperature (°C)	-30,0	-30,0	-30,0	-30,1	-26,7	-30,0	-30,0	-30,0	-30,0	-30,0	-28,1	-30,3
Tcd	condenser temperature (°C)	37,0	36,8	36,6	36,4	32,6	37,0	37,0	37,0	37,0	37,0	38,0	34,0
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
Pnom	Nominal compressor cooling power (W)	129	129	129	129	65	129	129	129	129	129	129	129
P	Cool power (W)	96	96	96	96	62	96	96	96	96	96	106	98
Cool. Load Ratio	Ratio of heat load to cool power	42%	42%	41%	41%	65%	39%	38%	39%	36%	42%	38%	40%
Cycling losses	Part load performance degradation losses (in % COP)	7%	7%	7%	7%	4%	8%	8%	8%	8%	4%	8%	7%
COP	COP value with actual Tev and Tcd temperatures	1,7	1,8	1,9	2,0	2,2	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	1,5	1,6	1,8	1,9	2,1	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	7,2	7,0
AE	annual electricity consumption (kWhel/a)	232	217	202	188	172	218	212	218	201	223	232	223
REDUCTION IN CONSUMPTION (%)			7%	13%	19%	26%	6%	8%	6%	13%	4%	0%	4%

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

<i>Base case</i>		COLD9	C1	C2	C3	VSD (+ C2)	I1	I2	I4	I5	PCM	F1
Vrf	refrigerated volume (m ³)	0,261	0,261	0,261	0,261	0,261	0,261	0,261	0,261	0,261	0,261	0,261
	refrigerated volume (litres dm ³)	261	261	261	261	261	261	261	261	261	261	261
Arf	refrigerator envelope surface (m ²)	3,280	3,280	3,280	3,280	3,280	3,370	3,462	3,280	3,280	3,280	3,280
Acd	condenser area (m ²)	1,244	1,244	1,244	1,244	1,244	1,309	1,375	1,244	1,244	1,244	1,244
Acp	compressor area (m ²)	0,236	0,236	0,236	0,236	0,236	0,241	0,246	0,236	0,236	0,236	0,236
Ldr	door perimeter length (m)	3,19	3,19	3,19	3,19	3,19	3,27	3,35	3,19	3,19	3,19	3,19
w	width (m)	0,945	0,945	0,945	0,945	0,945	0,965	0,985	0,945	0,945	0,945	0,945
d	depth (m)	0,7	0,7	0,7	0,7	0,7	0,72	0,74	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	0,9	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
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
t	average wall thickness (m)	0,080	0,080	0,080	0,080	0,080	0,090	0,100	0,080	0,080	0,080	0,080
Tc	compartment temperature (°C)	-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
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
Uwall	heat transfer coefficient wall (W/m ² K)	0,25	0,25	0,25	0,25	0,25	0,22	0,20	0,23	0,21	0,25	0,25
Ptrans	transmission heat loss (W)	37	37	37	37	37	34	31	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
Pmisc	door and misc. heat loss Ldr*Udoor (W)	4	4	4	4	4	4	5	4	4	4	4
Ploss_tot	total heat power loss Ptrans + Pdoor (W)	41	41	41	41	41	38	36	39	35	41	41
Eloss_tot	annual heat energy loss (kWh/a)	361	361	361	361	361	334	313	341	303	361	363
ΔTev	evaporator temperature difference (K)	10,0	10,0	10,0	10,0	5,9	10,0	10,0	10,0	10,0	10,0	8,0
ΔTcd	condenser temperature difference K	12,0	11,9	11,7	11,5	6,8	12,0	12,0	12,0	12,0	12,0	13,1
Tev	evaporator temperature (°C)	-30,0	-30,0	-30,0	-30,0	-25,9	-30,0	-30,0	-30,0	-30,0	-30,0	-28,0
Tcd	condenser temperature (°C)	37,0	36,9	36,7	36,5	31,8	37,0	37,0	37,0	37,0	37,0	38,1
COPnom	nominal at -23.3/54.4°C, sub-cooling 32.2°C	1,65	1,73	1,85	1,98	1,85	1,65	1,65	1,65	1,65	1,65	1,65
Pnom	Nominal compressor cooling power (W)	141	141	141	141	59	141	141	141	141	141	141
P	Cool power (W)	104	104	105	105	59	104	104	104	104	104	116
Cool. Load Ratio	Ratio of heat load to cool power	40%	39%	39%	39%	69%	37%	34%	37%	33%	40%	36%
Cycling losses	Part load performance degradation losses (in % COP)	8%	8%	8%	8%	4%	8%	8%	8%	8%	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
COPcyc	COP value with actual Tev and Tcd temperatures and cycling losses	1,6	1,6	1,7	1,9	2,2	1,5	1,5	1,5	1,5	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	7,1
AE	annual electricity consumption (kWhel/a)	236	228	212	198	170	222	209	226	203	230	237
REDUCTION IN CONSUMPTION (%)			3%	10%	16%	28%	6%	12%	4%	14%	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%	15%	9%	7%	3%
C2	Compressor nominal COP improvement	12%	20%	15%	13%	10%
C3	Compressor nominal COP improvement	7%	15%	21%	19%	16%
VSD	Variable frequency drive	11%	24%	27%	26%	28%
I1	Increased insulation thickness	11%	17%	11%	6%	6%
I2	Increased insulation thickness	23%	29%	19%	8%	12%
I3	Increased insulation thickness	31%	36%	24%	NA	NA
I3+	Increased insulation thickness	40%	41%	29%	NA	NA
I4	Use of vacuum insulated panels, 70 % of door are covered	8%	NA	7%	6%	4%
I5	Use of vacuum insulated panels, 50 % of lateral and back sides covered	16%	14%	13%	13%	14%
D1	Glass door double glazing E-coating, krypton fill	NA	9%	NA	NA	NA
D2	Glass door triple glazing E-coating, krypton fill (heavy door)	NA	14%	NA	NA	NA
PCM	Phase change material (water for refrigerator or water and ammonium chloride solution for freezer)	5%	3%	4%	4%	3%
F1	Improved convection heat transfer with indoor fan and multiflow	3%	3%	NA	0%	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	19%
COLD2	1,47	1,50	23%
COLD7	1,57	1,85	14%
COLD8	1,62	1,85	15%
COLD9	1,65	1,85	19%

Regarding insulation, results largely depend on 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. Note also that the loss in volume due to the addition of 3 mm of PCM is not accounted for because the impact is low. This could reduce the gains by maximum 10%, ie 4.5 instead of 5% gains, but this could be lower as this depends on the specific heat exchanger design.

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 COLD1 and COLD2. Note that the volume envelope increase of option F1 has not been considered¹⁴⁹. The increase indoor volume required for the multiflow and fan of F1 design option may increase the heat losses by as much as 1 %, reducing consequently the gains from 3% to nearly 2%. As the final impact of this design option on the global improvement potential is very low, this was however not included in the calculation. Still for the F1 design option, the gains for freezers are respectively very low (COLD8) or negative (COLD9). The F1 option is thus not considered when simulating the impact of cumulative options for these appliances.

The gain of the inverter option is shown, net of the COP variation. Except for COLD2 base case, the gain lies between 14 and 23 %. The COLD2 base case has a large improvement, because of large initial temperature differences at design conditions. Conversely, the COLD7 base case exhibits a smaller improvement because the relative gain is limited for the refrigerator evaporator as its temperature is linked to the one of the freezer evaporator.

12.3 Costs per option

The prices of the base cases as well as the estimated manufacturer selling prices have been given in Task 4 and are summarized below.

Table 55. Base case price information

Basecase	energy	net volume	avg unit price	msp	ratio price/ msp
	<i>kWh/a</i>	<i>litre</i>	euros	euros	-
COLD1	119	248	495	202	2,5
COLD2	177	207	1344	336	4,0
COLD7	258	309	557	231	2,4
COLD8	232	203	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			
Option	Compressor		F_OEM
	Evaporator(s) / aspiration storage volume		F_MANUF
	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 ...			
Option	Cabinet / door steel sheet		F_MANUF
	Insulation PUR cyclopentane		F_MANUF
	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
Option F1	Drawers	FINISH	F_OEM
	Handle	FINISH	F_OEM
	Multiflow	FINISH	F_OEM
ELECTRIC			
Option F1 and F2	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
	Fan(s)		F_OEM
		Subtotal	
	TOTALS	Components	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 kept in the model, 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: a low value 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 components as 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	2,38	3,32	2,00	1,67	1,98
FINISH	1,66	3,50	1,66	1,00	1,00
Total component / raw material value in Euros	113	132	143	150	125
Total component / raw material value in % of MSP	56%	39%	62%	69%	58%
Overhead, energy, labor ... in Euros	89	204	88	67	91
Overhead, energy, labor ... in % of MSP	44%	61%	38%	31%	42%
Manufacturer selling price (MSP)	202	336	231	217	215

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

A compressor price increase of 10 USD¹⁵⁶ for 0.3 point improvement in nominal COP has been used¹⁵⁷. 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 / m². 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 estimates for D1 and D2 options are based on information supplied by M. Janssen¹⁴⁹; D1 glass door extra cost is 46 euros and D2 is 200 euros.

Phase change material

The cost from Yusufoglu¹⁵⁸ have been used, 0.45 USD per kg, considering 3 mm thick packs.

Heat exchanger options (F1 and F2)

¹⁵⁶ With a change USD / EURO of 0.9 in the model.

¹⁵⁷ Greenblatt, Jeffery B.. Technical Support Document for the Final Rule on Residential Refrigerators, Refrigerator-Freezers and Freezers. U.S. Department of Energy, 2011.

¹⁵⁸ Y.Yusufoglu, T. Apaydin, S. Yilmaz, H.O. Paksoy, Improving Performance of Household refrigerators by Incorporating Phase Change Materials, International Journal of Refrigeration, 2015.

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.

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		557		439		356	
C1	11	2%	51	4%	18	3%	11	2%	5	1%
C2	25	5%	76	6%	32	6%	23	5%	14	4%
C3	41	8%	102	8%	46	8%	37	8%	23	7%
VSD	22	4%	71	5%	88	16%	73	17%	49	14%
I1	30	6%	77	6%	31	6%	24	6%	16	5%
I2	62	12%	241	18%	63	11%	37	8%	33	9%
I3	94	19%	417	31%	97	17%	NA	NA	NA	NA
I3+	175	35%	707	53%	135	24%	NA	NA	NA	NA
I4	53	11%	NA	NA	31	6%	36	8%	21	6%
I5	109	22%	138	10%	82	15%	77	18%	61	17%
D1	NA	NA	46	3%	NA	NA	NA	NA	NA	NA
D2	NA	NA	200	15%	NA	NA	NA	NA	NA	NA
PCM	16	3%	19	1%	9	2%	15	4%	16	4%
F1	19	4%	54	4,0%	NA	NA	12	3%	13	4%
F2	7	1%	12	1%	7	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.

The above section does not incorporate cost-reduction to the learning effect. The learning effect will be taken into account in the scenario analysis (section 13).

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:

$$LCC = PP + N \cdot OE + EoL$$

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 consumption (kWh)	Reduction in consumption (%)	Price (Euros)	Price increase (Euros)	Price increase (%)	SPB (years)	LCC (Euros)
BC	119		495				884
F2	114	3,7%	502	7	1%	7,9	877
VSD	105	11,4%	517	22	4%	8,0	862
C1	113	5,2%	506	11	2%	8,4	875
C2	105	11,6%	520	25	5%	9,0	865
I2	92	22,6%	557	62	12%	11,2	858
I1	106	11,0%	525	30	6%	11,3	872
I3	82	30,6%	590	94	19%	12,7	860
PCM	114	4,3%	511	16	3%	15,4	884
I3+	71	40,0%	671	175	35%	18,0	904
C3	111	6,9%	536	41	8%	24,5	899
F1	115	2,9%	514	19	4%	27,0	892
I5	100	15,6%	604	109	22%	28,7	933
I4	110	7,5%	548	53	11%	28,8	908

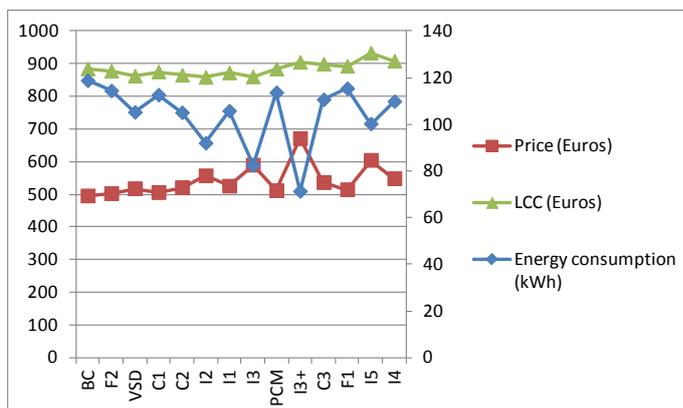


Table 60. COLD2. LCC of individual options.

	Energy consumption (kWh)	Reduction in consumption (%)	Price (Euros)	Price increase (Euros)	Price increase (%)	SPB (years)	LCC (Euros)
BC	177		1344				1925
F2	168	5,0%	1356	12,00	1%	6,6	1890
VSD	134	24,3%	1415	70,55	5%	8,0	1882
C1	151	14,8%	1395	51,00	4%	9,5	1938
C2	141	20,5%	1420	76,00	6%	10,2	1854
I1	147	16,8%	1421	77,18	6%	12,6	1904
PCM	170	4,0%	1363	18,89	1%	13,1	1996
D1	160	9,3%	1390	45,56	3%	13,4	2135
C3	150	15,4%	1446	102,34	8%	18,3	2395
I2	125	29,3%	1585	240,92	18%	22,7	1983
I5	153	13,7%	1482	137,60	10%	27,7	1920
I3	114	35,6%	1761	417,39	31%	32,3	1961
D2	152	14,1%	1545	200,45	15%	39,3	1908
I3+	105	40,7%	2051	706,63	53%	47,9	1916
F1	172	3,1%	1398	54,00	4%	48,8	2044

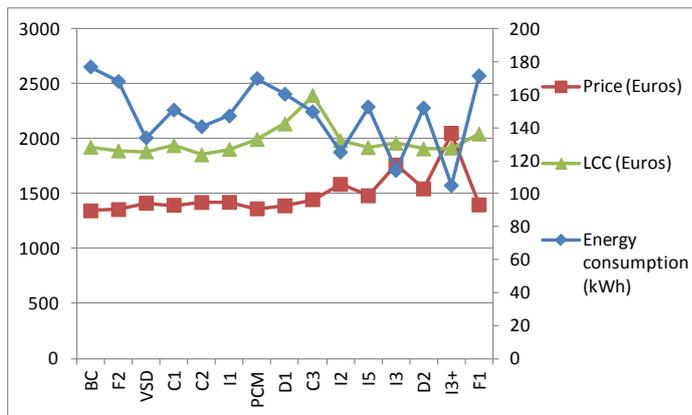


Table 61. COLD7. LCC of individual options.

	Energy consumption (kWh)	Reduction in consumption (%)	Price (Euros)	Price increase (Euros)	Price increase (%)	SPB (years)	LCC (Euros)
BC	258		557				1403
F2	248	3,8%	564	6,88	1%	3,4	1378
C1	235	9,1%	575	17,53	3%	3,6	1344
C2	219	15,3%	589	31,67	6%	3,9	1306
C3	204	20,8%	603	46,37	8%	4,2	1273
PCM	247	4,2%	566	9,35	2%	4,2	1377
I1	230	10,9%	588	30,78	6%	5,3	1341
VSD + C2	188	27,2%	645	87,64	16%	6,1	1261
I2	209	19,2%	620	62,97	11%	6,2	1304
I3	195	24,5%	654	96,57	17%	7,5	1293
I3+	184	28,6%	692	135,21	24%	8,9	1296
I4	241	6,5%	588	31,16	6%	9,0	1379
I5	224	13,2%	639	82,17	15%	11,8	1374

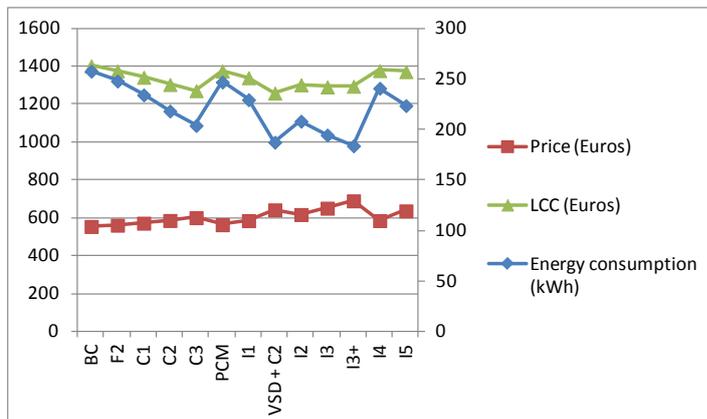


Table 62. COLDB. LCC of individual options.

	Energy consumption (kWh)	Reduction in consumption (%)	Price (Euros)	Price increase (Euros)	Price increase (%)	SPB (years)	LCC (Euros)
BC	232		439				1200
C1	217	6,5%	450	10,9	2,5%	3,5	1161
F2	223	4,0%	445	6,0	1,4%	3,2	1175
C2	202	13,0%	462	23,5	5,3%	3,8	1124
C3	188	18,9%	475	36,5	8,3%	4,1	1092
VSD (+C2)	172	25,7%	512	73,3	16,7%	6,0	1077
I1	218	6,0%	463	24,4	5,6%	8,6	1179
PCM	223	3,7%	454	15,4	3,5%	8,7	1187
I2	212	8,5%	476	37,0	8,4%	9,2	1172
I5	201	13,3%	516	77,2	17,6%	12,2	1176
I4	218	6,2%	475	36,2	8,2%	12,3	1189

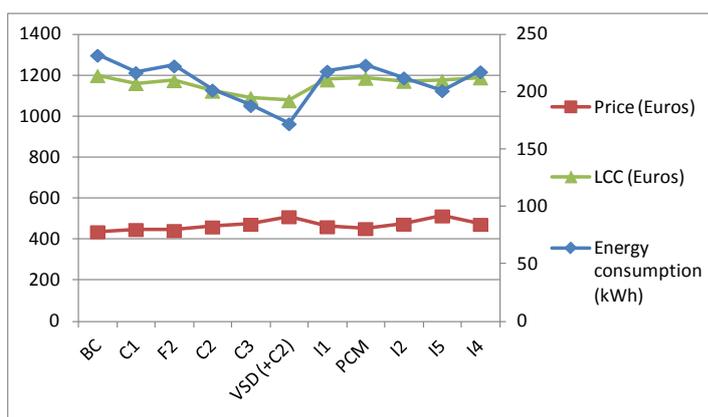
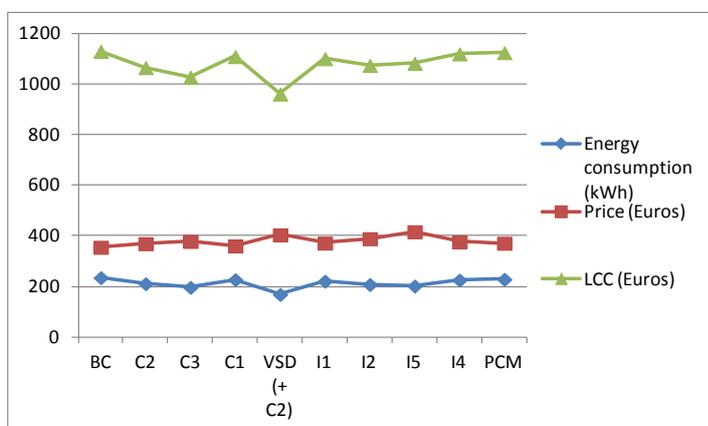


Table 63. COLDB. LCC of individual options.

	Energy consumption (kWh)	Reduction in consumption (%)	Price (Euros)	Price increase (Euros)	Price increase (%)	SPB (years)	LCC (Euros)
BC	236		356				1130
C2	212	10,1%	370	14,04	3,9%	2,9	1066
C3	198	16,2%	379	23,21	6,5%	3,0	1028
C1	228	3,4%	361	5,22	1,5%	3,2	1109
VSD (+ C2)	170	28,1%	405	48,90	13,7%	3,6	961
I1	222	5,9%	373	16,49	4,6%	5,8	1101
I2	209	11,5%	390	33,67	9,5%	6,0	1075
I5	203	14,0%	417	61,31	17,2%	9,0	1083
I4	226	4,1%	377	21,20	6,0%	10,8	1120
PCM	230	2,7%	372	15,91	4,5%	12,0	1125



For cumulative design options, the simple payback time criterion of individual options 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 before.

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 corresponding points are not drawn as they would be misleading. The same is true for A+ and A++ wine coolers. Except for these specific cases, the comparison is convincing : most of the points added with these market prices lie close to the LCC curve. Only for COLD1 appliances, the modelled impact of design options tends to underestimate the potential seen from the market because of higher prices of cumulative design options as compared to prices issued from market data for A++ and A+++ energy label grades.

In the tables below, options in red are not kept as cumulative options because their addition at their position would increase the consumption rather than cutting it.

Two lines with EEI values are also added in these tables. The first line is for the appliance supposing it has a SN climate class. As this value may not be representative for the whole class, because of existing correction factors ofr no frost, built-in and specific climate class, a second line is proposed. It starts with the average EEI for the category. Indications on anchor points are based on the category average. The feasibility of the improvement potential for no-frost and built-in appliances is dicussed below Table 69 hereafter.

In the case of wine coolers, the category average previously identified does not match closely the base case, as explained before.

Table 64. COLD1. LCC of cumulative options. Table and LCC (Euros) curve versus annual consumption (kWh).

Anchor points	A++		LLCC		A++ +		BEP	BEP	BAT					
Option	BC	F2	VSD	C1	C2	I2	I1	I3	PCM	I3+	C3	F1	I5	I4
Energy consumption (kWh)	119	114	104	109	101	79	90	71	67,0	58,0	60,2	62,1	58	55
Cons. reduction in %		4%	12%	9%	15%	34%	24%	41%	44%	51%	49%	48%	51%	54%
Price (Euros)	495	502	524	513	528	589	558	622	639	720	736	755	861	922
Price increase in %		1%	6%	4%	7%	19%	13%	26%	29%	46%	49%	53%	74%	86%
SPB		7,9	9,7	8,5	9,2	11,5	10,8	12,9	13,6	18,1	20,1	22,4	29,5	32,8
LCC	884	877	865	869	860	847	854	853	858	911	933	959	1052	1103
EEl / product (SN)	39%	37%	34%	36%	33%	26%	30%	23%	22%	19%	20%	20%	19%	18%
EEl / category average	36 %	35 %	32 %	33 %	31 %	24 %	27 %	21%	20 %	18 %	18 %	19 %	18 %	17 %

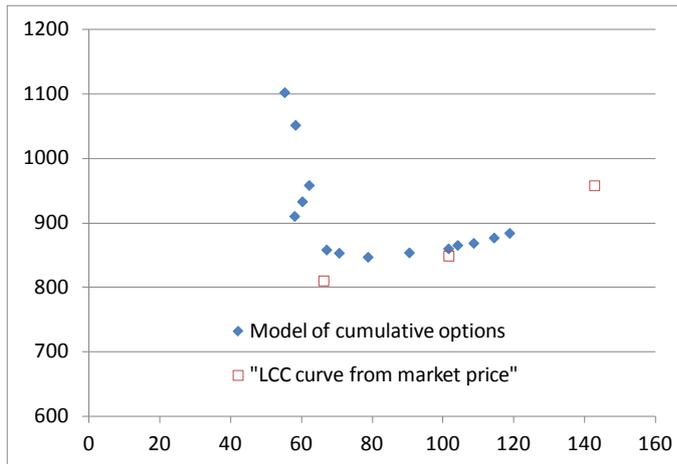


Table 65. COLD2. LCC of cumulative options. Table and LCC (Euros) curve versus annual consumption (kWh).

Anchor points	B	A	LLCC / A+		A+	A++ / BEP		A++ / BEP		A++ +	A++ +	BAT			
Option	BC	F2	VSD	C1	C2	I1	PCM	D1	C3	I2	I5	I3	D2	I3+	F1
Energy consumption (kWh)	177	144	131	144	135	110	107	99	104	83	77	71	60	53	52
Cons. reduction in %		19%	26%	19%	24%	38%	40%	44%	41%	53%	56%	60%	66%	70%	71%
Price (Euros)	1344	1407	1427	1407	1432	1504	1523	1571	1603	1741	1867	2040	2241	2553	2607
Price increase in %		5%	6%	5%	7%	12%	13%	17%	19%	30%	39%	52%	67%	90%	94%
SPB		9,6	9,0	9,6	10,4	12,0	12,7	14,5	17,8	21,2	26,2	32,9	38,3	48,9	50,4
LCC	1925	1880	1856	1880	1874	1866	1873	1895	1945	2014	2121	2274	2437	2728	2777
EEl / product (SN)	64%	52%	47%	52%	49%	40%	39%	36%	38%	30%	28%	26%	22%	19%	19%

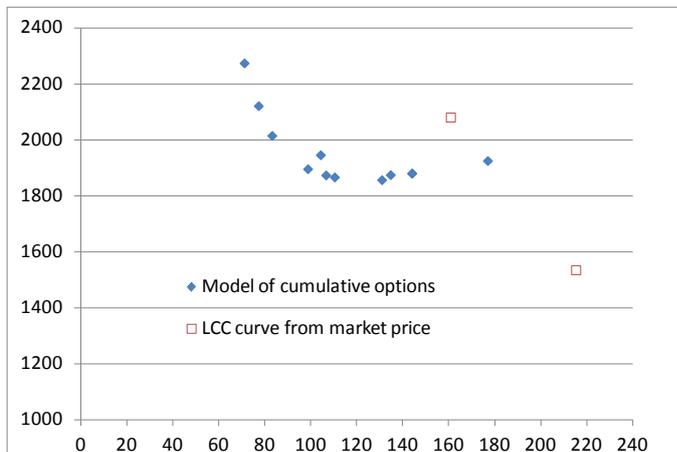


Table 66. COLD7. LCC of cumulative options. Table and LCC (Euros) curve versus annual consumption (kWh).

Anchor points	A++					LLCC	A++ +	A++ +	BAT				
	BC	F2	C1	C2	C3	PCM	I1	VSD + C2	I2	I3	I3+	I4	I5
Energy consumption (kWh)	258	249	227	212	198	191	169	163	148	139	132	125	112
Cons. reduction in %		4%	12%	18%	23%	26%	34%	37%	42%	46%	49%	51%	57%
Price (Euros)	557	564	581	595	610	619	651	691	723	757	796	818	905
Price increase in %		1%	4%	7%	10%	11%	17%	24%	30%	36%	43%	47%	62%
SPB		3,6	3,8	4,1	4,3	4,6	5,1	6,9	7,4	8,2	9,2	9,6	11,6
LCC	1403	1380	1325	1290	1260	1246	1206	1225	1210	1213	1228	1230	1272
EEI / product (SN)	42%	41%	37%	34%	32%	31%	28%	27%	24%	23%	21%	20%	18%
EEI / category average	36%	35%	32%	30%	28%	27%	24%	23%	21%	20%	19%	18%	16%

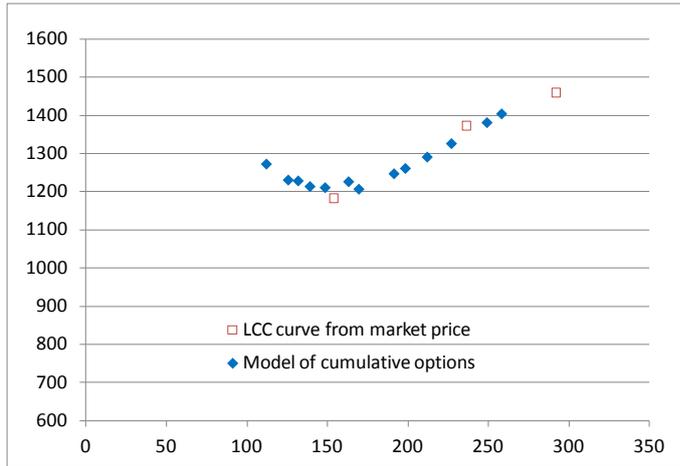


Table 67. COLD8. LCC of cumulative options. Table and LCC (Euros) curve versus annual consumption (kWh).

Anchor points	A++			A++	LLCC			A+++	A+++	BAT	
Option	BC	C1	F2	C2	C3	VSD (+C2)	I1	PCM	I2	I5	I4
Energy consumption (kWh)	232	217	209	194	182	171	162	158	154	136	127
Cons. reduction in %		7%	10%	16%	22%	26%	30%	32%	34%	42%	45%
Price (Euros)	439	450	456	468	481	518	543	558	571	651	689
Price increase in %		2%	4%	7%	10%	18%	24%	27%	30%	48%	57%
SPB		3,6	3,6	3,9	4,2	6,5	7,4	8,0	8,4	11,0	11,9
LCC	1200	1161	1140	1106	1077	1080	1073	1076	1075	1096	1106
EEI / product (SN)	42%	39%	38%	35%	33%	31%	29%	29%	28%	25%	23%
EEI / category average	37%	34%	33%	31%	29%	27%	26%	25%	24%	21%	20%

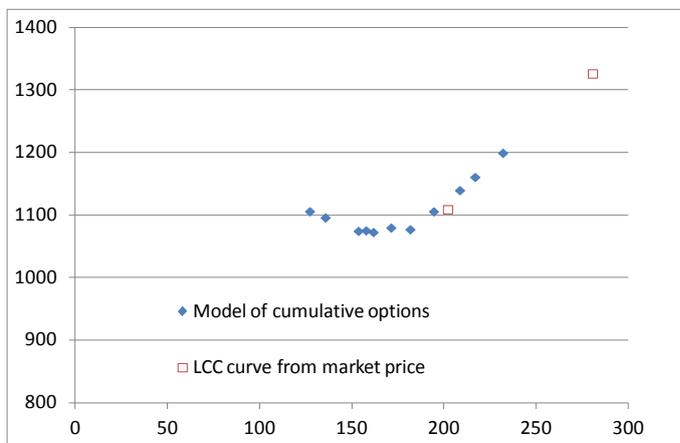
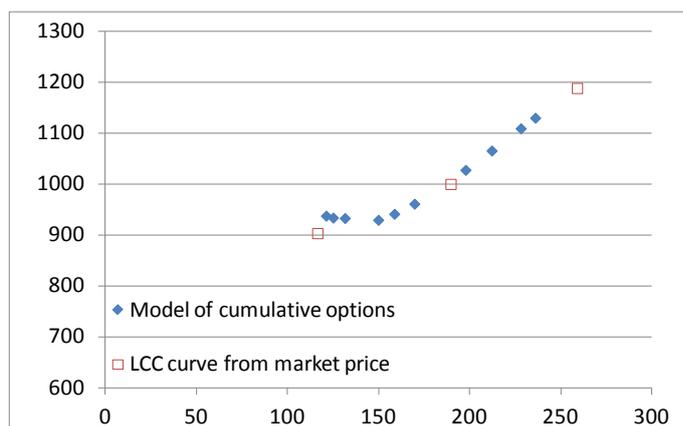


Table 68. COLD9. LCC of cumulative options. Table and LCC (Euros) curve versus annual consumption (kWh).

Anchor points	A++				A++		LLCC		A+++		A+++ /BAT
Option	BC	C2	C3	C1	VSD (+ C2)	I1	I2	I5	I4	PCM	
Energy consumption (kWh)	236	212	198	228	170	159	150	131	125	121	
Cons. reduction in %		10%	16%	3%	28%	33%	37%	44%	47%	49%	
Price (Euros)	356	370	379	361	405	421	438	502	524	541	
Price increase in %		4%	7%	1%	14%	18%	23%	41%	47%	52%	
SPB		2,9	3,0	3,3	3,7	4,2	4,8	7,0	7,6	8,0	
LCC	1130	1066	1028	1109	961	942	930	933	934	938	
EEI / product (SN)	43%	39%	36%	41%	31%	29%	27%	24%	23%	22%	
EEI / category average	39%	35%	33%	38%	28%	26%	25%	22%	21%	20%	



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

Product category	energy					money				
	BC	LLCC	BEP	BAT		BC	LLCC	BEP	BAT	
COLD1	kWh/a	119	79	62	55	Price (€)	495	589	680	922
	EEI / Category	36%	24%	19%	17%	LCC (€)	884	847	884	1103
	% gain	ref	34%	47%	54%	SPB (yr)	ref	11,5	15,8	32,8
COLD2	kWh/a	177	131	99	52	Price (€)	1344	1427	1571	2607
	EEI BC	58%	43%	32%	17%	LCC (€)	1925	1856	1895	2777
	% gain	ref	26%	44%	71%	SPB (yr)	ref	9,0	14,5	50,4
COLD7	kWh/a	258	169	na	112	Price (€)	557	651	na	905
	EEI / Category	36%	24%	na	16%	LCC (€)	1403	1206	na	1272
	% gain	ref	34%	na	62%	SPB (yr)	ref	5,1	na	11,6
COLD8	kWh/a	232	162	na	127	Price (€)	439	543	na	689
	EEI / Category	37%	26%	na	20%	LCC (€)	1200	1073	na	1106
	% gain	ref	30%	na	45%	SPB (yr)	ref	7,4	na	11,9
COLD9	kWh/a	236	150	na	121	Price (€)	356	438	na	541
	EEI / Category	39%	25%	na	20%	LCC (€)	1130	930	na	938
	% gain	ref	37%	na	52%	SPB (yr)	ref	4,8	na	8,0

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. Grey areas are interpolated values.

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').

Conclusion regarding improvement potential

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 25 to over 35 % with respect to the average new product. Benchmarks for Best Available Technology (BAT) show savings from 45 to 70% with respect to the average new product. It is important to notice the LCC curves are relatively flat. This explains that the BEP savings are about 45 % for refrigerators and that there is no BEP for freezers and combined appliances.

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 RTD¹⁵⁹ in its program development.

¹⁵⁹ European Commission, Directorate-General for Research and Innovation

13 Scenarios (Task 7)

13.1 Introduction

The policy and scenario analysis in this review study is limited and does not cover all subjects mentioned in the MEErP methodology. A first reason is the fact that currently the Energy Labelling Directive 2010/EC is under review by Parliament and Council. Until that review is concluded it is not possible to formulate detailed energy labelling measures. And because energy labelling and Ecodesign measures are linked, any details of Ecodesign measures are also uncertain.

A second reason is the limited scope and budget of this review study, which already from the start did not foresee a full impact assessment according to MEErP-standards. A comprehensive impact assessment study will be the subject of a separate study by the European Commission that will run in the context of preparing the Commission's working documents and support the following consultation and decision-making procedure.

Thirdly, the new metric proposed in Chapter 9, following the new IEC standard, has to be discussed in the political decision making process. Depending on the details of that decision making, the outcomes may vary considerably.

Having said that, the previous chapters on Task 1 to 6, do give an indication of the savings and related impacts that may be expected, e.g. with limits at least life cycle costs (LLCC) that are a yardstick for minimum Ecodesign requirements at approximately 35% below the current average (see table 70) and historical savings of effective energy labelling at a level of 3% annually.¹⁶⁰

Table 70. Calculation main scenario inputs (sales weighted average)

base case 2015	energy				Money				unit sales %	Vnet, ltr per unit	Vnet sales %	€/kWh/a	€/kWh/a
		BC	LLCC	BAT		BC	LLCC	BAT				BC-->LLCC	LLCC -->BAT
COLD1 (rc=1)	kWh/a	119	79	55	Price (€)	495	589	922	18.6%	251	16.4%	2.35	13.88
	EEl	36	29	17	LCC (€)	884	847	1103					
	% gain	ref	34%	54%	SPB (yr)	ref	11.5	32.8					
COLD2 (rc=0.52)	kWh/a	177	131	52	Price (€)	1344	1427	2607	1.5%	207	1.1%	1.80	14.94
	EEl	58	43	17	LCC (€)	1925	1856	2777					
	% gain	ref	26%	71%	SPB (yr)	ref	9	50.4					
COLD7 (rc=1.31)	kWh/a	258	169	112	Price (€)	557	651	905	59.3%	309	64.4%	1.06	4.46
	EEl	36	24	16	LCC (€)	1403	1206	1272					
	% gain	ref	34%	62%	SPB (yr)	ref	5.1	11.6					
COLD8 (rc=2.15)	kWh/a	232	162	127	Price (€)	439	543	689	7.2%	226	5.7%	1.49	4.17
	EEl	37	26	20	LCC (€)	1200	1073	1106					
	% gain	ref	30%	45%	SPB (yr)	ref	7.4	11.9					
COLD9 (rc=2.15)	kWh/a	236	150	121	Price (€)	356	438	541	13.4%	261	12.3%	0.95	3.55
	EEl	38	24	18	LCC (€)	1130	930	938					
	% gain	ref	37%	52%	SPB (yr)	ref	4.8	8					
unit sales weighted average	kWh/a	226	149	103	Price (€)	522	615	870	100%	284	100%	1.20	5.56
	EEl	37	25	17	LCC (€)	1264	1103	1207					
	% gain	ref	34%	55%	SPB (yr)	ref	6	16					
sold volume (Vnet) weighted avg.	kWh/a	223	155	111	Price (€)	614	711	1062	100%	284	100%	1.42	8.08
	EEl	40	29	19	LCC (€)	1341	1214	1420					
	% gain	ref	31%	50%	SPB (yr)	ref	7	19					

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

¹⁶⁰ Historical value up to 2011

Around these values it is customary to create alternative scenarios that are more lenient (e.g. limit at 30% below base case) and more stringent (e.g. limit at 50% below base case). This will provide policy makers with a range of impacts in terms of energy savings, CO₂-emission abatement (climate change), consumer expenditure and business revenues. The 'Ambitious' scenario is comparable, but still less stringent, to what is proposed by ECOS and TopTen. UBA/BAM proposes to use one of the scenarios to assess the impact of life time requirements, but the study team thinks that this has been handled adequately in Chapter 7.

The target values in table 70 are based on the EEI according to the current metrics. The new metrics are foreseen to be more stringent for larger fridge-freezers and thus will generate an extra estimated saving of around 10% (e.g. LLCC target at current EEI of 21-22, comparable to the current A++ level). This is taken into account.

The starting point for the scenario-analysis, the Business-as-Usual (BAU) scenario, is the 'realistic' saving scenario as indicated in the 2007 preparatory study, which is duplicated as the 'ECO' scenario in the Ecodesign Impact Accounting study 2015¹⁶¹. However, for the period 2012-2014 the values are adjusted for the findings of Task 2 (Chapter 6) that show that there has been a stagnation in the improvement of the energy efficiency index in that period. Overall, all scenarios take into account that the increase in net volume of ca. 1% per year (10% over 10 years) will persist also in the future.

As regards the timeline for the Ecodesign and labelling measures, it is now estimated that –assuming a first presentation of the draft Working Document by the Commission after the summer of 2016—the Ecodesign and Energy Labelling could be published and enter into force by the end of 2017. Taking into account a customary 9-12 months period for the industry to prepare, the implementation of the first tier of these measures could be per 1.1.2019. A second tier usually follows two years later (1.1.2021), which is what is assumed in the scenario analysis.

It should be stressed that these are estimates for the sake of presenting plausible scenarios. It may well be that in the political decision making there are shifts of e.g. 6 months sooner or later. It might also be that labelling is implemented as soon as possible, e.g. in 2018, and that a single and final tier of minimum Ecodesign requirements only takes effect per 1.1.2020.

The scenario calculation follows the stock model methodology as indicated in the MEErP [VHK for EC, 2011] and further detailed in the Ecodesign Impact Accounting report [VHK for EC, 2015]. The latter report also provides full documentation of input dates, such as inflation- and escalation rates (2 and 4% respectively), inflation-corrected energy rates (in Euro 2010), efficiency and CO₂-emissions for power generation, etc.. The EIA-report data for product prices and price increases due to efficiency improvements have been corrected for the latest findings in the previous chapters. The price decrease due to the learning effect (production volume increase, automated production etc.) is kept at a level of 1% annually for price-increments above the current base case level¹⁶². The discount rate, a parameter relevant for the assessment of the discounted payback period, is kept at a rate of 4%, as indicated in the MEErP.

¹⁶¹ Note that the 'BAU' scenario in the Ecodesign Impact Accounting aims to show the total effect of the labelling and Ecodesign policy and refers to the BAU-projections before the first time that energy labelling and minimum requirements are introduced, i.e. in 1995. This should be clearly distinguished from the BAU scenario here, which starts from a situation with the current measures in place.

¹⁶² 'Learning effect' or 'experience curve' is assumed to relate to production cost reduction through increased labour productivity and capital investments at mass production. Imports from countries with low labour costs or commercial price setting strategies are not considered as a structural part of 'learning'. The figure of 1%/year is derived from analyses by CECED to study the price effect of energy labels after 1995.

As regards the impact of Ecodesign measures on reparability, the modelling will assume that –without these measures regarding e.g. replacement of door gaskets—the energy consumption of the refrigeration appliances will deteriorate by 10% over their 16 year product life. This is the case for the BAU scenario. The LLCC-scenario will be calculated with two sub-options: without these measures (LLCCa) and with these measures (LLCCb) to show the difference. The other two scenarios (Lenient, Ambitious) will be calculated with the reparability measures.

The following paragraphs present the scenario-results in the form of diagrams. Annex G gives the full data-tables over the analysis period 2010-2035.

13.2 Energy consumption

The graphs below show projected energy consumption trends per scenario. Figure 57 gives the projected average energy consumption per unit placed on the market in a particular year over the period 2005-2030. It shows

- the stagnation in improvement between 2012-2014;
- from 2015 the continuation of the pre-2012 trend in the BAU scenario, as an anticipation/reaction to a more effective labelling and ecodesign scheme;
- the impact of the Ecodesign measures in 2019 and 2021 forcing a steeper slope;
- The continued impact of the energy label (3% saving per year) over the 2021-2030 period.

In 2030, the BAU scenario is expected to bring a 37% saving with respect to 2015. The Lenient scenario gives an 8% lower average than the BAU scenario. The LLCCa scenario is 25% lower. The ambitious scenario is 42% lower than BAU with a market average that is slightly lower than the current BAT (Best Available Technology) identified in Chapter 12.

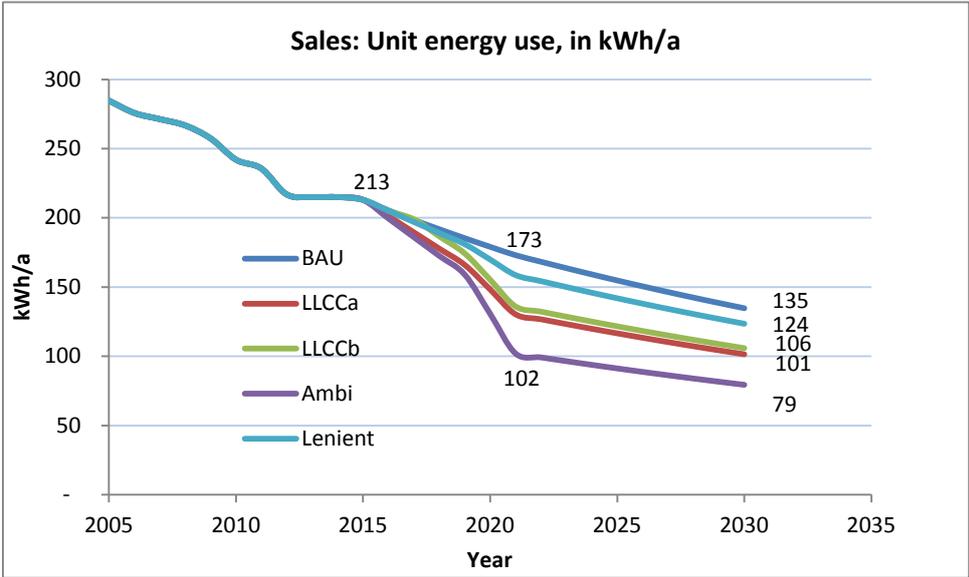


Figure 57. Average energy consumption of units sold over the period 2005-2030, in kWh/a electricity.

Figure 58 shows how the EU energy consumption of new units works out on the energy consumption of the total population of household refrigeration appliances. Given the

lifetime of 16 years there is a substantial delay before the whole stock of products has changed. The graph indicates that

- there is only a small spread between scenarios in 2020, as can be expected;
- the BAU scenario gives a saving of 14 TWh (16%) in 2020 and 29 TWh (33%) in 2030 with respect of 2015;
- in 2030, the Lenient scenario gives an extra 3 TWh saving with respect of BAU (-5%),
- the LLCCa scenario saves 10 TWh (18%) extra and
- the Ambitious scenario saves 16 TWh (28%) more than BAU in 2030.

Note that the LLCCb scenario, assuming a 10% deterioration of efficiency over product life gives 2 TWh less savings than the LLCCa scenario.

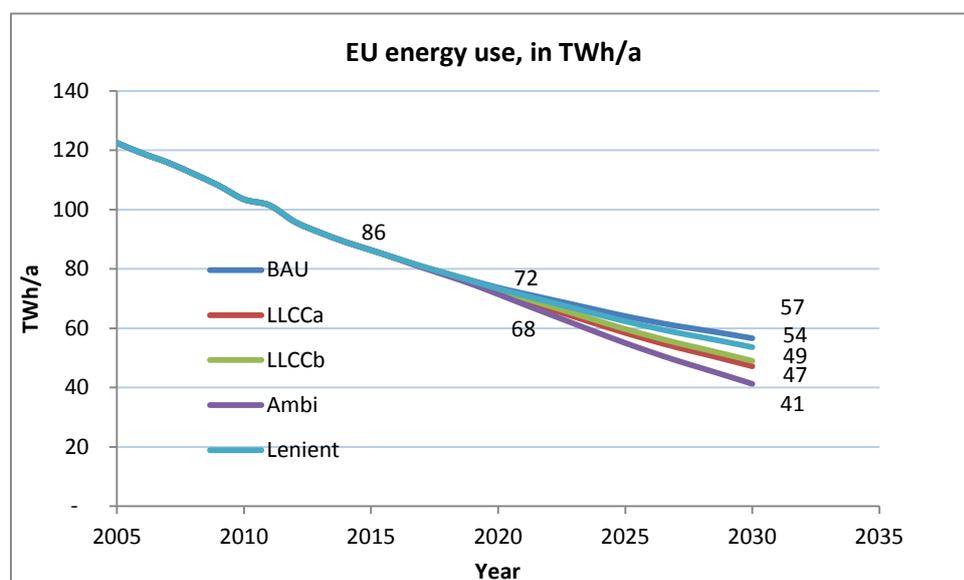


Figure 58. EU energy consumption over the period 2005-2030, in TWh/a electricity, for various scenarios

13.3 Greenhouse Gas emissions

As it is established that the transition towards low-GWP, no-ODP refrigerants and foaming agents is practically complete for this product group (>98% isobutane for refrigerant, cyclopentane as foaming agent), the trends in scenarios for greenhouse gas (GHG) emissions are similar to the energy consumption trends. The main difference is that the absolute savings over time are higher: The energy scenarios use, by convention, a fixed power generation and distribution efficiency of 40%, whereas for the projections of the GHG-emissions the changes in carbon-intensity of electric power generation are taken into account.

In that sense, figure 59 shows that

- the BAU scenario gives a saving of 7.1 Mt CO₂ equivalent (21%) in 2020 and 14.9 Mt CO₂ eq. (44%) in 2030 with respect of 2015;
- in 2030, the Lenient scenario gives an extra 1 Mt saving with respect of BAU (-5%);
- the LLCCa scenario saves 3.2 Mt (18%) extra and

- the Ambitious scenario saves 5.2 Mt (28%) more than BAU in 2030.

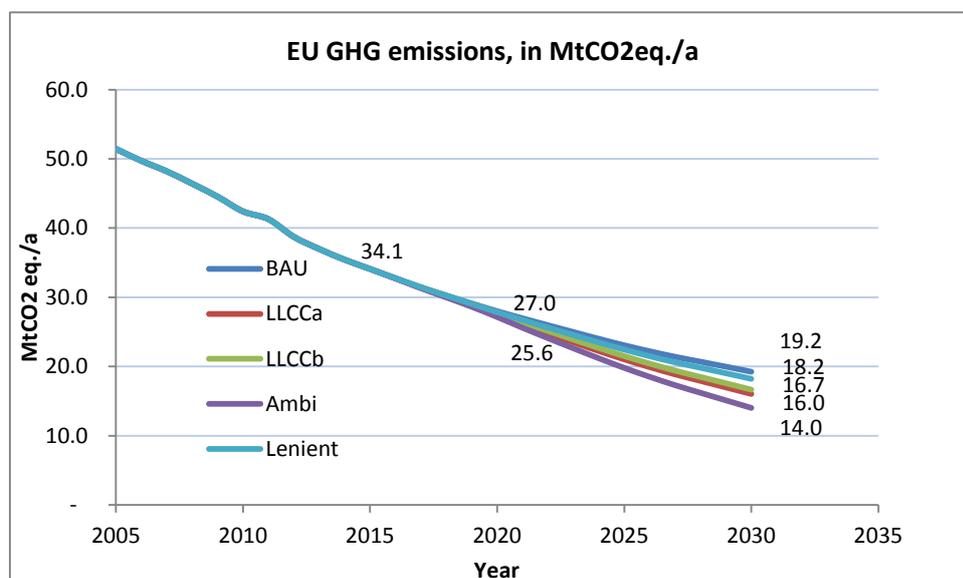


Figure 59. EU greenhouse gas over the period 2005-2030, in Mt CO₂ equivalent, for various scenarios

13.4 Business impacts

In order to realise the energy and carbon savings, industry has to invest and make more production costs. Likewise, with wholesale- and retail margins (and VAT) assumed fixed, this will also lead to higher retail costs. In short, despite the fact that the scenario calculation assumes a learning effect of 1% for prices above the current base case level, the policy scenarios require the consumers to invest. And this investment translates in a higher turnover for the industry and retail sector, as indicated in table 71.

The BAU scenario already gives an increase of 0.3 billion Euros (NPV 2010) in 2030 with respect to 2015. Taking the BAU scenario as a reference the LLCCa scenario gives an extra 20% in turnover (+1.8 bn Euro). For the Ambitious scenario there is an extra 44% (3.9 bn Euros) in total business turnover. The Lenient scenario does not lead to an increase with respect to BAU.

Table 71. Overview business revenue per scenario, in billion Euro [2010**]

sector	INDUSTRY			WHOLESALE			RETAIL*			TOTAL			Increase 2030
	2015	2020	2030	2015	2020	2030	2015	2020	2030	2015	2020	2030	
BAU	4.1	4.2	4.3	0.3	0.3	0.3	4.1	4.2	4.3	8.6	8.7	8.9	ref
LLCCa	4.1	4.4	5.2	0.3	0.3	0.4	4.1	4.4	5.1	8.6	9.1	10.7	1.8
LLCCb	4.1	4.3	5.0	0.3	0.3	0.4	4.1	4.3	4.9	8.6	9.0	10.3	1.3
Ambitious	4.1	4.6	6.2	0.3	0.3	0.5	4.1	4.5	6.2	8.6	9.4	12.9	3.9
Lenient	4.1	4.2	4.3	0.3	0.3	0.3	4.1	4.2	4.3	8.6	8.7	8.9	-

*= includes repair (estimated 0.5 bn Euro/a) . ** inflation-corrected/recalculated in Euros 2010 at 2% inflation

Figure 60 shows the overall trend, singling out the industry revenue.

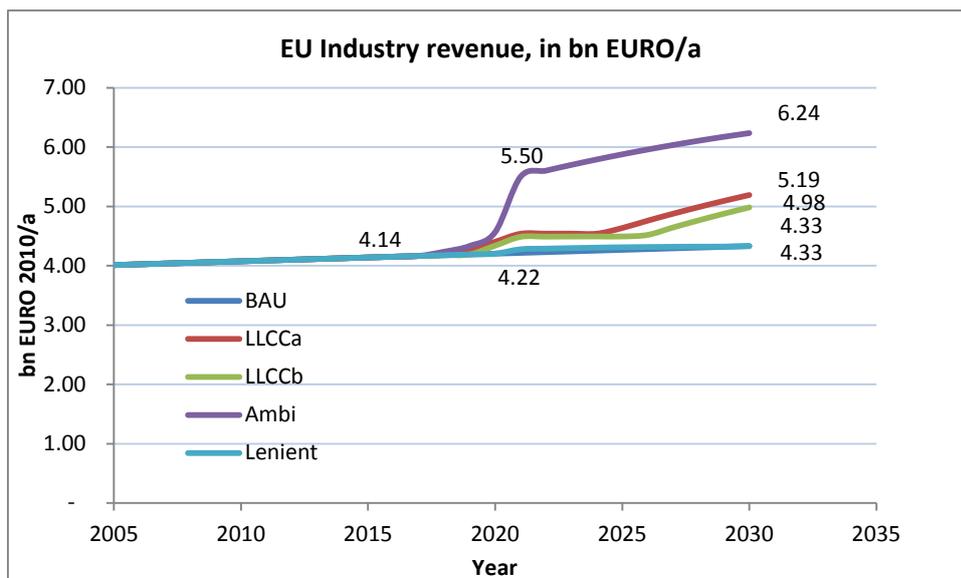


Figure 60. Projected industry revenue over the period 2005-2030, in Mt CO₂ equivalent, for various scenarios

Estimating the EU employment impact from the increase in revenue is notoriously difficult. There is always the question if new jobs are created or if existing jobs –which otherwise would be lost—are retained. For industry jobs there is the uncertainty what part of the jobs will be retained/created in the EU and how much will be realised outside the EU, including jobs at EU-suppliers and EU-subidiaries in low-cost countries. Finally, there are methodological issues regarding the extent of the scope: Take into account only direct jobs in the end-product manufacturing/trading or also include the suppliers and distributors? Take into account also the indirect jobs (or induced jobs) that are created because the new employees spend their money?

Nonetheless, applying the principles of Ecodesign Impact Accounting, this study only looks at direct jobs but from all actors in the production and distribution column (including suppliers), calculated from turnover per employee at around 50.000 Euro per job. In that sense, e.g. the LLCCa scenario would deliver approximately 36000 jobs, equally divided between industry and trade. The Ambitious scenario would deliver more than twice as much.

This is a rough estimate. In a full impact assessment, using the latest industry analysis¹⁶³, this estimate can be refined.

13.5 Consumer expenditure

Consumer expenditure consists of acquisition costs, maintenance/repairs and running costs. In this case, where repair costs are modest (estimated in the order of €0.5 bn/year) they are assumed to be included in the acquisition costs. The running costs consist thus only of energy costs.

The acquisition costs with various scenarios are given in Figure 61. For the LLCC scenarios they show some increase following the introduction of the ecodesign measures but they also show a similar increase when –somewhere around 2024 the low-cost improvement options are exhausted and manufacturers would have to use the most advanced and costly design options depicted in Chapter 12.

¹⁶³ Europe Economics, The Economic Impact of the Domestic Appliances Industry in Europe, Report for the European Committee of Domestic Equipment Manufacturers (CECED), April 2015.

The Ambitious scenario indicates that manufacturers would have to use these more advanced and costly options already in 2021 when confronted with the ambitious minimum requirements. After that, improvement options are more limited and further price increase will be slower than e.g. with the LLCC-scenarios. Anyway, it is clear that the Ambitious scenario is very challenging for the average consumer, not only in terms of overall economics (SPP >10 years as can be deduced from Table 70) but also in terms of affordability (procuring the money to finance the purchase).

For the Lenient scenario there is hardly any impact on the product price, i.e. the small increase in production costs will be compensated by the learning effect.

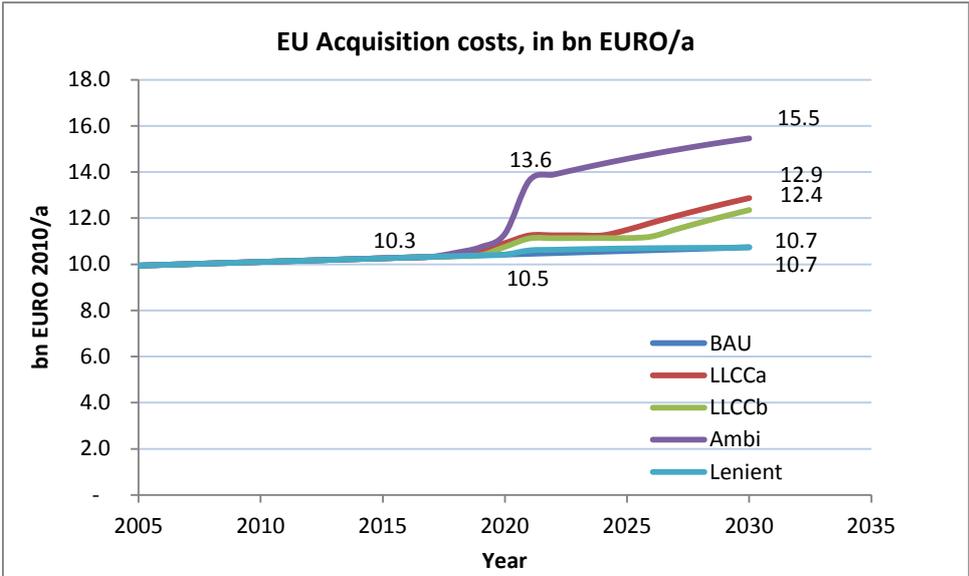


Figure 61. Projected consumer acquisition costs over the period 2005-2030, in billion Euros (NPV ¹⁶⁴ 2010), for various scenarios

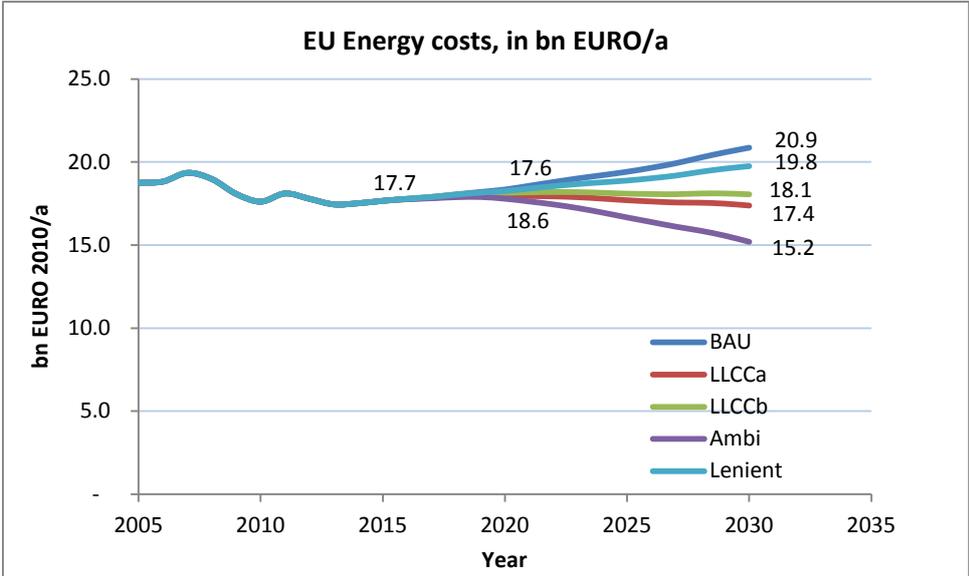


Figure 62. Projected consumer energy costs over the period 2005-2030, in billion Euros [2010], for various scenarios

¹⁶⁴ 'Net Present Value', meaning in this context that the money values are inflation-corrected back to 2010 Euros.

Figure 62 shows the energy costs for various scenarios. Not surprisingly in the light of ever increasing electricity prices, energy costs go up (BAU, Lenient scenarios) or stay more or less equal (LLCC scenarios) with respect to 2015. The exception is the Ambitious scenario, which –at the expense of heavy investments in acquisition costs as mentioned—manages to save some 2.5 billion Euros (14%) in 2030 with respect of the 2015 average and 5.4 billion Euros (26%) with respect of the BAU in 2030 .

The LLCCa scenario saves 3.5 billion Euros (17%) and the Lenient scenario saves 1.1 billion Euros (5%) with respect of the BAU in 2030.

Counting together the impacts of both acquisition and running costs the trends in overall consumer expenditure become clear (figure 63). In the BAU scenario the consumer expenditure rises by 3.7 billion Euros (13%) between 2015 and 2030. The expenditure of the Ambitious scenario is considerably more than any other scenario over the 2021-2030 period and only in 2028 starts to be lower than BAU and similar to the other policy scenarios in 2030. For these other scenarios, i.e. LLCC and Lenient, there is not much difference and the savings are in the order of 1-1.2 billion Euros (3-4%) with respect of the BAU in 2030.

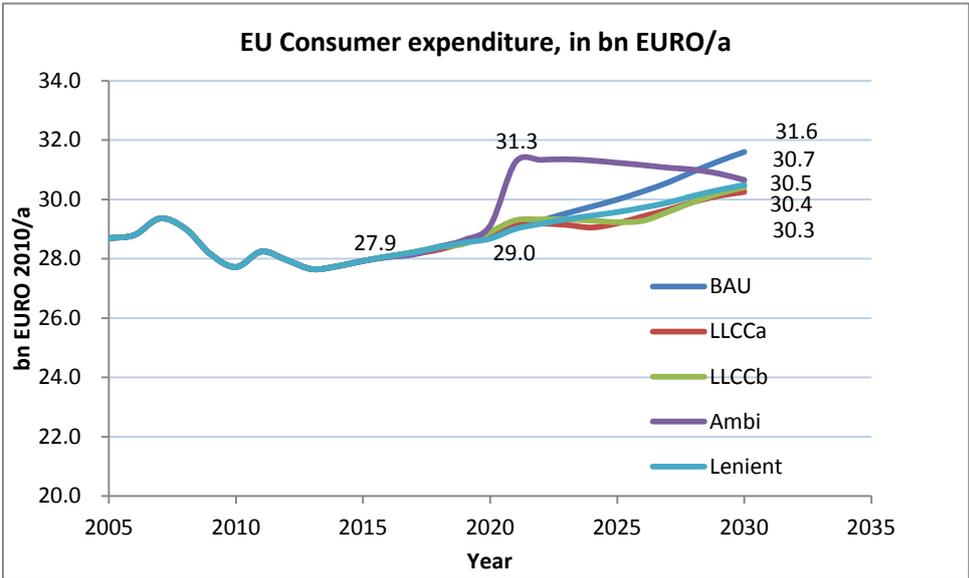


Figure 63. Projected consumer expenditure over the period 2005-2030, in billion Euros [2010], for various scenarios

13.6 Summary

This is a very preliminary scenario analysis with considerable uncertainties that need to be addressed in a full impact assessment at a more advanced stage of political decision making. Nonetheless it is plausible that an ambition level of the LLCCa-scenario is most appropriate, because the saving potential of the Lenient scenario is too low and the Ambitious scenario is (too) challenging in terms a significant negative impact on affordability and payback. The LLCCb scenario, without measures to maintain efficiency measures, is not a real alternative but was shown to give policy makers an estimate of the impacts.

It is estimated that –in 2030-- the LLCCa will save an extra 10 TWh/a in electricity, 3.5 Mt CO₂ equivalent/a in greenhouse gases and around 1 billion Euro in consumer expenditure with respect of the BAU scenario. Total business revenue (all sectors) is projected to increase by 1.8 billion Euros, creating or pertaining around 36000 direct jobs.

13.7 Verification tolerances

The assessment of verification tolerances is a self-standing part of the assignment and will be discussed here.

Status quo

The current verification tolerances in Annex V of the Ecodesign regulation and Annex VII of the Energy Label Delegated Regulation on household refrigeration appliances entail

- a tolerance of (not less than) 3% or 1 litre, whichever is the greatest value, for the rated gross and storage volumes,
- a tolerance of 10% of freezing capacity, energy consumption and humidity levels in wine storage appliances.
- For airborne acoustical noise emissions the measured value shall meet the rated value. ('rated value' means the value declared by the manufacturer).

If the parameters measured for conformity assessment of a single appliance do not meet the values declared by the supplier within the ranges mentioned above, the measurements shall be made on three more household refrigerating appliances. The arithmetical mean of the measured values of these three household refrigerating appliances shall meet the requirements within the ranges defined. Otherwise, the model and all other equivalent household refrigerating appliance models shall be considered not to comply.

The 2016 draft Commission Regulation¹⁶⁵, amending the above regulations, with regard to the use of tolerances in verification procedures, adds

The verification tolerances defined in this Annex relate only to the verification of the measured parameters by Member State authorities and shall not be used by the manufacturer as an allowed tolerance to establish the values in the technical documentation or in interpreting these values with a view to achieving compliance or to communicate better performance by any means.

Points 2a, 2b and 3 add further stringency to the stipulations in the original regulation:

“(2) The model shall be considered to comply with the applicable requirements if:

(a) the values given in the technical documentation pursuant to point 2 of Annex IV to Directive 2009/125/EC, and, where applicable, the values used to calculate these values, are not more favourable for the manufacturer or importer than the results of the corresponding measurements carried out pursuant to paragraph (g) thereof; and

(b) the values used to determine the compliance of the model and those provided in the product information as required by this Regulation, and, where applicable, the values used to calculate these values, are not more favourable for the manufacturer or importer than the values given in the technical documentation file, including in the test reports; and

(c) when the Member State authorities test the unit of the model, the measurements

¹⁶⁵ Draft COMMISSION REGULATION (EU) .../..., amending Regulations (EC) No 1275/2008, (EC) No 107/2009, (EC) No 278/2009, (EC) No 640/2009, (EC) No 641/2009, (EC) No 42/2009, (EC) No 643/2009, (EU) No 1015/2010, (EU) No 1016/2010, (EU) No 327/2011, (EU) No 206/2012, (EU) No 547/2011, (EU) No 932/2012, (EU) No 617/2013, (EU) No 666/2013, (EU) No 813/2013, (EU) No 814/2013, (EU) No 66/2014, (EU) No 548/2014, (EU) No 1253/2014, (EU) 2015/1095, (EU) 2015/1185, (EU) 2015/1188, (EU) 2015/1189 and (EU) 2016/XXX, [Air heating/cooling and chillers Number of the Regulation to be inserted before publication in the OJ] with regard to the use of tolerances in verification procedures. Brussels, 4 Feb. 2016.

obtained for all the parameters and the values calculated from these measurements are within the respective verification tolerances as given in Table 1.

(3) If the results referred to in points 2(a) and (b) are not achieved, the model and all models that have been listed as equivalent household refrigerating appliance models in the manufacturer's or importer's technical documentation shall be considered not to comply with this Regulation.”

Point 7 adds an explicit obligation of surveillance authorities to report their decision on non-compliance to Commission and other Member States. It also explicitly mentions that no other tolerances, such as those in harmonised standards or in any other measurement, shall be applied.

(7) The Member State authorities shall provide all relevant information to the authorities of the other Member States and to the Commission within one month of a decision being taken on the non-compliance of the model according to points 3 and 6.

The Member State authorities shall only apply the verification tolerances that are set out in Table 1 and shall only use the procedure described in points 1 to 7. No other tolerances, such as those set out in harmonised standards or in any other measurement method, shall be applied.

As regards the 'Power consumption of household refrigerating appliances with a storage volume below 10 litres' the amendment states that 'The determined value shall not exceed the limit value laid down in Annex II, point 1(2c), by more than 0.10 W at the 95 % confidence level.'

Assessment

The above describes the modality of applying verification tolerances. As regards the values of the verification tolerances it can be noted that none of the stakeholders, neither in the consultation of the review study nor in the consultation on the new draft on tolerances, provided any comment or input that would induce a change of the values of the verification tolerances for household refrigeration appliances.

With the new IEC 62552:2015 being the future basis of the regulations, this would have been premature. The new standard makes some fundamental changes in the testing method and without actual testing results according to this new standard it is difficult to assess whether e.g. the verification tolerances could be tighter.

The most important changes include:

- All parts of the standard have been largely rewritten and updated to cope with new testing requirements, new product configurations, the advent of electronic product controls and computer based test-room data collection and processing equipment.
- There is no longer a difference between 'gross' and 'net' ('storage') volume. In order to be more robust, only technical spaces are excluded and all drawers or other interior elements are included in 'the volume'. Only experience will tell if this new assessment will give smaller tolerances than 3% or 1 litre.
- Instead of an energy consumption test at one ambient temperature of 25 °C, there are two tests, i.e. one at 16 °C and one at 32 °C, from which a weighted average consumption is calculated. Given the fact that 1 K ambient temperature difference can influence the test result by 6-8% this can cause potentially a larger tolerance. In the informative Annex L of IEC 62552-3 there is an ambient

temperature correction formula that should correct most of the tolerances, but it is difficult to estimate whether it will be sufficient.

- Instead of testing for 24 hours, the new standard proposes testing until, during some time, a stable power requirement is established. This procedure has its own tolerances to assess what is 'stable'. It is as yet unknown whether this new procedure gives smaller or higher tolerances than the current test procedure.
- In the current standard the compartment temperature of freezers is established through sensors in the test packages. The new standard now prescribes to measure the air temperature in freezer compartments. This may speed up the process, but the thermal inertia of the test package may have contributed to tighter tolerances. Also –instead of the current different differentiation in sizes— the new test standard prescribes one size of test packages. There are also significant differences in the position of temperature sensors in unfrozen compartments that may have an impact. The impact of all these changes on verification tolerances will only become apparent after experience in testing.
- Instead of two test points (per ambient temperature test) it is now also allowed to determine the energy consumption from triangulation of 3 test points. This should increase the accuracy of the outcome, but it is not known by how much and if manufacturers will actually use this option.

All in all, most of the above changes aim to increase or maintain the accuracy, reliability and reproducibility of the test results. On the other hand, the objective to also streamline the test procedure might take its toll. Again, the real consequences of the changes for the verification tolerances can only be established after the new standard is introduced and after the surveillance authorities and industry laboratories have gained experience with the new test protocol.

Hence it is recommended not to change the values of the verification tolerances from the ones that are currently in the regulations.

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Consumer Electronics Show, Prototype Wine Cooler using magnetic refrigeration. Las Vegas, January 2015

Corrigendum to Commission communication in the framework of the implementation of Commission Regulation (EC) No 643/2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for household refrigerating appliances (Official Journal of the European Union C 16 of 22 January 2010)(2010/C 272/08), OJ C272, p.11, 8.10.2010

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ANNEX A: Definitions IEC 62552-1¹⁶⁶

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

¹⁶⁶ 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 single 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 manually ejected

*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 the making 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 are reconfigured 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 $-6\text{ }^{\circ}\text{C}$

3.16.2

two-star

compartment where the **storage temperature** is not warmer than $-12\text{ }^{\circ}\text{C}$

3.16.3

three-star

compartment where the **storage temperature** is not warmer than $-18\text{ }^{\circ}\text{C}$

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 regulate 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 adjustment 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**

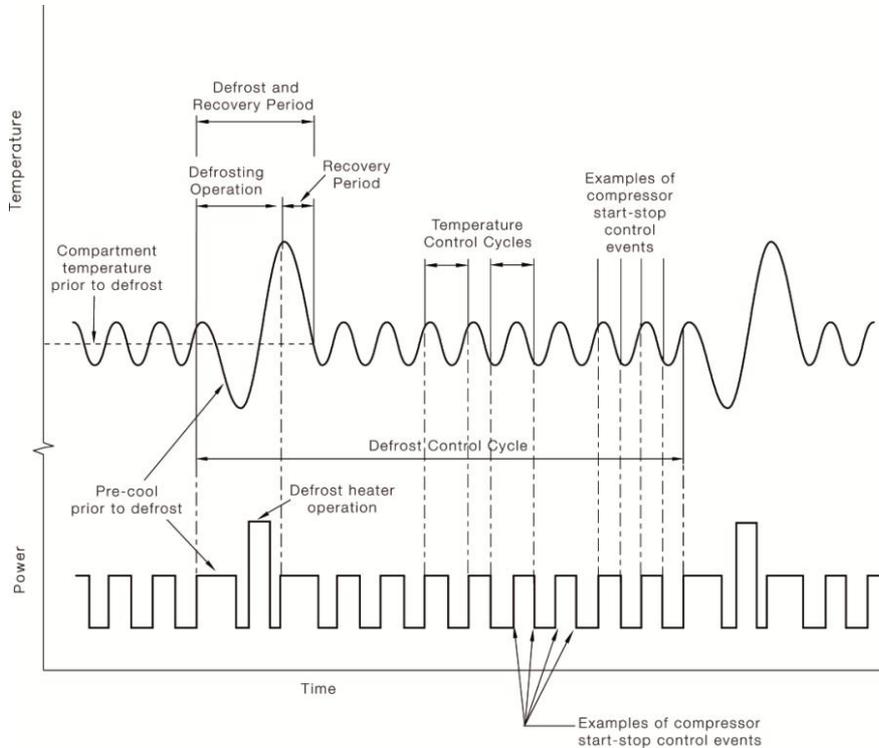


Figure 1 – Illustration of selected definitions

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 4.¹⁶⁷

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 4/32 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 % more 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.

¹⁶⁷ For Tref=4 °C: $COP(T_a) = 0.6 \cdot [(4-15) + 273.15] / [(T_a+10) - (4-15)] = 157.29 / (T_a+21)$. Likewise for Tref=5 °C: $COP(T_a) = 0.6 \cdot [(5-15) + 273.15] / [(T_a+10) - (5-15)] = 157.89 / (T_a+20)$

Table 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, Refrigerant R600a, Blowing agent cyclopentane,
gross volume (litres)	230	294	202	260	
Noise(dB)	38	40	40	42	
categories	1-6	7&10	8	9	
Material/component mass→	g	g	g	g	EcoReport Category
PRODUCT					
Iron	8956	16118	10529	15766	3-Ferro 23-Cast iron 22-St tube/profile 25-Stainless 18/8 coil
Mixed steel + plastic	57	7	613	170	
Stainless Steel	63	867	43	0	22-St tube/profile 21-St sheet galv.
Steel other	2373	1385	1368	1859	
Steel strip	9944	12640	12807	9459	
Total ferro	21392	31017	25360	27254	
Al	945	1355	721	3360	4-Non-ferro 26-Al sheet/extrusion 30-Cu tube/sheet 29-Cu wire
Cu tube	1847	1910	1641	1242	
Cu wiring 230V	275	275	275	275	
Total non-ferro	2792	3265	2362	4602	
ABS	775	848	1015	206	1-BikPlastics 10-ABS 6-EPS 2-HDPE 4-PP 5-PS 8-PVC 9-SAN 1-LDPE
EPS - Insulation	3	39	2	0	
HDPE	56	86	589	53	
PP	950	1563	1902	883	
PS	5837	8981	10485	2310	
PVC	352	355	537	2117	
SAN	0	0	1252	0	
Elastomers (NBR)	76	211	60	48	
Total bulk plastics	8049	12083	15843	5617	
PA	58	20	56	43	
PC & POM	26	10	21	10	
PU Foam - Insulation	3843	6280	6627	6081	
PUR	2153	1728	2017	2285	
Total tech. plastics	6080	8038	8721	8419	
Coating	65	200	144	100	5-Coating 39-powder coating
Capacitor	2	20	11	8	6-Electronics 44-big caps & coils 98-controller board 98-controller board
PWBs, switches, lamp	84	157	244	27	
Thermostat	149	147	90	134	
Total electronics	235	324	345	169	
Glass	5	6276	0	0	7-Misc. 54-Glass for lamps 57-Office paper
Paper	197	274	185	120	
Total misc.	202	6550	185	120	
Lubricating oil	140	190	170	250	Other
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 6-EPS 1-LDPE 4-PP
EPS	1034	1257	1046	1729	
LDPE foil	248	257	328	542	
PP	31	35	48	64	
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.

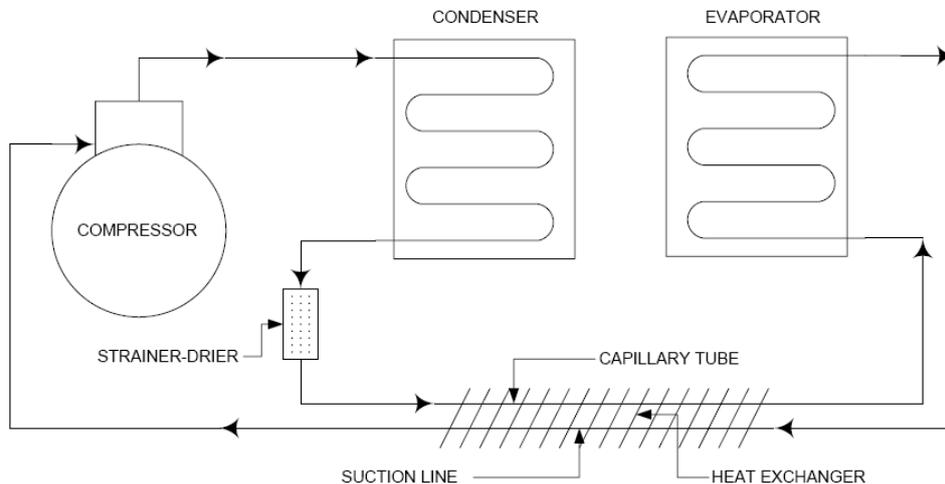


Figure D.1a: Standard refrigeration circuit for domestic refrigerators

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, $T_{3'}$ 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, $T_{3'}$ temperature depends on the efficiency of the IHX and of the operating conditions.

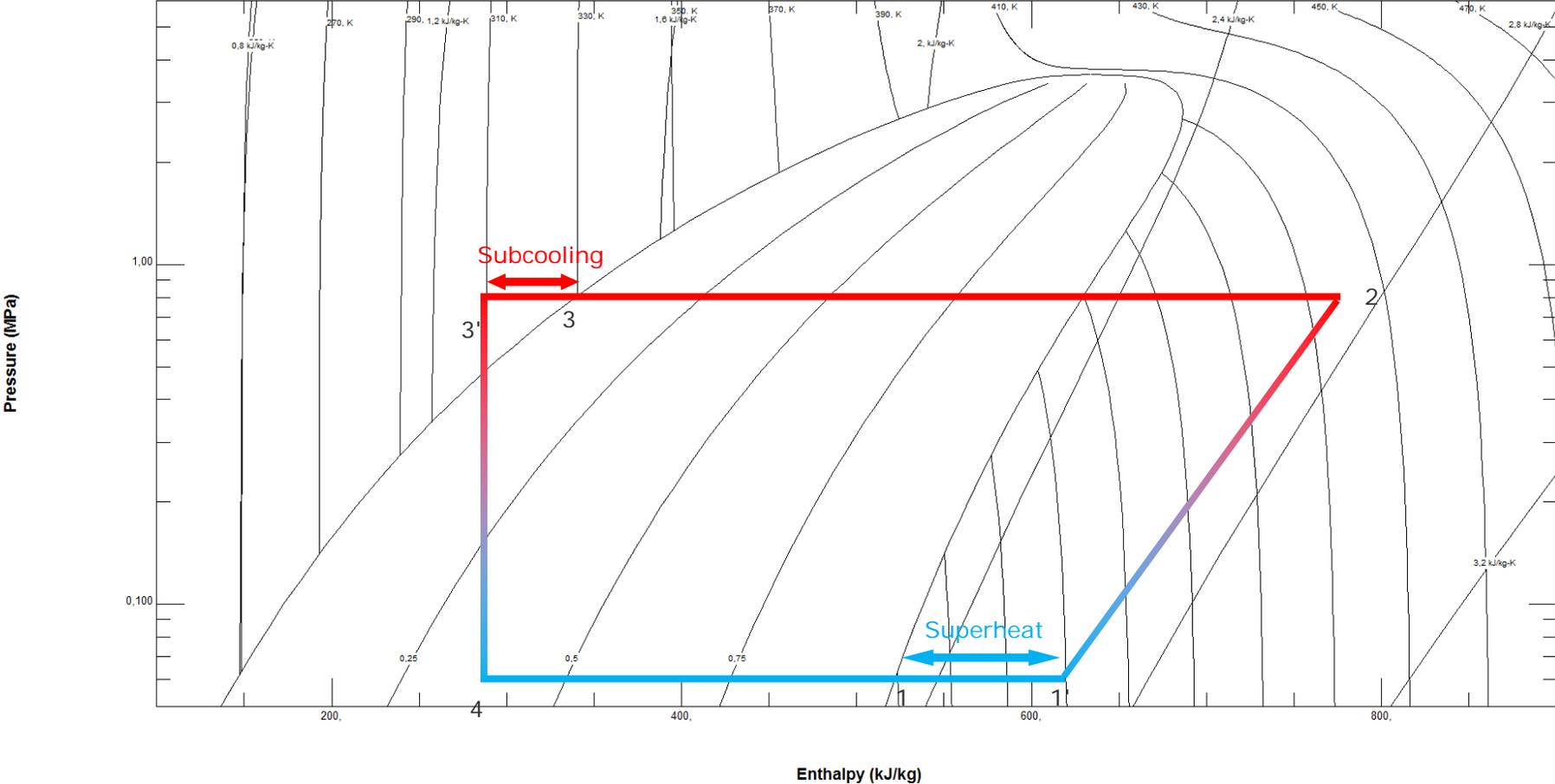
Because of these differences, we seek to model the performance of the compressor starting from manufacturer data and to add a simple IHX model.

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 T_{ev} and T_{cd} , the following approach is adopted:

- regression of the volumetric and isentropic efficiency for ASHRAE conditions with varying T_{ev} and T_{cd} ,
- integration of the IHX,
- cycle calculation for varying T_{ev} and T_{cd} 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 T_{ev} and T_{cd} .

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



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

- regression of the volumetric and isentropic efficiency for ASHRAE conditions with varying T_{ev} and T_{cd} ,
- integration of the IHX,
- cycle calculation for varying T_{ev} and T_{cd} 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 T_{ev} and T_{cd} .

The volumetric efficiency η_{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).

$$\eta_{V} = \frac{mf}{(N \cdot \rho_{suc} \cdot V_{swept})}$$

With

- η_{V} : volumetric efficiency in %
- mf = gas mass flow given by the manufacturer $\text{kg} \cdot \text{s}^{-1}$
- N : Frequency of rotation of the compressor in s^{-1}
- ρ_{suc} : density at the suction of the compressor in $\text{kg} \cdot \text{m}^{-3}$
- V_{swept} : volume of the cylinder in cm^3

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

$$\eta_{V} = a_{V} \cdot \text{PI} + b_{V}$$

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.

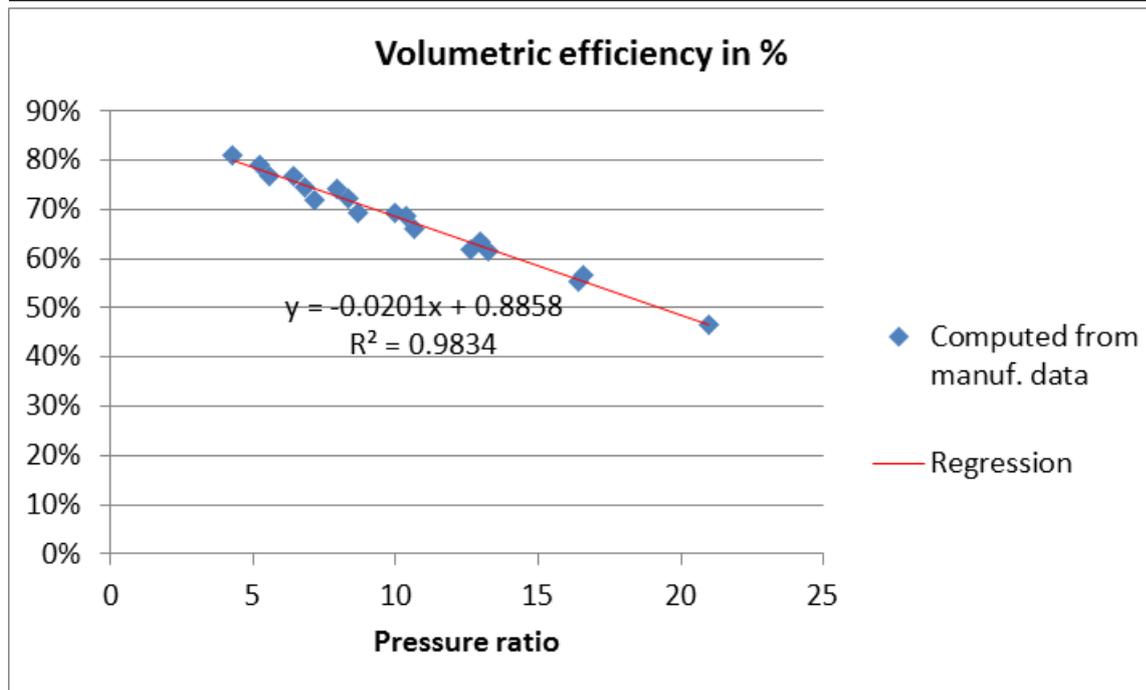


Figure D.2: Computed volumetric efficiency versus pressure ratio and regression curve

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

$$\text{Eta}_{\text{is}} = (\text{mf} \cdot \text{DHis}) / \text{Pe}$$

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 $\text{kg} \cdot \text{s}^{-1}$
- DHis : enthalpy difference in an adiabatic reversible compression $\text{J} \cdot \text{kg}^{-1}$
- 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:

$$\text{Eta}_{\text{is}} = \begin{cases} a_{\text{is}} + b_{\text{is}} \cdot (\text{PI} / \text{PI}_{\text{max}}) & \text{if } \text{PI} \geq \text{PI}_{\text{max}} \\ \text{Else} & \end{cases}$$

Else

$$\text{Eta}_{\text{is}} = (a_{\text{is}} + b_{\text{is}} \cdot (\text{PI} / \text{PI}_{\text{max}})) \cdot (\text{PI} / \text{PI}_{\text{max}}) / ((1 - c_{\text{is}}) + c_{\text{is}} \cdot (\text{PI} / \text{PI}_{\text{max}}))$$

PI_{max} is the compression ratio corresponding to $\text{Eta}_{\text{is_max}}$

a_{is} , b_{is} and c_{is} are regression coefficients.

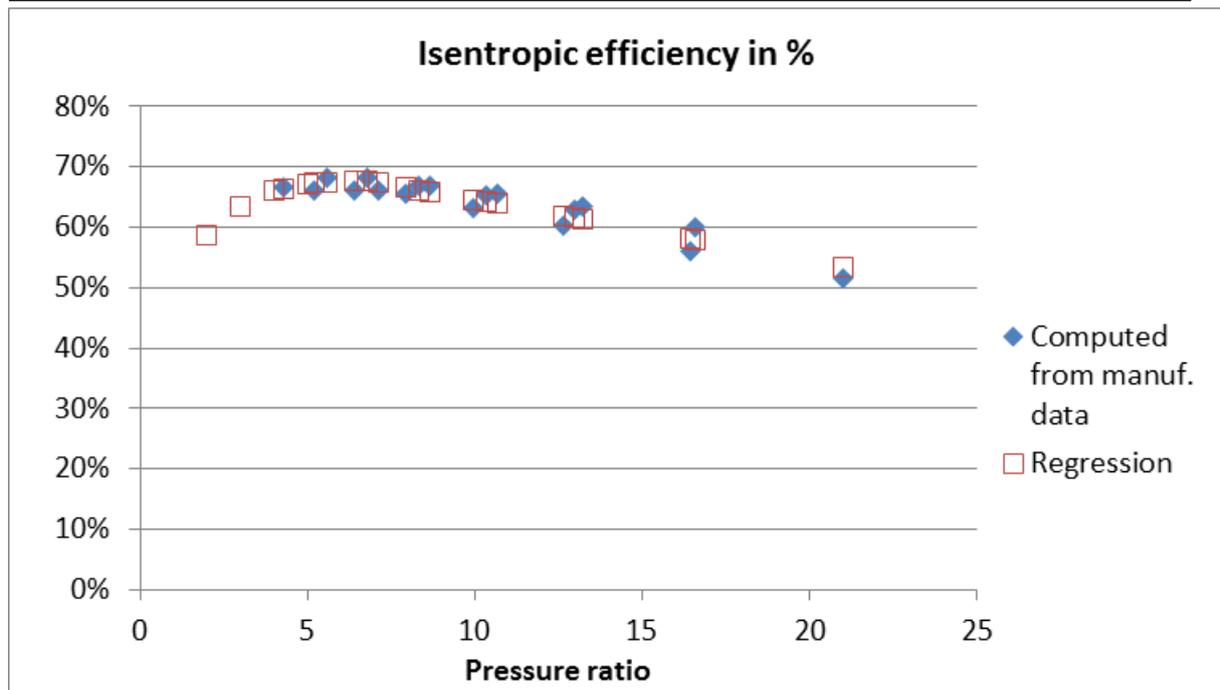


Figure D.3: Computed isentropic efficiency versus pressure ratio and regression curve

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 %¹⁶⁸.
- 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:

$$mf = \text{Eta}_V \cdot N \cdot \rho_{suc} \cdot V_{swept}$$

$$P_c = mf \cdot (h_1 - h_4)$$

$$P_e = (mf \cdot D_{His}) / \text{Eta}_{is}$$

$$COP = P_c / P_e$$

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

¹⁶⁸ Ref to be added.

- COP / COP_{nom} as a function of T_{ev} and T_{cond}
- P_c / P_{cnom} as a function of T_{ev} and T_{cond}

Maps are thus proposed for refrigerator optimized and freezer optimized compressors for COP/COP_{nom} and P_c/P_{cnom}. These tabulated correction enable to deduct the COP and cooling capacity from the knowledge of T_e evaporation temperature in °C) and T_c (condensation temperature in °C):

$$y = c_1 + c_2 \cdot t_e + c_3 \cdot t_c + c_4 \cdot t_e^2 + c_5 \cdot t_e \cdot t_c + c_6 \cdot t_c^2 + c_7 \cdot t_e^3 + c_8 \cdot t_c \cdot t_e^2 + c_9 \cdot t_e \cdot t_c^2 + c_{10} \cdot t_c^3$$

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:**

<i>Tcd</i>	-19		
<i>Tev</i>	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
<i>Tev</i>	c2	0.192766	0.152086	-3.66	-2.89
<i>Tcd</i>	c3	-0.194250	-0.028372	-8.94	-1.31
<i>Tev</i> ²	c4	0.002446	0.002061	0.88	0.74
<i>Tev</i> * <i>Tcd</i>	c5	-0.004600	-0.000866	4.02	0.76
<i>Tcd</i> ²	c6	0.002458	0.000030	5.20	0.06
<i>Tev</i> ³	c7	0.000013	0.000010	-0.09	-0.07
<i>Tcd</i> * <i>Tev</i> ²	c8	-0.000033	-0.000009	-0.55	-0.15
<i>Tev</i> * <i>Tcd</i> ²	c9	0.000031	0.000001	-1.26	-0.04
<i>Tcd</i> ³	c10	-0.000012	0.000000	-1.14	-0.01
TOTAL multiplier				1.12	1.21

Output:

ACTUAL COP or Pc	1.90	57
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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
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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)

$$P_{cd_req} = P(T_{ev}, T_{cd}) \cdot (1 + 0.85 \cdot 1 / COP(T_{ev}, T_{cd}))$$

Maximum capacity available (estimate from empirical formula)

$$P_{cd_max} = (31 \cdot \Delta T_{cd} - 40) \cdot A_{cd}$$

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 P_c [W], evaporator temperature difference ΔT_{ev} [K] and evaporator capacity h_{ev} [W/m²K]

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

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 Household (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 Rüdener (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 300l¹⁶⁹ 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.

¹⁶⁹ 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 °C) 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 were 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 Rüdener (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 °C 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 CO₂, 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 than in this meeting.

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

Technical analysis Task 4

Jochen Haerlen (BSH), reacting to the slides, acknowledges that forced 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 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

ANNEX F: Minutes 2nd Stakeholder meeting

Minutes of the 2st Stakeholder meeting Ecodesign & Labelling Review household refrigeration appliances

Date: Monday 2015-12-14, 10.00-16.00h

Place: European Commission, Centre Broschette, 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.

Timing Issues

Andras Toth (EC) explained that this is an additional meeting which was not planned, but due to the complexity of the product this meeting was added at the request of the stakeholders. The aim of this meeting is to reach consensus about the technical content (task 1-6) which will be the input for task 7 (policy options), this latter task will be finished in the first quarter of 2016.

Presumably in the autumn of 2016 there will be a Consultation Forum (CF) meeting on refrigerators. The Commission is awaiting the outcome of the revised Energy Labelling Directive so it can be incorporated in the proposals for this CF meeting.

Changes to task 1-4

Hans-Paul Siderius (NL) appreciates that lifetime extension is included and discussed in the update of the report. A significant energy improvement in refrigerators can be seen, so replacing old ones with new ones is good and there is no need for lifetime prolonging. This however might have to be reconsidered when reaching higher improvement levels and further improvements are limited. Therefore, it is worthwhile to see in the LLCC calculation what can be achieved and base this discussion on the findings there.

The chair replies that later in the presentation it can be seen that savings of 90% can be achieved compared to 1995 levels. At this moment we are at 60% savings compared to 1995. It will take years for improvement to be realised. The investigation of lifetime extension can be put in a review clause, which is performed 5-6 years after entry into force of the Regulation, to see how far savings are and ask for a study towards lifetime extension. At this moment it is too soon to include it as there are still large savings potentials to be reached the coming years.

Edouard Toulouse (ECOS) has three remarks:

- During the presentation the chair stated something different then can be read on page 18 of the report. In the presentation the chair stated that they are working on a formulation that would not restrict the scope to only household products and in the report it is still written that it is only referred to household products. What is the right scope?

The chair replies that the reaction of environmental NGO's, that non-household appliances should be included, is added in this presentation. We include comments given by all stakeholders.

- If a circumvention device is found, this should be noted in the test report and Market Surveillance Authorities should be alerted. The regulation should say something explicit about this.

The chair replied that this is not up to the consultants to say something about it. Member States deal with this (fines etc.). Up to now testing facilities were not obliged to notify when a product was wrong but by including this circumvention clause they have to. It was agreed upon that at the very least the regulation could say that if circumvention is detected, the product is non-compliant.

- Looking at the balance energy – material use and savings. According to the AEA-Ricardo study 50% of the products is being replaced (trade-off) within the first 8 years of their life and two-thirds of consumers mention that this due to some deficiency in the product. Extending this period to 10 years might already be beneficial for the material use, if it is not beneficial to extend the overall lifetime from 16 to 18 year. It is therefore interesting to know the failure rates after for instance 2,5 or 10 years.

The chair answers that this type of information is not available and the large effort to retrieve such information on intermediate failure rates (between the end of guarantee at 2 years life and before the average lifetime) is certainly not within the project-budget. Also, it is statistically not possible to prolong the lifetime of only a part of the population without influencing the average of that population unless (hypothetically) measures to prevent a too long lifetime would be invented. In other words, the effect of possible measures, e.g. between 8 and 10 years of life will lead to an increase of the average lifetime and this is not beneficial to the environmental impact, given the saving potential with new products that is still out there. Finally, in practical terms there is the question of how we could achieve what ECOS wants. For instance, if the decision would be to prolong the warranty period then it would have a large economic impact (cost for manufacturers, that would then have to pass this cost on to a higher purchase price) and it would be a decision that would create a precedent for all products, i.e. if it is proportional to do this for a refrigerator –where there is no clear benefit—it would automatically pass for all appliances.

Hans-Paul Siderius (NL) adds that a clear Anti-Fraud Detection clause is proposed in the new Energy Labelling Directive. Test products should not reply to test conditions Market Surveillance Authorities have to deal with non-compliant products, but there should be somewhere in the Regulation a mentioning of fraud. On the issue of lifetime extension we need more information and that could be placed in a review clause.

Ina Rüdener (Öko-Institut) states that the durability aspect is not covered properly in this report. There is an increase in share of appliances that have a defect during the first 5 years of their lifetime. The Ricardo study elaborates more on the durability study and a minimum lifetime of 7 years is mentioned. So we should discuss the minimum durability lifetime.

Marie Baton (CLASP) supports the lifetime extension and asks for an update of the lifetime calculation and if voluntary labels (ECO-label, Nordic Swan etc.) have been taken into account when calculating life time.

Jeremy Tait (Tait Consulting Limited) asks to include “non-household” in the scope of the study, similar to the inclusion of wine-coolers and minibars. In the professional refrigerator cooling lot the professional chest freezers are excluded because they should be included in this study. The reason for the exclusion is that the professional chest freezers can be tested similar to the domestic products.

The chair replies to the questions of ECOS that DG ENVIRONMENT has done two projects to research the benefits of life time extension and in both reports the conclusion was that there are no benefits from extending lifetime. Concerning the two year warranty period, DG Consumer should be dealing with this issue. If something can be done about life time extension it is probably in the area of spare parts (e.g. door gaskets), to ensure reparability.

Edouard Toulouse (ECOS) asks to take out the 1990 Japanese example of the report as this is too old and not representative for current discussion. Where does the 16 year lifetime come from?

The chair answers that the 16 year lifetime is based upon studies showing the fridge will have a second hand lifetime of 3-4 years and first-hand life time of 12. In the previous (2007) preparatory study a life time of 15 years was assumed.

Andras Toth (EC) asks if it is possible to test the durability life of refrigerators.

The chair replies that there is no specific test to evaluate the durability life of the complete refrigerator, but the acceptance test for compressors is 20 years. The thermostat or door casqued can be replaced more easily.

Martien Janssen (Re/genT) confirms that there are only tests for components not for the complete refrigerator.

Hans-Paul Siderius (NL) states that the washing machines, dishwashers and dryers had similar discussions. It has to be seen at which point the lifetime extension makes sense. The tests have to be performed in reasonable time otherwise they should for sure not be included in the Ecodesign regulation. Furthermore, he agrees with the chair that the raising of minimal legal warranty periods is not a discussion for this meeting and is a horizontal issue. He also agrees with Edouard Toulouse to update the Japanese fridge example.

In this assignment these issues (lifetime extension, testing of lifetime extension) have not been the most important tasks, but if the consultants cannot deal with these issues at this moment (end of the study is coming) the questions will come up later to the European Commission when presenting documents at the Consultation Forum. These things take a long time to change and will have to be incorporated by all stakeholders so it would be good if we could do some first steps in this revision but of course it has to be seen how this could be feasible. This will be more a task for the Commission to look into these things based on the study.

The chair replies that the Japanese example can be replaced by a future prediction for the EU situation, but he doubts that the outcome will be very different for refrigerators.

Edouard Toulouse (ECOS) states that this is what they are expecting, an update on this issue. The Ricardo study talks about 50% of the products, in 2012, breakdown in the first 8 years.

The chair answers that the main conclusion of AEA-Ricardo report is included on page 65 and it is clear enough.

Anette Michel (TopTen) would like the wine-coolers and minibars included in the scope, but it needs to be well coordinated with other refrigerator studies. She adds that there is no general agreement on the built-in factor. A label should show the difference between stand-alone and built-in and better consumer information would be required.

The chair answers that at this moment built-in or not built-in is purely based on declaration by the manufacturer. There is no need for any technical difference. The built-

in factor proposed in Chapter 9 is mainly to compensate for the difference in the test method; without it there is a chance that two 100% identical products might have a different rating purely on the basis of declaration and the test method linked to that declaration. That is not helping anyone.

The example of Jeremy Tait of professional chest freezers is interesting in this respect and shows the problems that might arise from not having technical parameters to make a distinction. This is also why the study team would like to ask all of the stakeholders to reconsider the naming “household” and “non-household” in the scope and/or making it more robust in another way.

Chapter 8

No questions or comments

Chapter 9

Martien Janssen (Re/genT) supports the chair that it is difficult to do statistical analysis for wine coolers. He shows a small PowerPoint presentation on this topic.

Edouard Toulouse (ECOS) opposes a compensation factor for glass door use. He suggests having a two-step procedure for wine coolers similar to products that are regulated for the first time under Ecodesign and have a more lenient first Tier. Also there could be a difference between Ecodesign, with compensation factor to keep at least some products available, and Energy Label without compensation factor to clearly show the consumer the difference.

Marie Baton (CLASP) states that a test method should reflect the real use. There should not be a built-in factor when the test method shows the difference between stand-alone and built-in. The difference can be seen in energy consumption (kWh/year) and energy class.

Hans-Paul Siderius (NL) states that there will be different kWh because of features and sizes. So there will be little relation between those features and the energy label class. The issue with the built-in is whether separate consumer information, as suggested by TopTen, would do the job or whether it indeed needs to be incorporated in the labelling formula. He guesses this debate might be ongoing until the last moment and the focus is on the average buyer in the average label class and very little on other information that you provide on such a label. Secondly, warning texts are not very much appreciated by industry. All in all he sees rationale for built-in factor, but this will be something that is going to be discussed until the end.

Regarding wine coolers there are large differences, important in principle for glass doors to improve. He wonders if this can be achieved. When these products are not mass produced the cost difference needs to be assessed.

Martien Janssen (Re/genT) states that there is progress in glass door wine coolers, which is also stated in the report but it will never reach the same values as completely insulated doors. Getting to a same MEPS level would be tremendously difficult for glass doors. The request here is to have the same MEPS and a compensation factor could help here.

The chair thinks that having a compensation factor in the Ecodesign regulation and no compensation in the Energy Label is an interesting alternative.

Anette Michel (TopTen) also opposes against the use of correction factors. Inefficient features should be shown by the label. For the Ecodesign requirements there should not be a correction factor in the formula, but a first Tier requirement that can be met by the glass door wine coolers. Furthermore, she does not think it makes sense to use multi-door compensation factors. In China there are fridges on the market with 6 doors.

The chair replies that in the report it is proposed to use a multi-door compensation for 3, 4 or more than 4 doors. Ecodesign and Energy label regulations can have slightly different calculations.

Hans-Paul Siderius (NL) is not happy to single out appliances for some certain compensation factors. At this moment discussion is on compartments and formulas and on the compartments we are discussing compensation factors. For instance for wine storage compartments with a certain design temperature and that would be the correct way for this approach, because otherwise you single out complete appliances instead of using compartment method.

For Market Surveillance the complication is more in the testing of the appliances than the complexity of the formula.

Martien Janssen (Re/genT) adds that CECED has proposed a very strict definition in order to avoid misuse of the compensation factor for built-in appliances.

Edouard Toulouse (ECOS) asks for an example in which stand-alone and built-in fridges are exactly the same. According to his understanding built-in fridges have less insulation compared to stand-alone models.

The chair explains that this is not about less insulation, but it has to do with clearances and air flow during the test.

Martien Janssen (RE/genT) gives a small presentation about the chill compartment compensation, promoting that a factor 1.25 for chill-compartments of a minimum size should be introduced, also because the new standard now uses +2 °C as a design temperature, instead of the 0 °C used before. This means that the rc factor also changes (1.1 instead of 1.25) and thus they need this extra compensation. CECED also mentions that the chill-compartment is ideal for fresh meat and fish, foodstuffs with high CO₂-emissions where food-waste through sub-optimal storage should most certainly be avoided. Finally, the chill-compartment is the only compartment (because always <3 °C) without French Listeria (bacteria).

Hans-Paul Siderius (NL) is not convinced using a compensation factor for chill compartments is the way to go. Manufacturers have the possibility to choose when to use compartments with or without compensation factor and this influences the test method used. He wonders if it was taken into account that the test method indeed increases the temperature of the chill compartment with 2 °C. Since there is a lot of flexibility in this new approach he is a bit weary in introducing new compensation factors for certain compartments that we have now because this could lead to new compensation factors for new/ other compartments. On the spot he is not convinced of this compensation factor. There is also a study from Defra from a couple of years ago where they also looked at this compensation factor and the conclusion was that this was not really justified, but the food preservation arguments will hold.

Martien Janssen (Re/genT) states that the target temperature is +2°C but one of the real-life challenges of the chill compartment, also used for e.g. salad, is to never go below freezing (0.5 °C) but also never above 3°C. It also means that a chill compartment typically needs a fan (extra energy!) to get equal temperature distribution.

The chair adds that in the report the starting temperature is from T_c at 0°C (old standard). With the new standard (rc 1.1 instead of 1.25) statements in the report may be reconsidered. Nonetheless, an overall technical model is still missing that would also show the energy-advantages of a chill-compartment being between freezer and fresh food compartment and thus –for part of its envelope—experiencing much lower ambient temperature than +24 °C.

Martien Janssen (Re/genT) reminds that fridge temperatures have an allowance to operate within a much larger temperature range than chillers, i.e. up to 8 K instead of only 3K.

Anette Michel (TopTen) states that there is a mistake in the formula: V_c is mentioned instead of V . She agrees that the chill compartment compensation can have advantages, but there is need for transparency.

Jochen Haerlen (BSH) asks to use the average temperature of $+2^\circ\text{C}$ instead of using the max and min values. They do not use the whole band width, but rather between $0 - 3^\circ\text{C}$.

The chair states that also in the light of a robust metric more time is needed to look into this. The division between to use either the freezer or the refrigerator lies exactly in between the chill and the 0-star compartment

Martien Janssen (Re/genT) agrees with Jochen and adds considering also the momentary spread. So for a chill it is actually the maximum of the maximum temperature, so any peak has to be lower and any peak on the other side as well and that is different for fresh food.

Thomas Ertel (Liebherr) states that fridges without chill compartment can lead indirectly to an increase of CO_2 emissions. Mostly highly perishable foods are stored in this compartment and when a fridge does not have such a compartment people have to go more often to the supermarket and use the car more.

The chair replies that e.g. also a 0 star fridge can be used to store for instance meat.

Thomas Ertel (Liebherr) replies that these are almost not found on the market.

Jeremy Tait (Tait Consulting Limited) asks what the position of the chair is on the Frost Free factors. He wonders if this is 1.2. DEFRA suggested using lower values and stated that they are equally efficient as non-frost-free.

The chair replies that the Australians implemented the new standards already and they use kWh values that suggest a factor of 1.2. For this issue there is no test data according to the new standard, so when looking at the statistical analysis a factor of 1.2 can be found. This issue might be put into a review clause, i.e. to be revisited when more test data are available. At this moment it is not clear if it should be 1,2 or 1,18 or something else.

Please send us comments or proposals with arguments for the compensation factors.

Chapter 10/11

Anette Michel (TopTen) states that the product price seems too high. The market monitoring report shows a price of €465,- per unit in 2014. She suggests using the TopTen report more explicitly, e.g. in task 7.

The chair answers that the price of the sales weighted A+ unit is €435,- and A++ €522,-. The share of A+++ and A++ causes the difference. The data was based on Task 2 for COLD1 and COLD7, but for COLD8 and 9, own desk research had to be done from (Internet) sales data. In any case in the report it will be stated more clearly that price data have a certain bandwidth, also depending on type of outlet and country. The TopTen report has certainly been used but not as the only sources for this section.

Chapter 12

Edouard Toulouse (ECOS) states that he misses costs decrease when more products reach a higher class. At this moment he sees flat costs after the last year.

The chair answers that the overall costs decrease can be taken into account. This has been done in the Ecodesign Impact Accounting project and this will be included in the Task 7 scenarios.

Hans-Paul Siderius (NL) states that costs are relevant for glass doors. Figures have been taken from the Window study, but that would be then a kind of new component for refrigerators where, and certainly when the volumes increase, learning curves could really make an impact. Aiming at LLCC with a LLC that is slowly decreasing but this also depends on the requirements. Please indicate where the assumptions are based on.

The chair replies that the table in the slides indicates improvement in the range 27%-40%. Industry figures and own estimations have been used. The BAT figures show a spectacular efficiency improvement of 60-70% compared to products that were on the market 20 years ago.

Martien Janssen (Re/genT) states that in the COLD7 case, in the beginning of the presentation, double thermostats were mentioned. Most fridges consist of a compressor and solenoid valve. But they do not switch the freezer and fridge evaporator, as is suggested, but between freezer only and freezer+fridge. Thus the average evaporator is lower than suggested. With some new technologies and VSD the manufacturers might get at higher evaporator temperatures through better switching/control, but this is a future option.

Philippe Rivière (Armines) replies that what is modelled as 1 thermostat has constant temperature for freezer and refrigerator. Furthermore, some reports have been found about alternating solenoid valves on the evaporator of the freezer with some gains despite refrigerant charge issues, which are mentioned. Maybe the technologies behind this could be included in the analysis but this needs further research.

Martien Janssen (Re/genT) replies that some technologies behind this use VSD compressor in combination with no return valves and these components handle the refrigerant distribution issue. It is in principle a difficult topic to get gain of the system to get really good use of the high temperature during the fresh food phase. Mostly because of the fact that when only running the fresh food phase the capacity of the compressor will be very large, even when you go to the smallest VSD compressor which will lower the efficiency during the fresh food phase. There are publications or studies on this, but he thinks everybody here has been playing and using them. However, it is not in practise so it is one of the future options, but it is at BNAT level at this moment.

The chair states that the stakeholders can send in written comments before 15 January 2016.

The end of January is the deadline and end of contract of this project so if things are not clear it can be discussed in the technical assistance before the CF meeting in the autumn of 2016.

Andras Toth (EC) agrees that there will be an opportunity to further elaborate on the conclusions of Task 7 of the final report in the impact assessment and in the working documents to be prepared for the Consultation Forum. However, any major issues with Tasks 1-6 of the final report should be tackled before the report is finalised.

Edouard Toulouse (ECOS) asks if the chair has an idea how many scenarios will be addressed in task 7.

The chair asks the stakeholders to come up with suggestions for scenarios. Mostly there are 3 scenarios outside the business as usual (BAU). Coming up with for instance an industry, NGO and MS proposal then this could be considered for the scenario analysis.

Martien Janssen (Re/genT) states that among the industry there is a general consensus not to have constant-width label classes but to have fixed percentages of increment between the classes of the Energy label.

The chair notes that this is a possibility, but one would have to accept that –as classes grow smaller when moving towards the top—the lower classes would have a relatively large width (given that the total number of classes is limited). He asks the stakeholders to send in their proposals.

The chair thanks everybody for coming and participating. Deadline for written comments is 15 January 2016.

Meeting closes at 16.00h.

List of participants

First name	Surname	Company / organisation name
Ciara	Leonard	AB Electrolux
Philippe	Rivière	ARMINES
Andrea	Harrer	BAM Federal Institute for Materials Research and Testing
Jochen	Haerlen	BSH Hausgeraete GmbH
Viktorija	Krastinyte	CECED
Matteo	Rambaldi	CECED
Marie	Baton	CLASP
Bernt	Andersson	Dometic Group
Edouard	Toulouse	ECOS
Andras	Toth	European Commission
Thomas	Ertel	Liebherr
Hans-Paul	Siderius	Netherlands Enterprise Agency
Ina	Rüdenauer	Öko-Institut e.V.
Martien	Janssen	RE/genT BV
Jeremy	Tait	Tait Consulting Limited
Anette	Michel	Topten International
Rene	Kemna	VHK
Roy	van den Boorn	VHK
Wai Chung	Lam	VITO

ANNEX G: Scenario-analysis results

	2005	2010	2015	2020	2025	2030
SALES (1000 units)						
all scenarios	18800	19100	19400	19700	20000	20300
STOCK (1000 units, at product life=16 years)						
all scenarios	291 400	297 800	303 200	308 000	312 800	317 600
Unit electricity consumption of sales (in kWh/a)						
	2005	2010	2015	2020	2025	2030
BAU	285	242	213	179	155	135
LLCCa	285	242	213	148	117	101
LLCCb	285	242	213	155	122	106
Ambi	285	242	213	131	91	79
Lenient	285	242	213	170	142	124
EU Electricity consumption stock (in TWh/a)						
	2005	2010	2015	2020	2025	2030
BAU	122	103	86	74	64	57
LLCCa	122	103	86	72	58	47
LLCCb	122	103	86	73	60	49
Ambi	122	103	86	71	55	41
Lenient	122	103	86	73	62	54
EU GHG emissions (in Mt CO2 eq./a)						
	2005	2010	2015	2020	2025	2030
BAU	51.4	42.4	34.1	28.0	23.1	19.2
LLCCa	51.4	42.4	34.1	27.4	21.0	16.0
LLCCb	51.4	42.4	34.1	27.7	21.5	16.7
Ambi	51.4	42.4	34.1	27.2	19.8	14.0
Lenient	51.4	42.4	34.1	27.9	22.4	18.2
Industry revenu (in bn Euros 2010)						
	2005	2010	2015	2020	2025	2030
BAU	4.01	4.08	4.14	4.20	4.27	4.33
LLCCa	4.01	4.08	4.14	4.40	4.64	5.19
LLCCb	4.01	4.08	4.14	4.34	4.49	4.98
Ambi	4.01	4.08	4.14	4.57	5.88	6.24
Lenient	4.01	4.08	4.14	4.20	4.31	4.33
Wholesale revenu (in bn Euros 2010)						
	2005	2010	2015	2020	2025	2030
BAU	0.30	0.30	0.31	0.31	0.32	0.32
LLCCa	0.30	0.30	0.31	0.33	0.34	0.39
LLCCb	0.30	0.30	0.31	0.32	0.33	0.37
Ambi	0.30	0.30	0.31	0.34	0.44	0.46
Lenient	0.30	0.30	0.31	0.31	0.32	0.32
Retail revenu (incl. repairs, in bn Euros 2010)						
	2005	2010	2015	2020	2025	2030
BAU	3.98	4.04	4.11	4.17	4.23	4.30
LLCCa	3.98	4.04	4.11	4.37	4.60	5.15
LLCCb	3.98	4.04	4.11	4.30	4.46	4.94
Ambi	3.98	4.04	4.11	4.53	5.83	6.18
Lenient	3.98	4.04	4.11	4.17	4.28	4.30

Acquisition costs (in bn Euros 2010)						
	2005	2010	2015	2020	2025	2030
BAU	9.9	10.1	10.3	10.4	10.6	10.7
LLCCa	9.9	10.1	10.3	10.9	11.5	12.9
LLCCb	9.9	10.1	10.3	10.8	11.1	12.4
Ambi	9.9	10.1	10.3	11.3	14.6	15.5
Lenient	9.9	10.1	10.3	10.4	10.7	10.7
Energy costs (in bn Euros 2010)						
	2005	2010	2015	2020	2025	2030
BAU	18.7	17.6	17.7	18.3	19.4	20.9
LLCCa	18.7	17.6	17.7	18.0	17.7	17.4
LLCCb	18.7	17.6	17.7	18.1	18.1	18.1
Ambi	18.7	17.6	17.7	17.8	16.7	15.2
Lenient	18.7	17.6	17.7	18.3	18.9	19.8
EU Consumer expenditure (in bn Euros 2010)						
	2005	2010	2015	2020	2025	2030
BAU	28.7	27.7	27.9	28.8	30.0	31.6
LLCCa	28.7	27.7	27.9	28.9	29.2	30.3
LLCCb	28.7	27.7	27.9	28.9	29.2	30.4
Ambi	28.7	27.7	27.9	29.1	31.2	30.7
Lenient	28.7	27.7	27.9	28.7	29.6	30.5