SUPPLEMENT TO THE REFRIGERATORS POLICY GUIDE:
«ACCELERATING THE GLOBAL ADOPTION OF CLIMATE-FRIENDLY AND ENERGY-EFFICIENT REFRIGERATORS»

MODEL REGULATION GUIDELINES - SUPPORTING INFORMATION

SEPTEMBER 2019

ENERGY-EFFICIENT AND CLIMATE-FRIENDLY REFRIGERATORS

UN Environment – Global Environment Facility | United for Efficiency (U4E)

Acknowledgements

The lead authors, Brian Holuj of UNEP's United for Efficiency Initiative, Won Young Park and Nihar Shah of Lawrence Berkeley National Laboratory, and Noah Horowitz and Alex Hillbrand of the Natural Resources Defense Council would like to thank the following for their valuable contributions as reviewers:

Rashid Ali Abdallah, African Energy Commission
Atef Marzouk, African Union Commission - Energy Division
Tolga Apaydin, Arçelik A.Ş.
Jochen Härlen, BSH Home Appliances
Li Pengcheng, China National Institute of Standardization
Marie Baton, CLASP
Naomi Wagura, CLASP
Philipp Munzinger, GIZ
Miriam Frisch, GIZ
Michael Kiza, East African Centre of Excellence for Renewable Energy and Efficiency
Charles Diarra, ECOWAS Centre for Renewable Energy and Energy Efficiency
Viktor Sundberg, Electrolux
S.P. Garnaik, Energy Efficiency Services Limited
Han Wei, Energy Foundation China
Antoine Durand, Fraunhofer ISI
Nora Steurer, Global Alliance for Buildings and Construction
Miquel Pitarch, HEAT
Anett Matbadal, Independent Consultant
James Wolf, Independent Consultant
Frank Gao, International Copper Association
Hal Stillman, International Copper Association
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Jinho Yoo, Korea Refrigeration & Air Conditioning Assessment Center
Jun Young Choi, Korea Testing Laboratory
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Hyunho Choi, LG Electronics
Juan Rosales, Mabe
Fabio García, Organización Latinoamericana de Energía (OLADE)
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Asad Mahmood, Pakistan National Energy Efficiency & Conservation Authority
Sara Ibrahim, Regional Center for Renewable Energy and Energy Efficiency
Maged Mahmoud, Regional Center for Renewable Energy and Energy Efficiency
Kudakwashe Ndhlukula, SADC Centre for Renewable Energy and Energy Efficiency
Hyun Seok Jung, Samsung Electronics
Eunsung Kwon, Samsung Electronics
Yongsik Cho, Samsung Electronics
Lin-Jie Huang, Sanhua Holding Group
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Stephen Cowperthwaite, UK Department for Environment, Food and Rural Affairs
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Ashok Sarkar, World Bank Group
Omar Abdelaziz, Zewail City of Science and Technology

Foreword

This document provides context on the rationale underpinning the Model Regulation Guidelines for Energy-Efficient and Climate-Friendly Refrigerating Appliances. It includes a brief explanation of the scope, product categories, and market and policy trends in energy efficiency and refrigerants. The Model Regulation Guidelines refer to International Electrotechnical Commission (IEC) 62552:2015 for testing and measuring energy consumption. Countries need to be familiar with either this standard or other approaches that they intend to pursue for their regulatory frameworks.

Refrigerating appliances expend a considerable amount of electricity during normal use, and there is a significant opportunity to cost-effectively improve energy efficiency and transition to lower global warming potential (GWP) refrigerants. Energy-efficient refrigerating appliances tend to be better insulated and therefore able to maintain temperatures during unstable electricity supply situations compared to inefficient models. United for Efficiency (U4E) has produced Country Savings Assessments (updated as of September 2019) for 150 developing and emerging economies, which project annual electricity savings, greenhouse gas emissions reductions, and utility bill savings for consumers if the countries adopt the Model Regulation Guidelines.[1] The following table draws from the Assessments to provide examples of the estimated annual impacts in 2030 if all countries in the sample regions were to adopt the proposed minimum energy efficiency and refrigerant requirements. Various combinations of countries, beyond the simplified list below, can be considered by reviewing the full set of Country Savings Assessments.

Estimated Annual Savings starting in 2030 based on the Minimum Ambition (MEPS) Scenario				
Region	**Electricity (Twh)**	**Power Plants (500MW each)**	**CO2 (Million tonnes)**	**Financial - Electricity Bill (Million USD)**
Central America	5.9	3	3.5	478.3
Africa	11.3	5	7.8	910.2
South East Asia	9.1	4	6.2	979.9
West Asia	7.4	3	6.5	604.8

[1] Country Savings Assessments are available at https://united4efficiency.org/countries/country-assessments

Disclaimer

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Acronyms

AD	automatic defrost
AECmax	maximum annual energy consumption
AHAM	Association of Home Appliance Manufacturers
ANSI	American National Standards Institute
AV	adjusted volume
BEE	Bureau of Energy Efficiency
CA	California
comp	compartment
DOE	U.S. Department of Energy
ED	Ecodesign
EL	energy label
EU	European Union
FR	freezer
GWP	global warming potential
HC	hydrocarbon
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
LBNL	Lawrence Berkeley National Laboratory
MD	manual defrost
MEPS	minimum energy performance standards
NAECA	National Appliance Energy Conservation Act
PAD	partial automatic defrost
RE	refrigerator
RE-FR	refrigerator-freezer
S&L	standards and labelling
TDID	through-the-door ice dispenser
U.S.	United States
U4E	United for Efficiency

1. Model Regulation Guideline Scope and Product Categories

Energy-efficiency standards and labelling (S&L) are based on energy consumption values obtained from test standards. While the standard for measuring refrigerator energy consumption is broadly similar across countries, a number of factors can result in variations in energy consumption values (i.e., Wh/day or kWh/year) across countries, in particular due to different specifications for ambient temperature, compartments' internal temperature, and additional features in the test procedure. Accordingly, product categories of refrigerating appliances vary based on market characteristics and regulatory perspectives. The differences in test conditions and/or use of the test results lead to different energy consumption values, which makes it difficult to compare across regions.

Table 1 shows key parameters considered in energy efficiency standards for refrigerating appliances. Tables 5. 6 ,7 in Annex 1 show examples of product categories defined in regional standards. The United States (U.S.) uses 18 product categories, the European Union (EU) currently uses 10, and other countries often use a similarly diverse array. However, the EU standard is being revised at the time of this writing and will not have such categories. It is expected that a streamlined approach is a reasonable starting point for those considering the Model Regulation Guidelines. Therefore, maximum energy consumption requirements are stipulated for refrigerating appliances within three broad product categories that can be adjusted in accordance with country- or region-specific market characteristics and regulatory perspectives.

Table 1: Parameters used to define product categories in energy-efficiency standards of refrigerating appliances

Structure or Type		Climate Classes	Built-in or Free Standing	Defrost	Icemaker	Size
Refrigerator	Refrigerator only, refrigerator with frozen compartment	Subtropical (ST), tropical (T), sub-temperate (SN), temperate (N)	Free standing, built-in	Manual, automatic, partial automatic	Through-the-door ice service	e.g., a product category with adjusted volume less than 300 L
Refrigerator-Freezer	Top-mounted, bottom-mounted, side-mounted freezer					
Freezer	Chest (horizontal), upright (vertical)					
By compartment*						

* Energy consumption requirements in the new EU standard are based on individual compartments.

Three standards are typically adopted across countries for refrigerating appliances. Many countries adopt or refer to IEC 62252 standards. For example, Brazil, China, the EU 2009 regulations, Republic of Korea,[1] and South Africa had/have their standards based on IEC 62552:2007, which uses an ambient temperature of 25°C. IEC 62552:2015 was recently developed to harmonize international residential refrigeration testing and efficiency metrics. China, Chinese Taipei, the EU (under revision), Indonesia, Kenya, Malaysia, and Thailand have already moved to, or are planning to, adopt the IEC 62552 standard that measures energy consumption at both 16°C and 32°C, providing improved information on the likely field performance of refrigerating appliances.

Australia and New Zealand use the harmonised test standard AS/NZS 4474:2018, which uses an ambient temperature of 32°C for minimum energy performance standards (MEPS) and 22°C for labels. India's test standard is largely consistent with the preceding AS/NZS 4474.1 standard that used an ambient temperature of 32°C.

Standards in Canada, Mexico, and the U.S. are based on the American National Standards Institute/Association of Home Appliance Manufacturers (ANSI/AHAM) test standard. The test standard is based on an ambient temperature of 32.2°C (90°F) to account for impacts of door openings and the addition of warm food on energy consumption.

Refrigerating appliances for household use are typically designed for an ambient temperature of 16°C or greater. However, some appliances are in environments with lower or higher ambient temperatures. Standards based on 32°C and 24°C (or 25°C) are consistent with many of the existing regional standards. Power consumption of refrigerating appliances does not increase in a linear scale between 16°C and 32°C (see Harrington 2015 for details). Actual performance at 25°C is closer to the performance (linearly interpolated by measured performance at 16°C and 32°C) for 24°C than that for 25°C. While 0.5 and 0.5 are mathematically the factors for 24°C, these better represent the actual performance at 25°C. Hence, the Model Regulation Guidelines have the reference temperature of 24°C (performance determined by measured performance at 16°C and 32°C) to align with the draft EU standard.

2. Trends in Energy Consumption and Performance Requirements of Refrigerating Appliances

In 2012, about 1.4 billion refrigerators and freezers were estimated to be in use worldwide, with an average annual electricity consumption of 450 kWh per unit (Barthel and Götz 2012). The average per-unit energy consumption of household refrigerators decreased in major economies (Figure 1), reaching less than 400 kWh per year (IEA 4E 2014). A study from an African market shows that a typical refrigerator-freezer (280 L net volume) consuming 700 kWh per year before regulations can be improved to 350–450 kWh per year or lower by suitable MEPS (U4E 2017),

[1] Also known as South Korea.

and significantly better by the time that the Model Regulation Guidelines are proposed to come into effect. For example, India's energy consumption requirements for frost-free refrigerators became more stringent by about 60 per cent for the 2016–2019 period compared with 2010–2011 (Figure 2). In 2018, Mexico announced its revised standards for refrigerating appliances, aligned with the current Canada and U.S. standards. A 35 per cent energy consumption reduction is expected in comparison with the earlier version (Mexico National Commission for the Efficient Use of Energy 2018). The revision will be implemented for three years: products with capacity ≥ 550 L in 2018, those with 400 L ≤ capacity < 550 L in 2019, and those with capacity < 400 L in 2020.

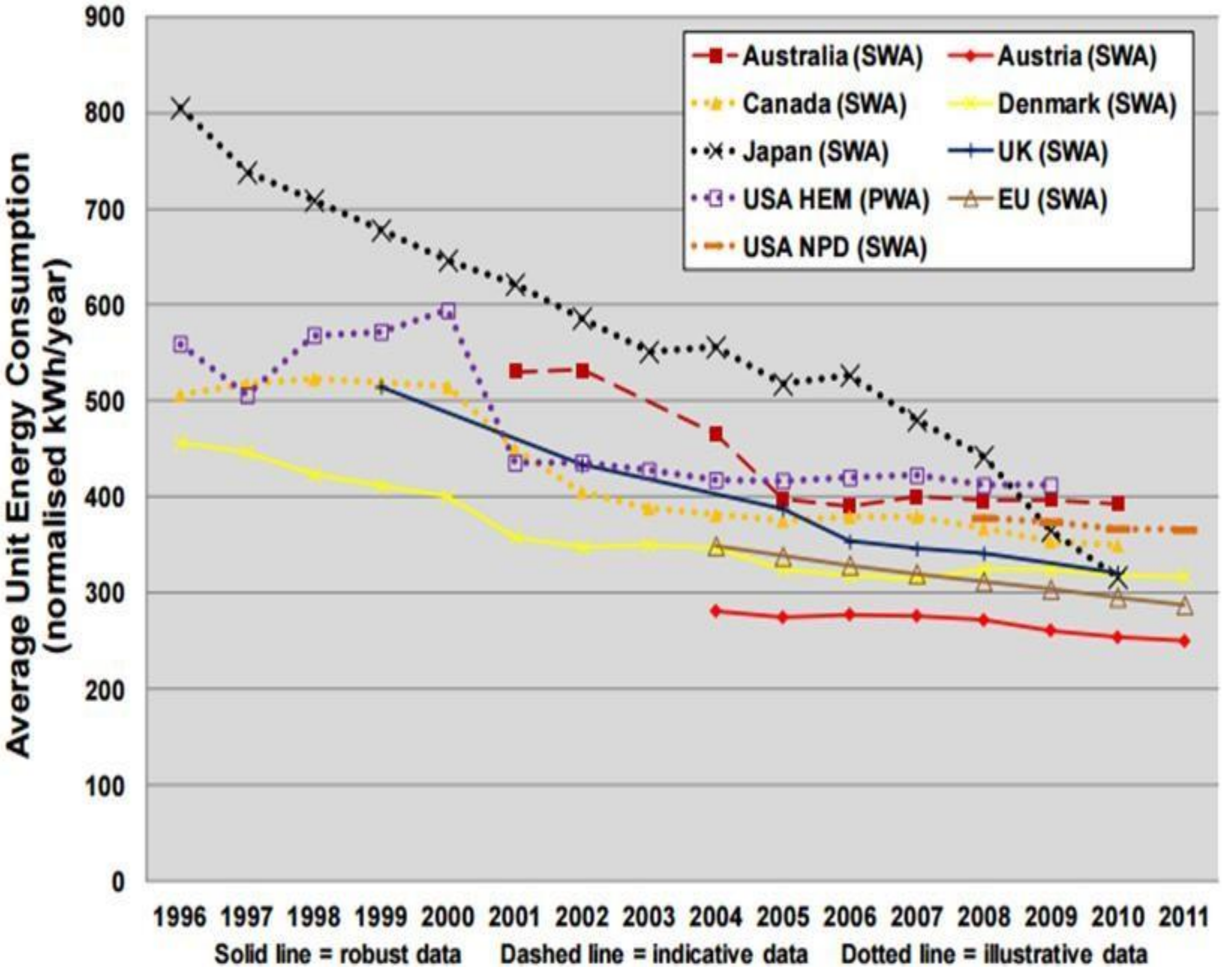


Figure 1: Normalised average unit energy consumption of new refrigerator-freezer combination

SWA = sales weighted average; PWA = product weighted average; USA HEM: data sourced from the Home Energy Magazine; USA NPD: data sources from the NPD Group's retail tracking service

Source: International Energy Agency–Energy Efficient End-Use Equipment [IEA 4E] 2014

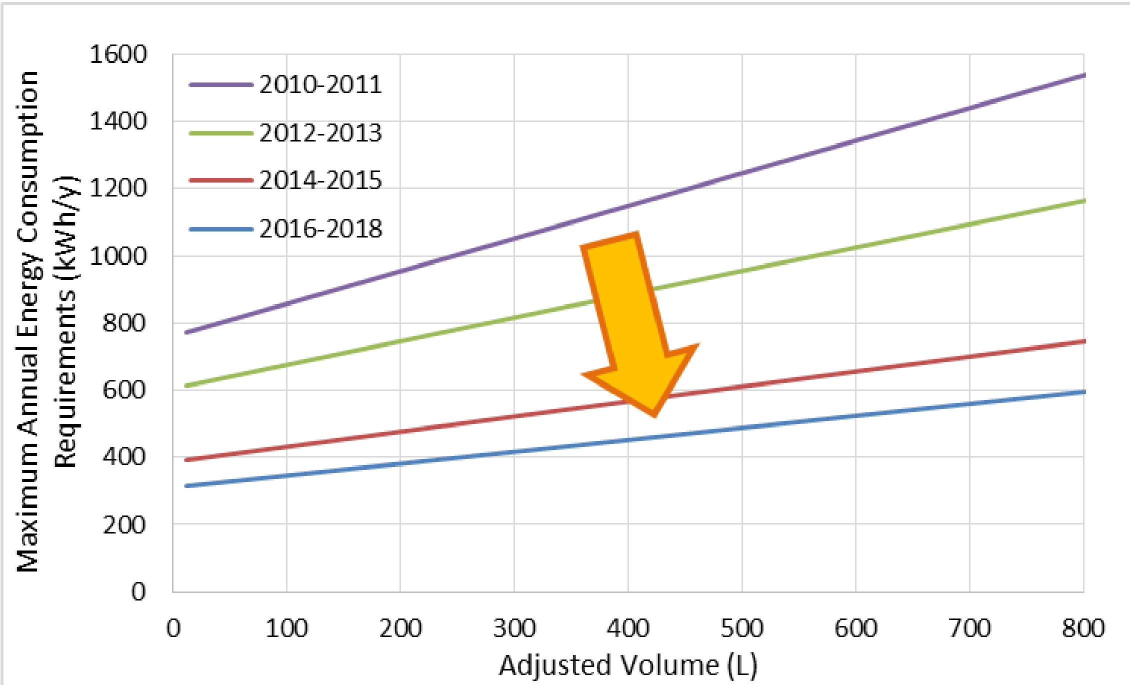


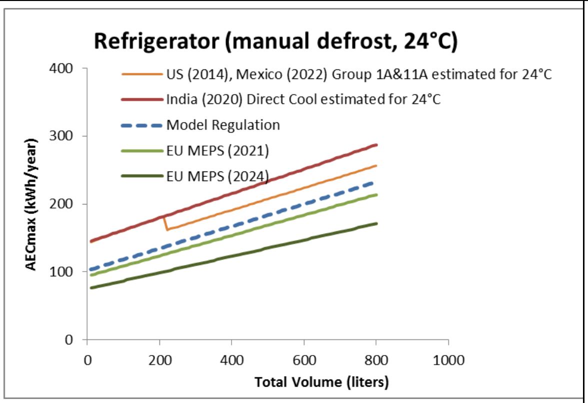
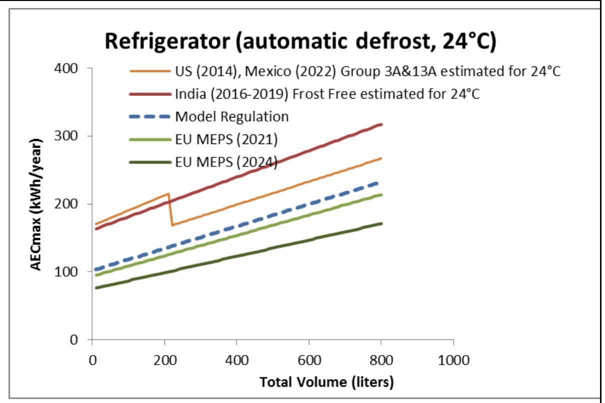
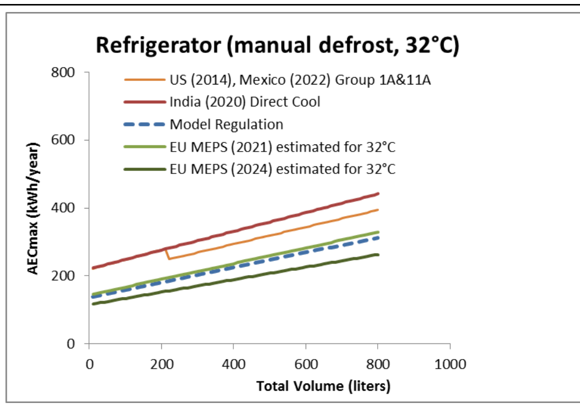
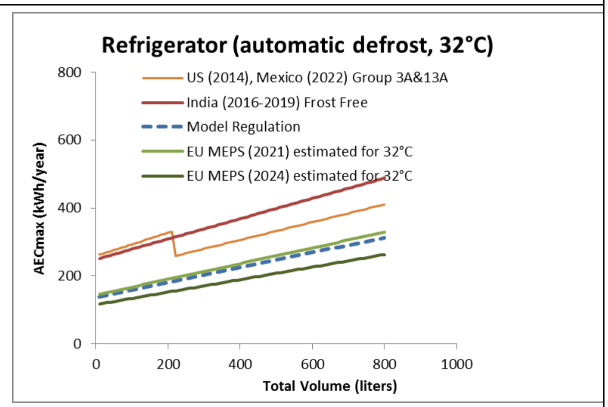
Figure 2: Annual energy consumption requirements of frost-free refrigerators in India
Source: BEE (2015)

Energy use requirements are typically defined by the adjusted volumes of individual products, ambient temperature, temperatures of compartments concerned, and so on. The requirements of existing standards are not directly comparable, because there are different approaches and parameters considered, resulting in some complexity and diversity in the way these products are regulated.

3. Energy-Efficiency Threshold: Benchmarking and Level for the Model Regulation Guidelines

Setting requirements that are consistent with the expected market transition in major emerging economies that have robust policies provides an important policy signal to manufacturers that also sell to markets that are targets of the Model Regulation Guidelines: those with outdated, under-enforced, or no mandatory MEPS and labels. A common or comparable set of requirements will help manufacturers prepare to offer products that can be sold more broadly, with an aim to unlock greater economies of scale so that energy-efficient solutions are more widely accessible. Combining the transition toward higher efficiency with the transition toward lower-GWP refrigerants would allow the industry to exploit synergies in redesigning equipment and retooling manufacturing lines to pursue both opportunities simultaneously. Tables 2, 3, and 4 show illustrative comparisons of the Model Regulation Guidelines with select standards for reference temperatures of 24°C and 32°C.

Table 2: Comparison of the Model Regulation Guidelines with select standards – refrigerators[1]

<table>
<tr><th rowspan="2">Ref. Temp.</th><th colspan="2">Maximum Annual Energy Consumption (AECmax, kWh/year) in Refrigerators</th></tr>
<tr><th>Manual Defrost</th><th>Automatic Defrost</th></tr>
<tr><td>24°C</td><td>
</td><td>
</td></tr>
<tr><td>32°C</td><td>
</td><td>
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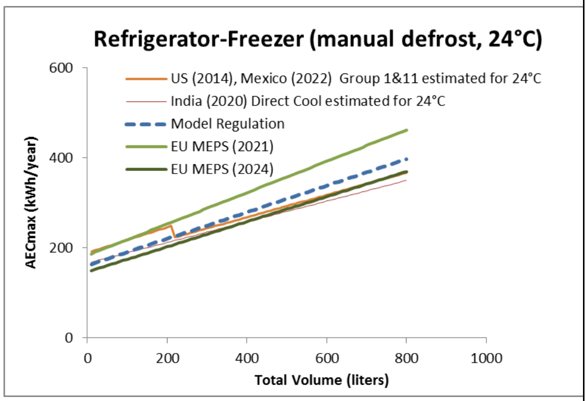
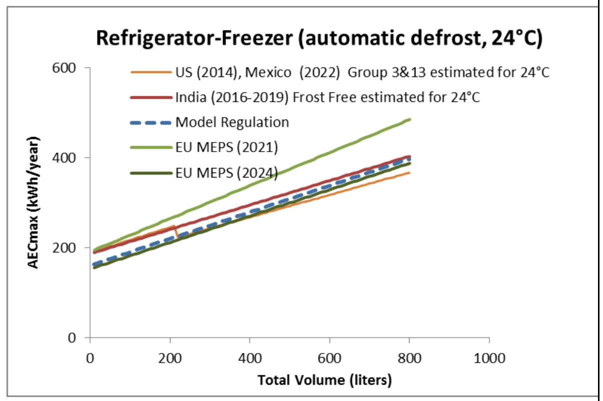
</table>

Notes:

1. For refrigerators, energy consumption at 24°C according to the Indian and Mexican standards is assumed to be less by 35 per cent than the energy consumption at 32°C. Energy consumption at 32°C according to the EU standard is assumed to be greater by 35 per cent than the energy consumption at 24°C.
2. Based on refrigerators with fresh food compartment only.

[1] The U.S. standard has different requirements for products of less than 220 L.

Table 3: Comparison of the Model Regulation Guidelines with select standards – refrigerator-freezers

<table>
<tr><th rowspan="2">Ref. Temp.</th><th colspan="2">Maximum Annual Energy Consumption (kWh/year) in Refrigerator-Freezers</th></tr>
<tr><th>Manual Defrost</th><th>Automatic Defrost</th></tr>
<tr><td>24°C</td><td>
</td><td>
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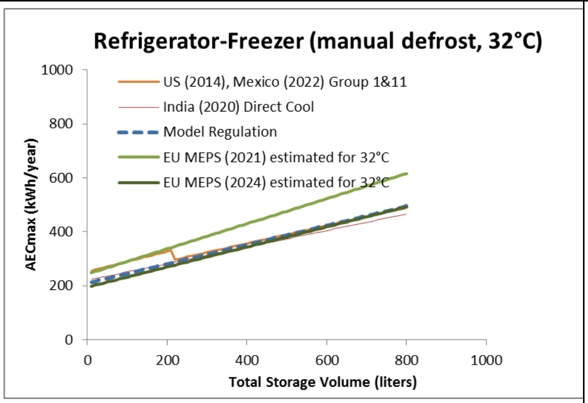
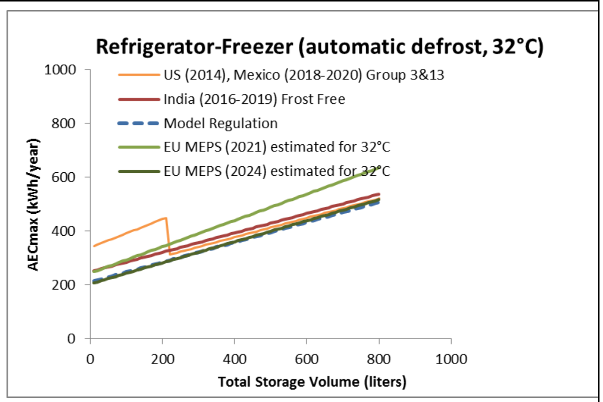
<tr><td>32°C</td><td>
</td><td>
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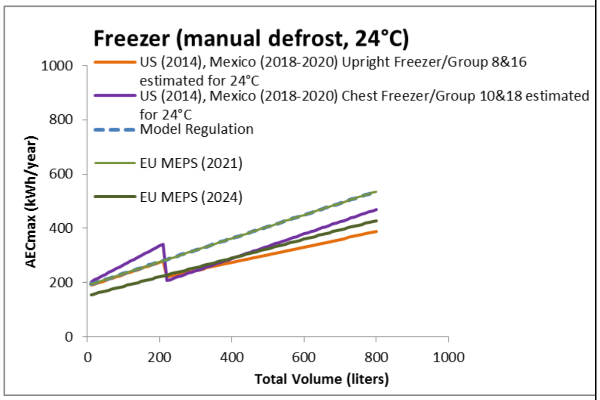
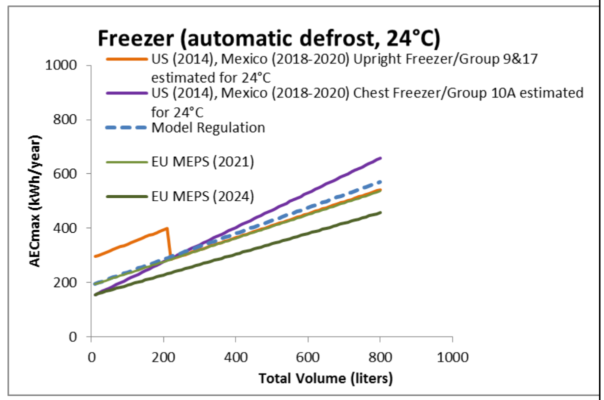
Notes:

1. For refrigerator-freezers, energy consumption at 24°C according to the Indian and Mexican standards is assumed to be less by 25 per cent than the energy consumption at 32°C. Energy consumption at 32°C according to the EU standard is assumed to be greater by 25 per cent than the energy consumption at 24°C.
2. Based on two-door frost-free refrigerators with fresh food compartment volume accounting for 70 per cent of the total storage volume.

Table 4: Comparison of the Model Regulation Guidelines with select standards – freezers

<table>
<tr><th rowspan="2">Ref. Temp.</th><th colspan="2">Maximum Annual Energy Consumption (kWh/year) in Freezers</th></tr>
<tr><th>Manual Defrost</th><th>Automatic Defrost</th></tr>
<tr><td>24°C</td><td>
</td><td>
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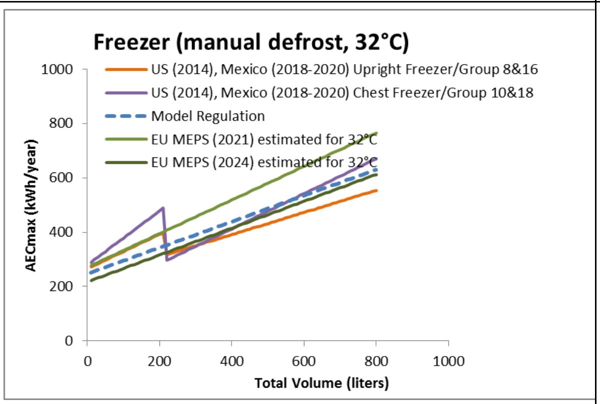
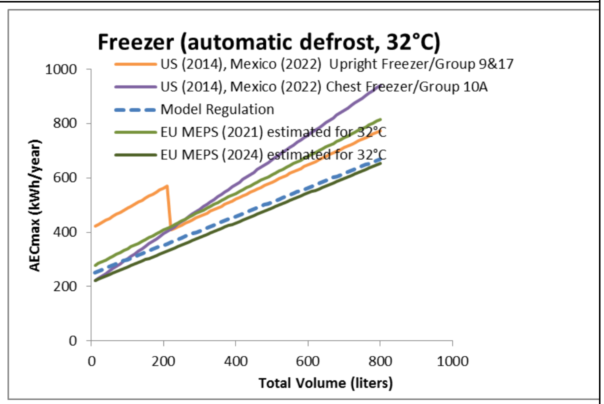
<tr><td>32°C</td><td>
</td><td>
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Notes:

1. For freezers, energy consumption at 24°C according to the Indian and Mexican standards is assumed to be less by 30 per cent than the energy consumption at 32°C. Energy consumption at 32°C according to the EU standard is assumed to be greater by 20 per cent than the energy consumption at 24°C.
2. According to the U.S. standard, there is a dimensionless correction factor of 0.7 for energy consumption in chest freezers and 0.85 for energy consumption in upright freezers. These correction factors are applied in the comparison.
3. As the automatic defrost type of freezers tends to need more energy than the manual defrost type, the Model Regulation Guidelines align the requirements further with the automatic defrost type.

Figures 3 and 4 show comparisons of maximum energy use requirements for refrigerators and refrigerator-freezers in several economies, showing a trend similar to the findings discussed above, e.g., a typical refrigerator-freezer (300 L net volume) is allowed to consume 240–640 kWh per year depending on the MEPS. The Model Regulation Guidelines requirements are similar to those from the current U.S. and draft EU standards. The Model Regulation Guidelines are expected to be cost-effective in many countries, mainly because the U.S. and EU set such requirements according to robust technical and economic analyses, and these are large markets that influence the cost and availability of such products more broadly.

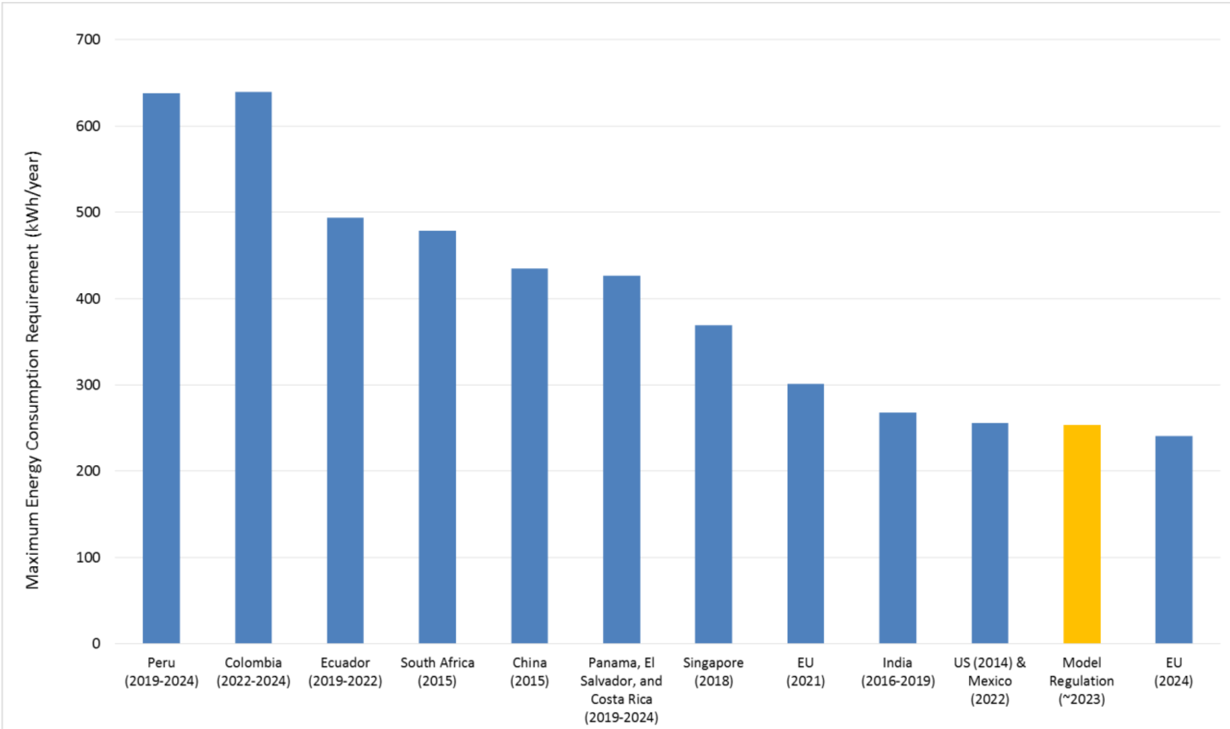

Figure 3: Comparison of maximum energy use requirements for refrigerator-freezers (25°C)

Source: Lawrence Berkeley National Laboratory [LBNL] analysis

Notes:

1. For refrigerator-freezers, energy consumption at 25°C according to standards in Colombia, Panama, El Salvador, Costa Rica, India, Mexico, Singapore, and the U.S. is assumed to be less by 25 per cent than the energy consumption at 32°C. Energy consumption at 32°C according to the EU standard is assumed to be greater by 25 per cent than the energy consumption at 25°C. South Africa's requirement is equivalent to the current EU B class.
2. The maximum energy use requirement for India, U.S./Mexico, and other countries are for frost-free type, refrigerator-freezers—automatic defrost with top-mounted freezer without an automatic icemaker, and refrigerator-freezers, respectively, as defined in the standards.
3. The comparison is based on calculations for a two-door frost-free refrigerator-freezer with 300 L storage volume and freezer compartment accounting for 30 per cent of total volume.

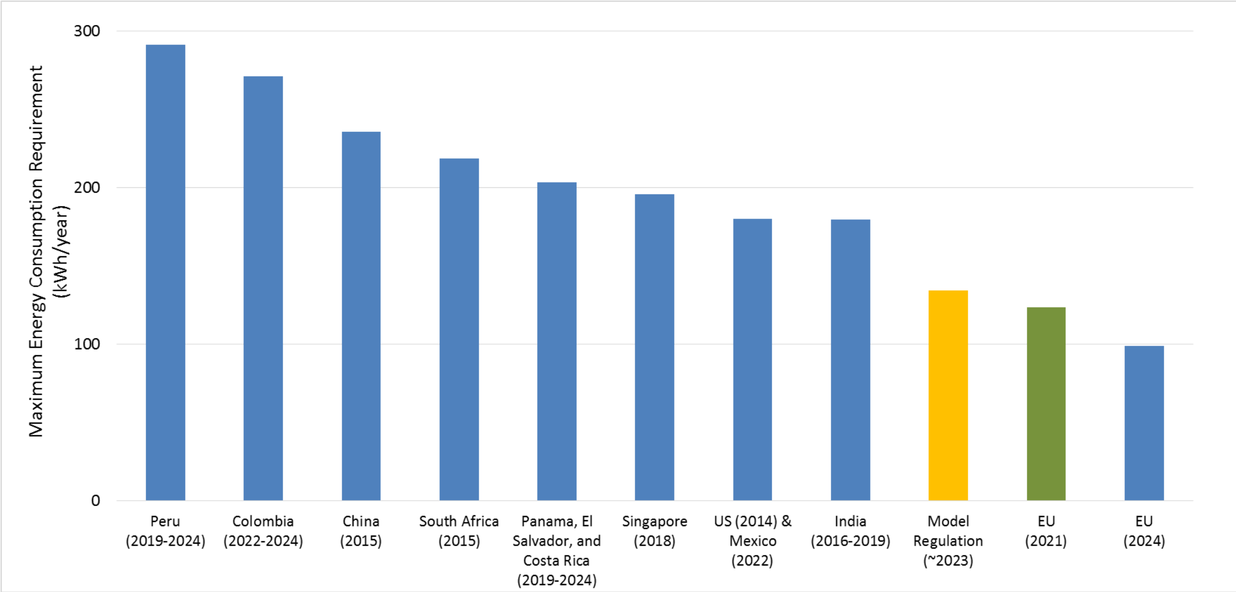

Figure 4: Comparison of maximum energy use requirements for refrigerators (25°C)

Source: LBNL analysis

a. For refrigerators (mostly small-size products), energy consumption at 25°C according to standards in Colombia, Panama, El Salvador, Costa Rica, India, Mexico, Singapore, and the U.S. is assumed to be less by 35 per cent than the energy consumption at 32°C. Energy consumption at 32°C according to the EU standard is assumed to be greater by 35 per cent than the energy consumption at 25°C. South Africa's requirement is equivalent to the current EU B class.

b. The maximum energy use requirement for India, U.S./Mexico, and other countries are direct-cool type, compact refrigerators—manual defrost, and refrigerators without frozen compartment, respectively, as defined in the standards.

c. The comparison is based on calculations for a one-door refrigerator with 200 L storage volume.

IEC 62552:2015 specifies test methods for determining load processing efficiency and energy consumption of specified auxiliaries (ambient controlled anti-condensation heaters and automatic icemakers). Some regional standards add load processing efficiency and/or auxiliary energy consumption to set the annual maximum energy consumption requirements. For example, the draft EU regulation adds auxiliary energy consumption for refrigerating appliances with ambient controlled anti-condensation heaters. A measure of load processing efficiency is to realistically estimate energy consumption contributed from user interactions (e.g., how much additional energy is used to remove heat from user interactions from the refrigerator such as door openings and the cooling of warm food and drinks). For example, the load processing efficiency at 24°C for energy labelling in Australia (effective from 2021 onward) is calculated based on the load processing efficiency measured at 32°C and 16°C (Harrington 2018).

Most energy-efficiency standards for refrigerating appliances have focused on energy consumption at one ambient temperature, with little attention paid to load processing efficiency at any ambient temperature or energy consumption at other ambient temperatures (Harrington 2015). These new energy consumption measurements may encourage manufacturers to optimise the energy performance of their products under real-world conditions, but compliance costs may increase as well. Implementation of these energy consumption measurements merits further exploration and discussion.

4. Recognition of Energy-Efficient Refrigerating Appliances

The high-efficiency level in the Model Regulation Guidelines is 1.5 times as efficient as the low-efficiency (i.e., maximum energy use) level, but it is similar to or less than the efficiency levels of the current best available technologies. For example, 54 of 315 frost-free refrigerator models (200–620 L) in India are estimated to meet the Model Regulation Guidelines' high-efficiency requirements (Figure 5). Only a few of the 366 direct-cool refrigerator models (40–260 L) in India are estimated to meet the Model Regulation Guidelines' high-efficiency requirements (Figure 6).

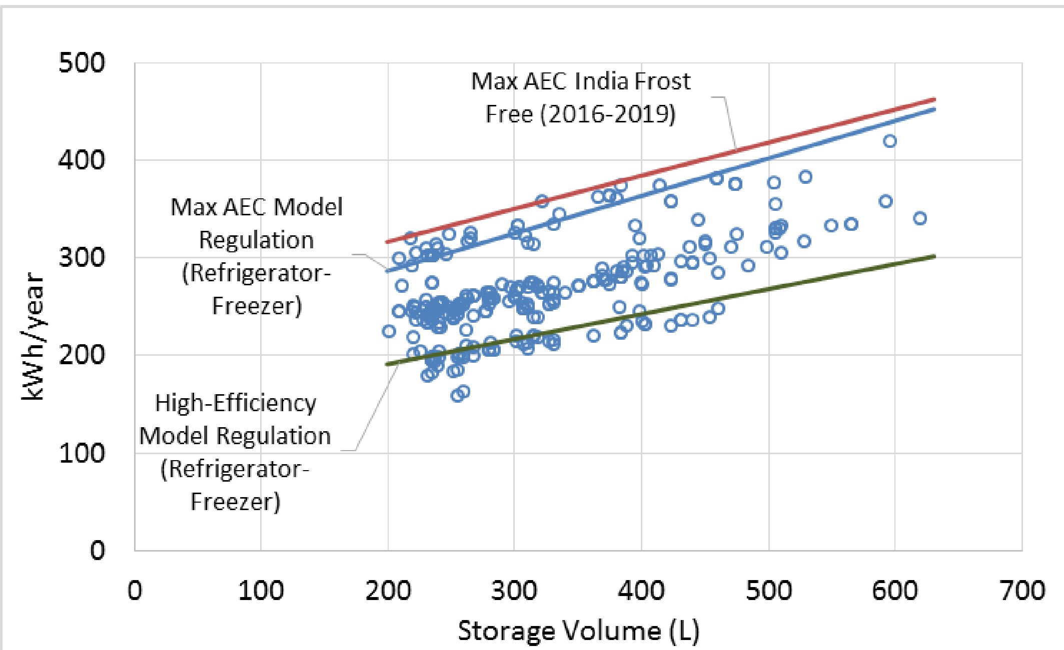

Figure 5: Efficiency classes of frost-free products in India

Source: Authors' work based on the Bureau of Energy Efficiency [BEE] database

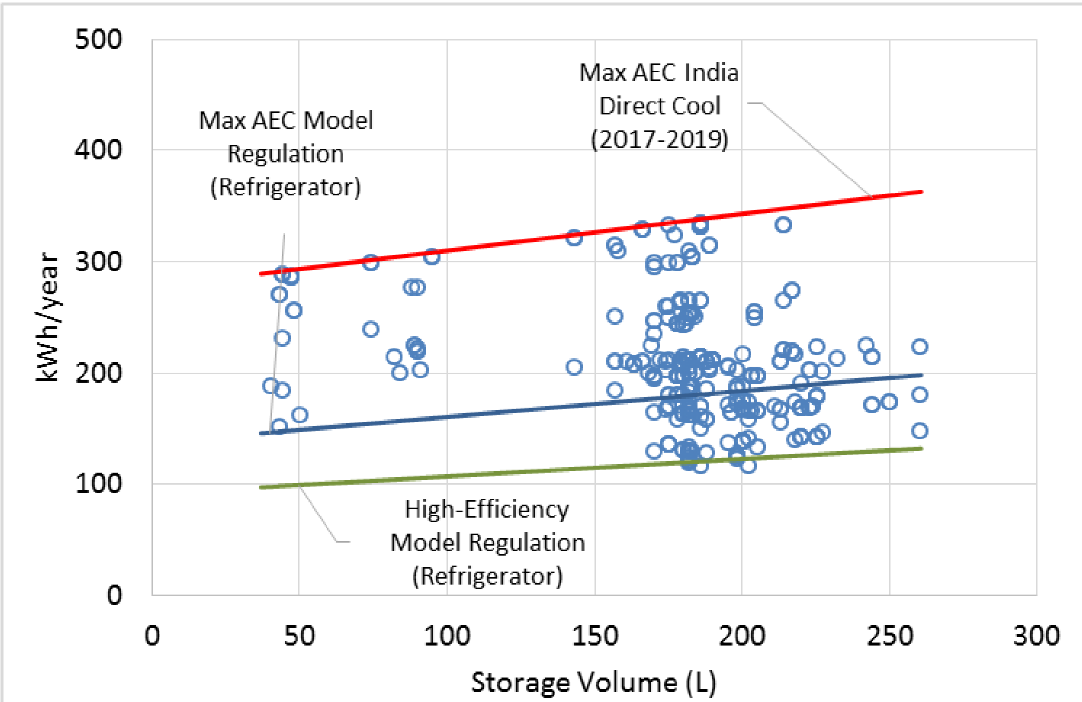

Figure 6: Efficiency classes of direct-cool refrigerators in India
Source: Authors' work based on the BEE database

Twenty-five of 32 of the most efficient (A+++) models of single-door refrigerators in the EU are estimated to meet the Model Regulation Guidelines' high-efficiency requirements, and 25 of 55 of the most efficient models of double-door refrigerator-freezers in the EU are estimated to meet those requirements. All (71 of 71) of the most efficient models of freezers in the EU are estimated to meet the Model Regulation Guidelines' high-efficiency requirements.

More than 500 million domestic refrigerators using low-GWP hydrocarbons (HCs) as refrigerants are already operating globally (United Nations Environment Programme 2015), which also enables more energy-efficient operation of the compressor compared to legacy refrigerants. Highly efficient refrigerating appliances using such lower-GWP refrigerants are commercially available today, with increasing market share globally.

R-600a (HC-600a) is the standard refrigerant for European domestic refrigerators and freezers. Topten EU (2018) and EU (2019) show that the average efficiency of refrigerating appliances in the EU region improved by 37 per cent during the 2004–2015 period. Nearly all products have been qualified as class A+ or higher since 2012 (Figure 7). The EU regulation will revert to an A–G scale, which requires a rescaling mechanism between existing and future labels. The new class G is roughly comparable with the current class A+ or even higher.

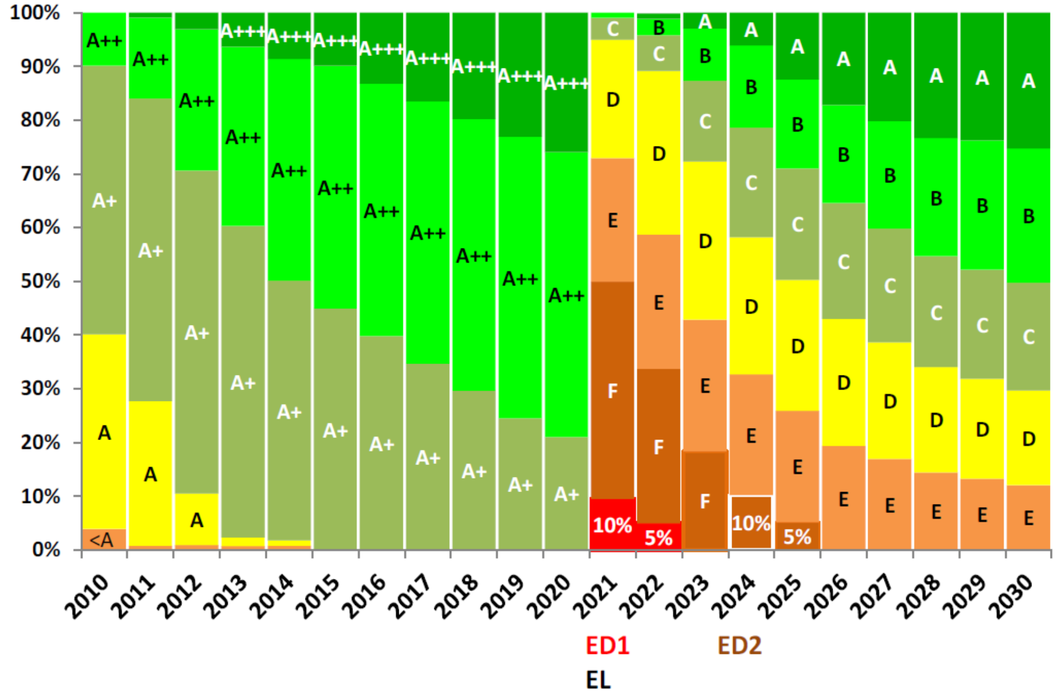

Figure 7: Actual (2010–2016) and projected (2017–2030) distribution of efficiency classes of refrigerator sales in the EU

Source: European Union [EU] 2019

Note: The new EU energy label (EL) and Ecodesign (ED) requirements will apply from 2021 onwards. The ED requirements will also improve from 2024 onwards. The share of models qualifying for the G energy-efficiency class is projected to be 10 per cent in 2021 and 5 per cent in 2022. The share of models qualifying for the F energy-efficiency class is projected to be 10 per cent in 2024 and 5 per cent in 2025.

Several studies have shown that appliance prices in real terms have continued to decline despite major efficiency improvements. For example, Van Buskirk et al. (2014) found that the introduction and updating of appliance standards, including refrigerator standards, are not associated with a long-term increase in purchase price and accelerated decline in life-cycle cost post-standards. Figures 8 and 9 show the trends in energy consumption and real prices of refrigerators in the U.S. and Australia.

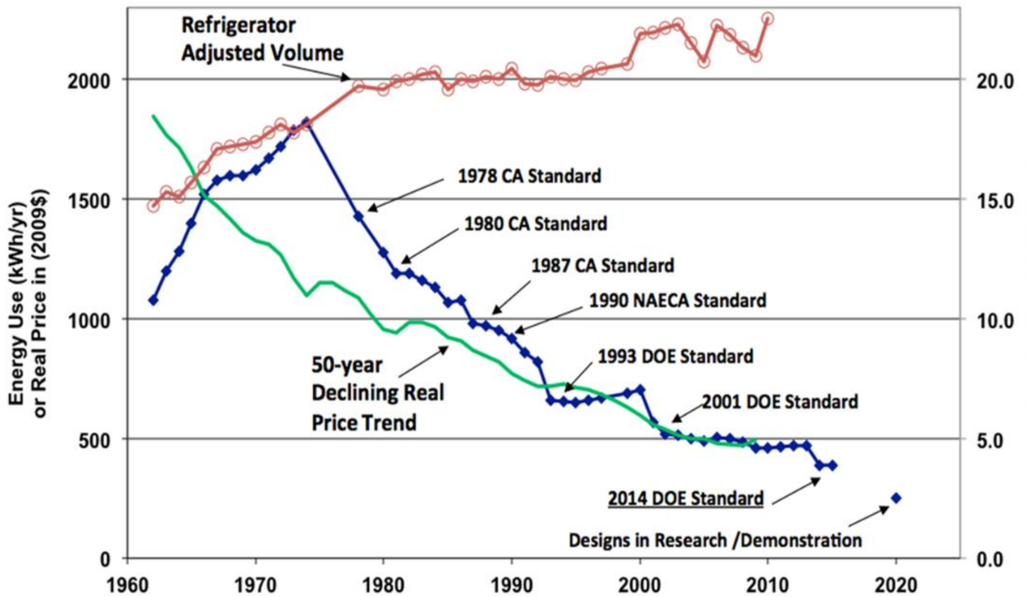

Figure 8: Refrigerator energy use and real price trends – U.S.

Source: LBNL

CA = California, DOE = U.S. Department of Energy, NAECA = National Appliance Energy Conservation Act

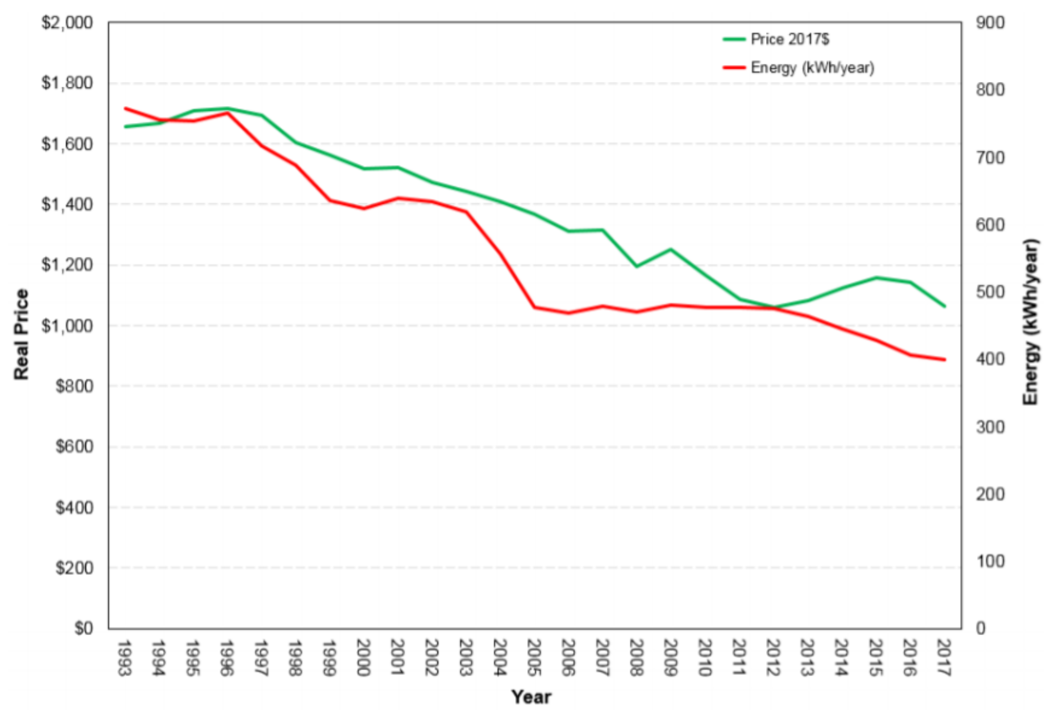

Figure 9: Refrigerator energy use and real price trends – Australia

Source: Commonwealth of Australia, Department of the Environment and Energy 2017

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Annex 1. Product Categories of Refrigerating Appliances

Table 5: Product categories of refrigerating appliances in select economies

India	Singapore	Republic of Korea	EU (old) and several countries in Asia, Africa, Latin America	Australia, New Zealand
1. Direct-cool RE 2. Frost-free RE	1. RE without FR (AV≤900L) 2. RE with FR (AV≤300L) 3. RE with FR (300L<AV≤900L) 4. RE with FR and TDID (AV≤900L)	1. RE 2. RE-FR (AV<500L) 3. RE-FR (500L≤AV<1000L without TDID) 4. RE-FR (500L≤AV<1000L with TDID) 5. RE-FR (AV≥1000L without TDID) 6. RE-FR (AV≥1000L with TDID) Freezer-only type not included	1. RE with one or more fresh-food comps 2. RE-cellar, cellar, and wine storage with a 0-star comp 3. RE-chiller and RE with a 0-star comp 4. RE with a 1-star comp 5. RE with a 2-star comp 6. RE with a 3-star comp 7. RE-FR 8. Upright FR 9. Chest FR 10. Multi-use and other refrigerating appliances	1. RE without a low-temperature comp, AD 2. RE with or without an ice making comp, MD (bar refrigerators) 3. RE with or without an ice making comp, includes a short-term frozen food comp 4. RE-FR, RE with AD, FR with MD 5B. RE-FR, AD, bottom-mounted FR 5S. RE-FR, AD, side by side 5T. RE-FR, AD, top-mounted FR 6C. Chest FR, all defrost types 6U. Vertical FR, MD 7. Vertical FR, AD

AD = automatic defrost, AV = adjusted volume, comp = compartment, FR = freezer, MD = manual defrost, RE = refrigerator, RE-FR = refrigerator-freezer, TDID = through-the-door ice dispenser

Table 6: Compartment-based approach of the new EU regulation

Compartment Type	Modelling Parameters	Correction Factors		
Pantry	• Adjusted volume factor • Refrigerator-freezer combination factor • Energy consumption parameter	• Manual defrost • Automatic defrost	• Freestanding • Built-in	• Number of doors or compartments, whichever is lowest
Wine storage				
Cellar				
Fresh food				
Chill				
0-star & icemaking				
1-star				
2-star				
3-star				
Freezer (4-star)				

Table 7: Product categories of refrigerating appliances in the U.S., Canada, and Mexico

U.S., Canada, and Mexico	
1	RE-FR and RE other than all-RE with MD
1A	All-RE—MD
2	RE-FR—PAD
3	RE-FR—AD with top-mounted FR without an automatic icemaker
3-BI	Built-in RE-FR—AD with top-mounted FR without an automatic icemaker
3I	RE-FR—AD with top-mounted FR with an automatic icemaker without TTID
3I-BI	Built-in RE-FR—AD with top-mounted FR with an automatic icemaker without TTID
3A	All-RE—AD
3A-BI	Built-in all-RE—AD
4	RE-FR—AD with side-mounted FR without an automatic icemaker
4-BI	Built-in RE-FR—AD with side-mounted FR without an automatic icemaker
4I	RE-FR—AD with side-mounted FR with an automatic icemaker without TTID
4I-BI	Built-in RE-FR—AD with side-mounted FR with an automatic icemaker without TTID
5	RE-FR—AD with bottom-mounted FR without an automatic icemaker
5-BI	Built-in RE-FR—AD with bottom-mounted FR without an automatic icemaker
5I	RE-FR—AD with bottom-mounted FR with an automatic icemaker without TTID
5I-BI	Built-in RE-FR—AD with bottom-mounted FR with an automatic icemaker without TTID
5A	RE-FR—AD with bottom-mounted FR with TTID
5A-BI	Built-in RE-FR—AD with bottom-mounted FR with TTID
6	RE-FR—AD with top-mounted FR with TTID
7	RE-FR—AD with side-mounted FR with TTID
7-BI	Built-in RE-FR—AD with side-mounted FR with TTID
8	Upright FR with MD
9	Upright FR with AD without an automatic icemaker
9I	Upright FR with AD with an automatic icemaker
9-BI	Built-in upright FR with AD without an automatic icemaker
9I-BI	Built-in upright FR with AD with an automatic icemaker
10	Chest FR and all other FR except compact FR
10A	Chest FR with AD
11	Compact RE—FR and RE other than all-RE with MD
11A	Compact all-RE—MD
12	Compact RE-FR—PAD
13	Compact RE-FR—AD with top-mounted FR
13I	Compact RE-FR—AD with top-mounted FR with an automatic icemaker
13A	Compact all-RE—AD
14	Compact RE-FR—AD with side-mounted FR
14I	Compact RE-FR—AD with side-mounted FR with an automatic icemaker
15	Compact RE-FR—AD with bottom-mounted FR
15I	Compact RE-FR—AD with bottom-mounted FR with an automatic icemaker
16	Compact upright FR with MD
17	Compact upright FR with AD
18	Compact chest FR

PAD = partial automatic defrost