«SUPPORTING DEVELOPING AND EMERGING ECONOMIES TO ACCELERATE THE TRANSITION TO ENERGY-EFFICIENT AND CLIMATE-FRIENDLY EQUIPMENT»

MODEL REGULATION GUIDELINES
—
SUPPORTING INFORMATION

NOVEMBER 2021

ENERGY-EFFICIENT AND CLIMATE-FRIENDLY COMMERCIAL REFRIGERATION EQUIPMENT

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Foreword

This document provides context on the rationale underpinning the U4E Model Regulation Guidelines for Energy-Efficient and Climate-Friendly Commercial Refrigeration Equipment (Guidelines). It includes an explanation to the extent possible of the scope, product categories, and market and policy trends in energy consumption and refrigerants of commercial refrigeration equipment. Section 1 presents an overview of the global commercial refrigeration market and policies. Section 2 discusses the scope of the Guidelines. Section 3 assesses technologically feasible energy-efficiency improvement options, adoption trends of such options, and the cost-effectiveness of these options on the energy consumption of two equipment types. Section 4 analyzes energy performance requirements in the Guidelines and leading economies. Section 5 addresses lower global warming potential (GWP) refrigerant options. The Guidelines refer to international standards (e.g., ISO 23953 for Performance and Energy Rating of Commercial Refrigerated Display Cabinets). Officials should be familiar with either the referenced standards or other established approaches to effectively utilize this information.

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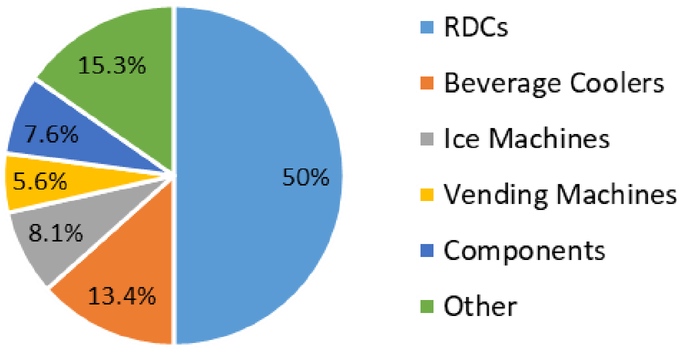
Acronyms

AEC	annual energy consumption
ACEC	anti-condensate energy consumption
AHRI	Air Conditioning, Heating, and Refrigeration Institute
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAT	best available technology
BEE	Bureau of Energy Efficiency
CC	climate class
CDEC	calculated daily energy consumption
CEC	compressor energy consumption
CFD	computational fluid dynamics
CO_2	carbon dioxide
COP	coefficient of performance
CPEC	pumping electrical energy consumption
CRE	commercial refrigeration equipment
DC	direct current
DEC	direct electrical energy consumption
DFEC	defrost energy consumption
ECM	electronically commutated motor
EC_{max}	maximum energy consumption
EEI	energy efficiency index
EEV	electronic expansion valve
EMD	energy-management device
ETL	Energy Technology List
EU	European Union
EV	consistency of evaluation methods
FEC	fan energy consumption
GWP	global warming potential
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
HCS	horizontal closed solid
HCT	horizontal closed transparent
HD	heavy duty
HFC	hydrofluorocarbon
HFO	hydrofluoroolefin
HVAC&R	heating, ventilation, air-conditioning, and refrigeration
HZO	horizontal open
IHC	integral horizontal chilled
IHF	integral horizontal frozen
IoT	Internet of Things
IP	impact potential
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IVC	integral vertical chilled
IVF	integral vertical frozen

L/LT	low temperature
LD	light duty
LEC	lighting energy consumption
LED	light-emitting diode
M/MT	medium temperature
MEPS	minimum energy performance standards
MP	market potential
MRG	Guidelines
ND	normal duty
PA	ease of policy adoption and enforcement
PEC	condensate evaporator pan energy consumption
PSC	permanent split capacitator
PV	photovoltaic
RAEC	reference annual energy consumption
RC	remote condensing unit
RDC	refrigerated display cabinet
RHC	remote horizontal chilled
RHF	remote horizontal frozen
RSA	Republic of South Africa
RSC	refrigerated storage cabinet
RVC	remote vertical chilled
RVC2	remote vertical chilled multi-deck
RVF	remote vertical frozen
SAEC	standard annual energy consumption
SC	self-contained condensing unit
SOC	service over counter
SVO	semi-vertical open
TDA	total display area
TEC	total daily energy consumption
TWh	terawatt-hours
U4E	United for Efficiency
U.S.	United States
VCS	vertical closed solid
VCT	vertical closed transparent
VIP	vacuum insulated panel
Vn	net volume
VOP	vertical open
WHO	World Health Organization

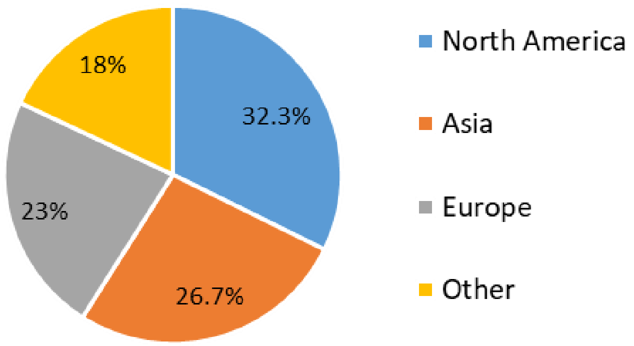
1. Overview of the Global Commercial Refrigeration Market and Policies

Commercial refrigeration equipment (CRE) refers generally to non-domestic (non-household) refrigeration equipment used in the retail and food service sectors for storage or display of foodstuffs. In 2010, about 120 million CRE units—including supermarket systems, standalone equipment, condensing units, etc.—were in operation globally [1]. Among various CRE types, refrigerated display cabinets (RDCs), which store and display chilled or frozen items in a retail environment for access by consumers, account for about half of the global CRE market by market value or revenue (Figure 1) [2]. North America is the largest market in the world, with a market value of USD $ 14.7 billion, followed by Asia (where China and India lead in growth) and Europe (Figure 2) [2].



Source: [2]

Figure 1. Global CRE market by product type, by market value



Source: [2]

Figure 2. Global CRE market by region, by market value

A shift in consumer shopping in large supermarkets to smaller supermarkets and convenience stores is driving RDC demand. Also, growing e-commerce is driving large cold-storage demand [2]. RDCs tend to be produced locally owing to their relatively large size and variations in specifications in each region along with customized delivery. Only a few RDC companies (e.g., Panasonic and Carrier) operate globally [2].

North America and Europe together account for the largest share of the global CRE market. Large manufacturers account for greater than 70% of each market (Table 1, [2-4]). CRE products with lower GWP [1] refrigerants are commercially available in these markets. However, there are differences in energy performance testing and energy-efficiency standards between these two regions (see Section 5).

Australia and New Zealand recently revised their energy-efficiency standards for refrigerated cabinets (including RDCs and refrigerated storage cabinets [RSCs], which store chilled or frozen items in a retail environment for access by staff), which went into effect in May 2021 and July 2021, respectively. Most refrigerated cabinets are imported, with more than 80% coming from Asia (notably China), about 15% from Europe, 2% from North America, and 0.5% from South Africa [5]. The test and performance rating standards in Australia, New Zealand, and the European Union (EU) are based on international standards, such as International Organization for Standardization (ISO) 23953 for RDCs.

In China, the CRE market is growing at an annual rate of 5%–30%, led by several manufacturers (Table 1, [2]). Estimated annual production or sales of RDCs vary by source and definition, from 440,000 units (2019) [2] to about 2 million units, with beverage RDCs making up 1.9 million of the 2 million units (2018) [6]. The estimated annual production or sales of RSCs are about 1.87 million units (2018) [6] to 11.38 million units (2019) [2]. The energy-efficiency standards for refrigerated cabinets—including supermarket refrigeration systems, beverage coolers, ice cream freezers, and service/storage cabinets with integral condensing units—are under revision at the time of this study. China's test standards are largely aligned with ISO 23953.

In India, sales of deep freezers—which cool food items rapidly (a few minutes to an hour) by exposing them to temperatures of -30°C to -50°C until the item temperature reaches -18°C or another target temperature point—have been growing rapidly [7]. Estimated annual sales vary by source and definition, from about 390,000 [8] to 500,000–600,000 units for 2017–2018 [7], and from 488,000 units [8] to 848,000 units for 2019–2020 [2], with chest types accounting for approximately 99% [7]. Deep freezers have recently been included in the Bureau of Energy Efficiency (BEE) Star Rating program [7]. Annual sales of "visi-coolers," a type of RDC with glass doors used for beverages and other refrigerated or frozen food, are estimated to be 194,000–199,000 units [2, 8].

[1] GWP is a measure of how much heat a greenhouse gas traps in the atmosphere up to a specific time horizon, relative to an equal mass of carbon dioxide (CO_2) in the atmosphere. Refrigerant GWP values in the Guidelines refer to those specified in the Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report, on which the GWPs of hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) listed in Annex C and Annex F of the Montreal Protocol are based. The GWP values of refrigerants not included in the IPCC fourth assessment can be based on the latest IPCC assessment report.

Table 1. Overview of regional markets and trends

Australia	• Most refrigerated cabinets are imported, with more than 80% coming from Asia (notably China), ~15% from Europe, 2% from North America, and 0.5% from South Africa. • The energy-efficiency standards for refrigerated cabinets were recently revised based on international standards (effective May 2021).
China	• CRE sales are growing with an annual growth rate of 5%–30%. • Leading manufacturers include Aucma, ER Shang-Fukushima, DunAn, Haier, Highly, Hiron, Hisense, Hussmann, Keli, Millennium Refrigeration Equipment, Panasonic, and Xingxing.
Europe	• Europe is currently the world's third largest (previously the second largest) CRE market (comparable with Asia). • Large manufacturers (Epta, Carrier, Arneg, Hauser, Hussmann, Norpe, etc.) account for greater than 70% of the EU market. • There is an ongoing shift to natural refrigerants, such as R744, R290, and R600a. • E-commerce is increasing, including cross-border activities.
India	• Deep freezer sales are growing, and these products have been included in the BEE Star Rating program.
U.S.	• North America is the world's largest CRE market. • Hillphoenix, Hussmann (acquired by Panasonic), and Kysor Warren account for greater than 70% of the U.S. RDC market. • Carrier is doing business globally. • CRE products with low-GWP refrigerants (e.g., R290 and R600a) are available.

Source: authors' work based on [2-8]

Energy consumption in commercial refrigeration

The International Institute of Refrigeration (IIR) estimated energy consumption to be 281 terawatt-hours (TWh) in the global cold chain, with 83 TWh of the 281 TWh at the retail sales stage, based on linear meters of refrigerated cabinets [9-10]. Waide et al. [11] estimated energy consumption in "reach-in coolers" (including refrigerated cabinets and beverage coolers) and refrigerated vending machines in nine economies: Australia, Brazil, China, EU, India, Japan, Mexico, South Africa (RSA in figure), and the U.S. The total energy consumption of reach-in coolers in the nine economies was projected to increase from 83 TWh in 2013 to 175 TWh by 2035 under a business-as-usual scenario (Figure 3). The study estimated energy-savings potential at 45–56 TWh in 2035. The total energy consumption of refrigerated vending machines in the nine economies was projected to increase from 16.7 TWh in 2013 to 27.4 TWh by 2035 under a business-as-usual scenario (Figure 4). The study estimated energy-savings potential at 11.4–18.5 TWh in 2035.

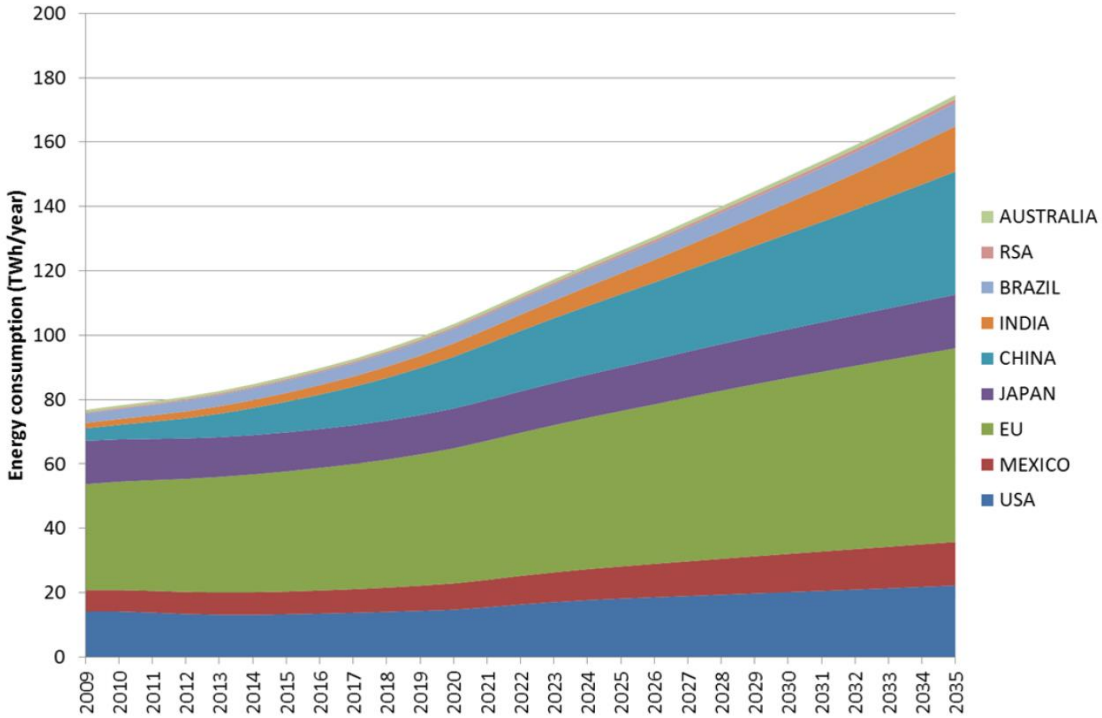


Figure 3. Estimated energy consumption for reach-in coolers in nine economies under the business-as-usual scenario Source: [11]

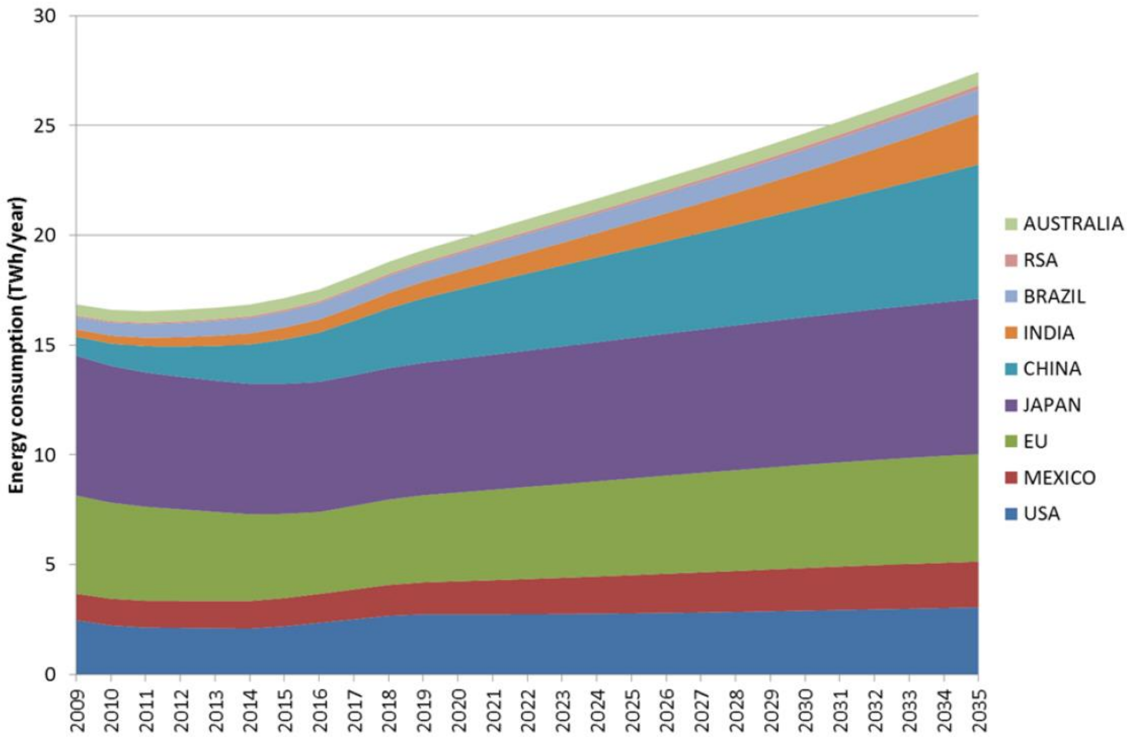
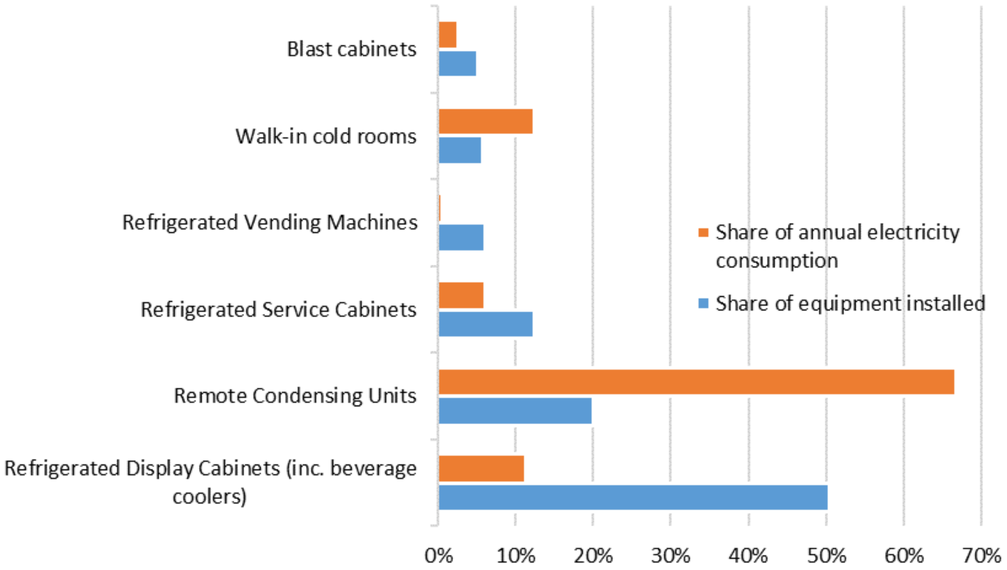


Figure 4. Estimated energy consumption for refrigerated vending machines in nine economies under the business-as-usual scenario Source: [11]

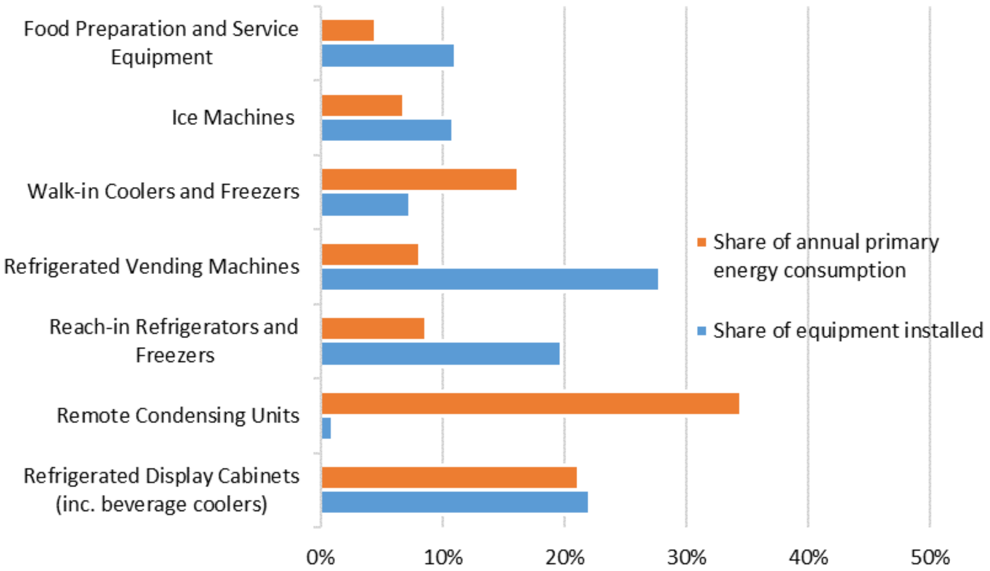
Technical and economic studies supporting EU and U.S. rulemakings provide more detailed information for the two economies. Based on EU preparatory studies [12-13], RDCs, RSCs, condensing units, and refrigerated vending machines accounted for about 89% of stocks and 85% of energy consumption, respectively, for the assessed products in the EU in 2008 (Figure 5). Based on a study by Goetzler et al. [14], RDCs, condensing units, reach-in refrigerators/freezers, and refrigerated vending machines accounted for about 71% of stocks and 72% of energy consumption, respectively, for the assessed products in the U.S. in 2008 (Figure 6). However, this is not a full comparison of the regional information because test standards to evaluate CRE energy consumption in the EU and U.S. differ in many respects (see Section 4).



For example, the orange bar and blue bar for Refrigerated Display Cabinets indicate that the energy consumption and equipment installed in the EU accounted for 11% of the total energy consumption and 50% of the total stocks, respectively, for the assessed products in the EU in 2008.

Source: Authors' work based on EU Preparatory studies [12-13]

Figure 5. EU CRE installed stocks and energy consumption in 2008

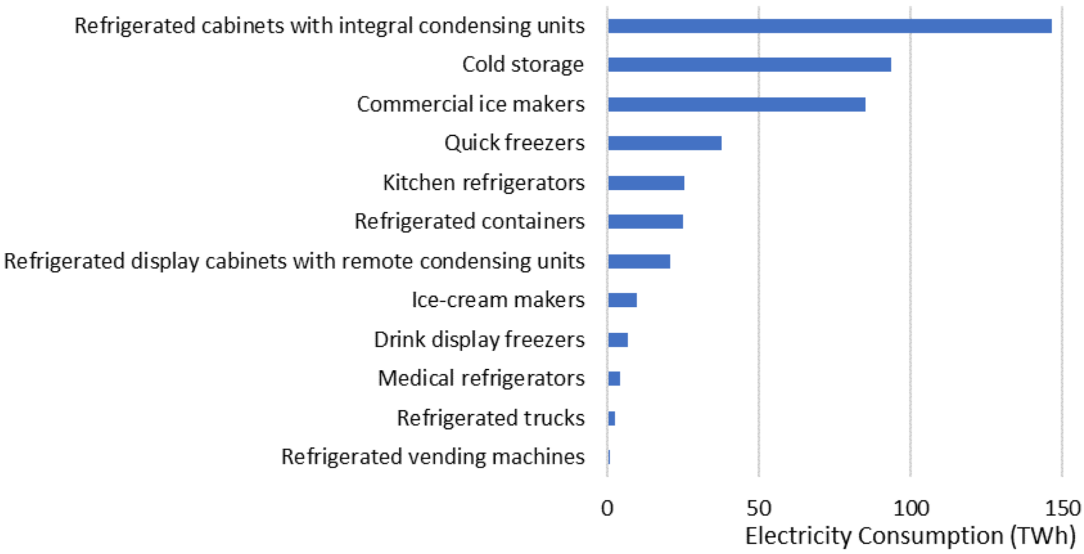


For example, the orange bar and blue bar for Refrigerated Display Cabinets indicate that the energy consumption and equipment installed in the U.S. accounted for 21% of the total energy consumption and 22% of the total stocks, respectively, for the assessed products in the U.S. in 2008.
Source: authors' work based on [14]

Figure 6. U.S. CRE installed stocks and energy consumption in 2008

Historically, CRE energy efficiency has been improving. For example, the average energy consumption, in terms of daily energy consumption per total display area (TDA in m^2) in RDCs classified as RVC2 (remote vertical chilled multi-deck), decreased by 30% between 2005 and 2013 and by 40% between 1997 and 2013 [13]. The EU Preparatory Study also described that this trend had been followed by all remote cabinet designs [13, pp. 45-47]. According to a preliminary interim report of the EU Review Study Phase 1.1 & 1.2 Technical Analysis PRELIMINARY DRAFT INTERIM REPORT for Professional Refrigeration, the average efficiency in terms of the EU energy efficiency index (EEI) of newly sold RSCs improved by about 40% from EEI 91-109 in 2015 to EEI 53-65 in 2020, varying by product category [15].

In China, a recent study estimated that energy consumption in cooling products accounted for more than 15% of total national electricity consumption [16]. Industrial and commercial refrigeration was estimated to consume 459 TWh (Figure 7), accounting for 34.1% of total energy consumption for the selected 29 cooling products in 2019. Commercial refrigerated cabinets with integral condensing units were estimated to account for about 11% of the total cooling energy consumption. At the same time, the study estimated that refrigerated cabinets with integral condensing units have the third-largest savings potential among the assessed products, after room air conditioners and variable refrigerant flow systems.

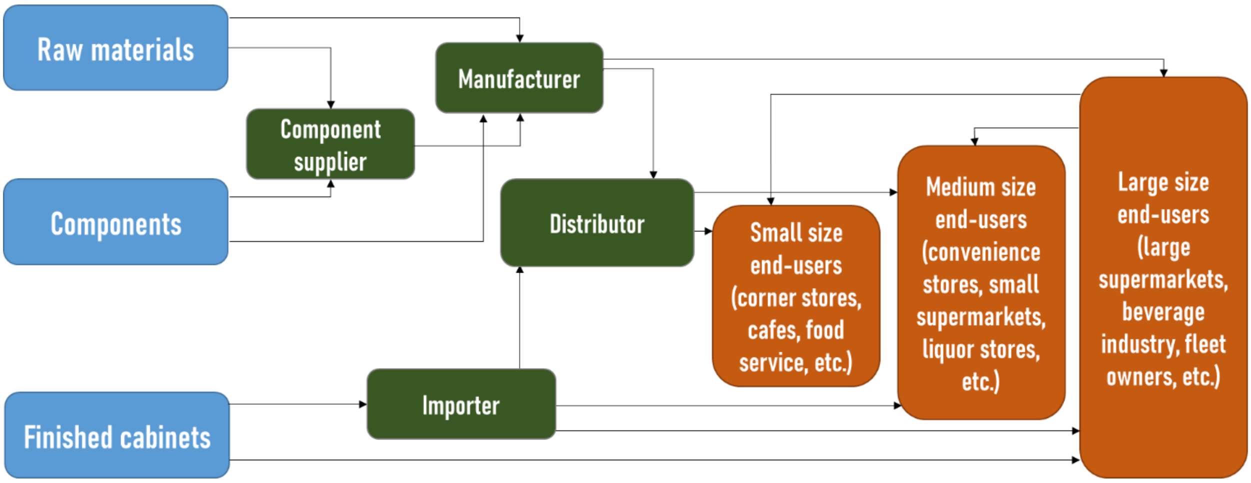


Source: authors' work based on [16]

Figure 7. Electricity consumption from commercial and industrial refrigeration in China in 2019

The supply chain for refrigerated cabinets in a country may be complex. Ownership arrangements may vary by the size of end users. Equipment in large supermarkets and convenience stores is usually supplied by companies in long-term relationships as preferred suppliers [5]. Larger companies may buy refrigerated cabinets directly from manufacturers and may become fleet owners (e.g., beverage companies) who provide and install cabinets for smaller end users free of charge. In this case, the provider or hirer of the refrigerated cabinets may be motivated by factors other than energy efficiency, such as upfront cost, because they are not responsible for paying the electricity bill at the site [5].

At the same time, global companies such as Coca Cola and Pepsi, have corporate social responsibility targets with energy and environmental accountability elements. Figure 8 is a schematic of the refrigerated cabinet supply chain, adapted from an Australian document [5] but likely applicable to many other countries. The figure shows that, in some instances, “importer” and “manufacturer” can be distributors to medium-sized or large end users. Fleet owners or large end users (e.g., beverage companies) usually offer free placement of logo-carrying RDCs to other end users, while rental or lease companies offer plain or standard refrigerated cabinets.



Source: authors’ work based on [5]
Blue rectangles represent materials, components, and finished products; green rectangles represent suppliers and manufacturers; and orange rectangles represent end users.

Figure 8. Schematic of the refrigerated cabinet supply chain

2. Model Regulation Scope and Product Categories

There are many different ways of categorizing CRE types based on combinations of key technical features (e.g., condensing unit, operating temperature, orientation, and closure). Table 2 shows elements that can be considered when classifying the CRE types for energy rating and test standards. Energy-efficiency standards for broader product groups will be inclusive and may avoid the issues or loopholes caused by slight differences in specific definitions or physical characteristics.

Table 3 shows product classes defined in the standards in Australia, China, the EU, and the U.S. Table 4, Table 5, Table 6, and Table 7 show simplified approaches in regional standards to further categorize products.

Table 2. Taxonomy of cabinet categories

Condensing unit location	Integral, remote direct, remote indirect
Cabinet operating temperature	Chilled, frozen, ice cream, multi-temperature
Orientation or cabinet configuration	Vertical, horizontal, chest, semi-vertical, multi-deck, combined, serve-over, roll-in, under-counter, pass-through, wall site, island
Closure or means of access to products	Open, glass door/lid, solid door/lid, drawer, combination (including 'serve-over' type)
Duty/capacity	Pull-down, light duty, normal duty, heavy duty
Air circulation method in cabinet	Static air, forced air

Source: [17]

Table 3. Product categories defined in regional standards

Australia	EU	U.S.[a]	China[c]
- Display cabinets (integral/remote, horizontal/vertical, refrigerator/freezer) - Drinks cabinets - Ice cream freezers - Scooping cabinets - Storage cabinets (integral, horizontal/vertical)	- Display cabinets (vertical/horizontal, refrigerator/freezer, roll-in) - Beverage coolers - Ice cream freezers - Gelato ice cream freezers - Vending machines (can & bottle/spiral) - Professional cabinets[b]	- Vertical open - Semi-vertical open - Horizontal open - Vertical closed transparent - Vertical closed solid - Horizontal closed transparent - Horizontal closed solid - Service over counter - Pull-down	- Display cabinets (integral/remote, horizontal/vertical/ combined, refrigerator/freezer) - Beverage display cabinets - Ice cream freezer display cabinets - Solid door commercial cabinets - Refrigerated beverage vending machines

a. Listed types in the U.S. are further divided by condensing unit type and operating temperature, e.g., vertical open types with remote condensing units for medium temperature (VOP.RC.M).

b. In Europe, "commercial" generally refers to cabinets for retail applications, i.e., with a direct sale function. "Professional" is a term used in Europe to describe cabinets and other refrigeration equipment designed for use and access by staff of the food service facility and not for access by customers/shoppers. EU "professional cabinets" are a subset of those referred to elsewhere as "commercial cabinets" or "storage cabinets." The term "professional" does not appear to be used in this way outside of Europe and so is not generally used within the Guidelines [15].

c. China set minimum energy performance standards (MEPS) for remote condensing RDCs in 2011 and for integral condensing refrigerated cabinets in 2015. The product categories are consistent with those used in the previous

Australian standard AS 1731 for remote condensing RDCs and ISO 23953's classifications for integral condensing refrigerated cabinets. The test standard is largely consistent with ISO 23953.

Table 4. Product categorization (except for refrigerated vending machines) – Australia

<table>
<tr><th>Application</th><td colspan="8">Display cabinets</td><td colspan="4">Storage cabinets</td></tr>
<tr><th>Configuration</th><td colspan="4">Integral</td><td colspan="4">Remote</td><td colspan="4">Integral</td></tr>
<tr><th>Temperature</th><td colspan="2">Refrigerator</td><td colspan="2">Freezer</td><td colspan="2">Refrigerator</td><td colspan="2">Freezer</td><td colspan="2">Refrigerator</td><td colspan="2">Freezer</td></tr>
<tr><th>Configuration</th><td>H</td><td>V</td><td>H</td><td>V</td><td>H</td><td>V</td><td>H</td><td>V</td><td>H</td><td>V</td><td>H</td><td>V</td></tr>
</table>

H: horizontal; V: vertical

Table 5. Product categorization (except for refrigerated vending machines) – EU

<table>
<tr><th>Temperature</th><td colspan="5">Refrigerator (medium temperature)</td><td colspan="5">Freezer (low temperature)</td></tr>
<tr><th>Application</th><td colspan="3">Display cabinets</td><td colspan="2">Storage cabinets</td><td colspan="3">Display cabinets</td><td colspan="2">Storage cabinets</td></tr>
<tr><th rowspan="2">Configuration / beverage, ice cream</th><td colspan="2">V</td><td rowspan="2">H</td><td rowspan="2">V</td><td rowspan="2">H</td><td rowspan="2">V</td><td colspan="2">H</td><td rowspan="2">V</td><td rowspan="2">H</td></tr>
<tr><td>Beverage</td><td>Others</td><td>Small ice cream</td><td>Others</td></tr>
<tr><th>Sub-temp class</th><td colspan="5">Temperature classes</td><td colspan="5">Temperature classes</td></tr>
</table>

H: horizontal; V: vertical

Table 6. Product categorization (except for refrigerated vending machines) – U.S.

<table>
<tr><th>Configuration</th><td colspan="3">Vertical</td><td>Semi-vertical</td><td colspan="3">Horizontal</td><td>Service over counter</td><td>Pull down</td></tr>
<tr><th rowspan="2">Closure/door</th><td rowspan="2">O</td><td colspan="2">C</td><td rowspan="2">O</td><td rowspan="2">O</td><td colspan="2">C</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>T</td><td>S</td><td>T</td><td>S</td></tr>
<tr><th>Condensing unit</th><td colspan="8">Remote or self-contained</td><td>Self-contained</td></tr>
<tr><th>Temperature</th><td colspan="8">Low, medium, ice</td><td>Medium</td></tr>
</table>

C: closed; O: open; S: solid; T: transparent

Table 7. Product categorization (except for refrigerated vending machines) – China

<table>
<tr><th rowspan="2">Application</th><th colspan="16">Integral RDCs[a]</th><th rowspan="2" colspan="11">Remote RDCs[a]</th></tr>
<tr><th colspan="12">RDCs</th><th colspan="2">Beverage RDCs
Ice cream freezer display cabinets</th><th colspan="2">Solid door cabinets</th></tr>
<tr><th>Temperature</th><td colspan="6">Refrigerator (MT)</td><td colspan="6">Freezer (LT)</td><td colspan="2"></td><td colspan="2"></td><td colspan="4">Refrigerator (MT)</td><td colspan="7">Freezer (LT)</td></tr>
<tr><th>Configuration</th><td colspan="3">H</td><td colspan="2">V</td><td>C</td><td colspan="3">H</td><td colspan="2">V</td><td>C</td><td>V</td><td>H</td><td>V</td><td>H</td><td>H</td><td colspan="3">V</td><td colspan="2">H</td><td colspan="3">V</td><td colspan="2">C</td></tr>
<tr><th rowspan="2">Closure/door</th><td rowspan="2">O</td><td colspan="2">C</td><td rowspan="2">O</td><td rowspan="2">T</td><td rowspan="2">O/T</td><td rowspan="2">O</td><td colspan="2">C</td><td rowspan="2">O</td><td rowspan="2">T</td><td rowspan="2">O/C</td><td rowspan="2">T</td><td rowspan="2">T</td><td rowspan="2">S</td><td rowspan="2">S</td><td rowspan="2">T</td><td rowspan="2">O</td><td colspan="2">C</td><td colspan="2">O</td><td rowspan="2">O</td><td colspan="2">C</td><td rowspan="2">O</td><td rowspan="2">T</td></tr>
<tr><td>T</td><td>S</td><td>T</td><td>S</td><td>T</td><td>S</td><td>T*</td><td>S*</td><td>T</td><td>S</td></tr>
<tr><th>Equipment code[b]</th><td>HC1
HC2
HC3
HC4</td><td>HC5-1
HC5-2
HC5-3
HC6-1
HC6-2
HC6-3</td><td>HC7
HC8</td><td>VC1
VC2
VC3</td><td>VC4</td><td>YC1
YC2
YC3
YC4</td><td>HF1
HF2
HF3
HF4</td><td>HF5-1
HF5-2
HF5-3
HF6-1
HF6-2
HF6-3</td><td>HF7</td><td>VF1
VF2
VF3</td><td>VF4</td><td>YF1
YF2
YF3
YF4</td><td>VC4</td><td>HC5-1
HC6-1
HF5</td><td>VC5
VF5</td><td>HC9
HF9</td><td>RS6
RS7
RS8
RS9
RS10</td><td colspan="3">RS1
RS2
RS3</td><td colspan="2">RS4
RS5</td><td>RS4
RS5</td><td>RS13
RS14</td><td>RS13
RS14</td><td>RS11,
RS12,</td><td>RS15
RS16
RS17
RS19
RS20</td></tr>
</table>

MT: medium temperature; LT: low temperature; H: horizontal; V: vertical; C: combined
O: open; C: closed; O/T: partially open and partially closed with transparent door/lid; T: transparent; S: solid; T*: open, glass enclosure; S*: open, solid enclosure

a. China's standard, Part 1: GB 26920.1-2011, covers remote RDCs, including beverage RDCs and ice cream freezer display cabinets, and solid door cabinets. Part 2: GB 26920.2-202x (under revision) covers integral refrigerated cabinets.
b. See Annex A for details.

The Guidelines determined the scope based on the following criteria:

1. **Market Potential (MP):** Is the product type widely available or a rapidly growing application in developing and emerging economies?
2. **Impact Potential (IP):** Is the product group expected to have significant impact potential on energy savings and direct (from refrigerant) greenhouse gas emissions?
3. **Ease of Policy Adoption and Enforcement (PA):** Is the product type regulated by MEPS in leading economies and considered for regulation in developing and emerging economies without undue complexity?
4. **Consistency of Evaluation Methods (EV):** Are international standards (testing, rating, safety) that have been proven in major markets available?

Table 8 shows the different CRE categories with assessment of the criteria above, followed by brief explanations.

Table 8. Prioritization of CRE for Guidelines development

<table>
<tr><th rowspan="2">Product type</th><th rowspan="2" colspan="2">Segmentation</th><th colspan="4">Assessment</th></tr>
<tr><th>MP</th><th>IP</th><th>PA</th><th>EV</th></tr>
<tr><td rowspan="2">Refrigerated Cabinets</td><td>RSCs</td><td>- Chilled/frozen
- Horizontal/vertical</td><td rowspan="2" colspan="2">High</td><td rowspan="2" colspan="2">Med[a]-High</td></tr>
<tr><td>RDCs</td><td>- Chilled/frozen
- Horizontal/vertical
- Integral/remote
- Ice-cream freezers
- Scooping cabinets
- Drink cabinets or beverage coolers</td></tr>
<tr><td colspan="3">Refrigerated Vending Machines</td><td colspan="2">Med</td><td colspan="2">High</td></tr>
<tr><td colspan="3">○ Walk-in Coolers and Freezers
○ Blast Chillers and Freezers
○ Transport Refrigeration Systems
○ Automatic Commercial Ice Makers
○ Laboratory Grade or Vaccine Refrigerators
○ Off-grid Solar Refrigerators</td><td colspan="2">Likely growing but more information needed</td><td colspan="2">Low to Med</td></tr>
</table>

a. RDCs with remote condensing units are typically large. The compressor rack and condensing system are usually manufactured by a different company than the company that makes the cabinet, and it is hard to test the full system together and get a representative value.

Refrigerated cabinets and refrigerated vending machines are covered by the Guidelines based on the following assessment:

1. These products are roughly estimated to constitute more than 50% of the global CRE market (see Section 1).
2. Many existing energy-efficiency improvement options can achieve energy savings of 2%–30% for each measure, resulting in cumulative savings potential of 20%–80% (typically 30%–50%), depending on product class and baseline energy performance (see Section 3).
3. Refrigerated cabinets are the products that have been regulated first in broadly defined CRE. Several leading and emerging economies (Australia, China, EU, U.S., etc.) have energy-efficiency standards for these products, although the detailed scopes are not identical. The EU, Australia, and New Zealand recently published their energy-efficiency standards (effective in March 2021, May 2021, and July 2021, respectively) [18-20]. Their test standards largely align with international standards, lending credence to the approach of using such standards for the development of the Guidelines. China's standard for refrigerated cabinets with integral condensing units is under revision at the time of this study in 2021 (see Section 1 and Section 4).
4. International standards for performance rating and testing (ISO 22041[2], ISO 23953, ISO 22043, and IEC 63252) are available, but there are multiple approaches for product categorization. One challenge is that these products are locally produced in many different configurations.

Market demand—and thus impact potential—for other commercial products appears to be growing, but region- or country-specific data would be needed for prioritization. Energy-efficiency and test standards for these products are available only in a few economies, or they are currently in development. Hence, regulations might be complex or burdensome in developing and emerging economies, requiring dedicated efforts and resources (walk-in cold rooms, transport refrigeration systems). Table 9 shows the Guidelines' approach to categorizing products.

Table 9. Product categorization – Guidelines

Application	Display cabinets								Storage cabinets			
Configuration	Integral				Remote				Integral			
Configuration	Horizontal		Vertical		Horizontal		Vertical		Horizontal		Vertical	
Temperature	C	F	C	F	C	F	C	F	C	F	C	F
Item-specific		ICF SC	BC									

C: chilled; F: frozen; ICF: small ice-cream freezer; SC: scooping cabinet; BC: beverage cooler

Annex C provides brief notes on products that are not covered by the Guidelines. Following is additional context that must be considered for selected product groups.

[2] In the EU, EN ISO 22041 supersedes EN 16825.

Ice-cream freezer cabinets

In the EU, small ice-cream freezers account for 19% of stocks and 4% of energy use in the market that includes refrigerated cabinets, beverage coolers, and vending machines [21]. The EU regulation defines these products in size up to 600 L, while the Australian standard defines them up to 500 L. These products could fall under, for example, integral horizontal closed frozen cabinets (IHF4, according to the ISO 23953 categorization). However, they have been segmented in the EU and Australia standards [5, 13], mainly because of the following:

1. The net volume for ice-cream freezers intended for merchandising is usually smaller than their counterparts in the supermarket segment.
2. The ratio of net volume to display area is usually bigger for small merchandising ice-cream freezers, because they are usually used as storage for ice cream (they often have storage compartments not for display at the bottom).
3. Small ice-cream freezers work with static air cooling (no forced air circulation by means of an evaporator fan), do not have gas defrost or electronic controls, and usually work with skin condensers and evaporators.

Scooping cabinets

Scooping cabinets are artisan gelato ice-cream cabinets specially designed to display and maintain the quality of "artisan" or "homemade" ice cream. They differ from both supermarket display cabinets and ice-cream freezers in content and function. They have different operating temperatures (-10°C) than supermarket cabinets or pre-packed ice-cream freezers (most often at the L1 condition, -15 to -18°C), because they are intended for display and immediate consumption of the product, not storage. They have a controlled airflow, two evaporators, and a defrost mechanism [5, 13].

RDC drink cabinets (beverage coolers)

In 2015, Australia's chilled drinks cabinets had the largest share (48%) of the refrigerated cabinet market. In 2013, the EU's beverage coolers accounted for 45% of stocks and 20% of energy use in the market that includes refrigerated cabinets, small ice-cream freezers, and vending machines. These products could be classified as integral, chilled, vertical, or closed cabinets (IVC4, according to the ISO 23953 categorization), but regional standards tend to have a separate category for these products [3, 5, 13].

1. Beverage coolers have been segmented in the EU regulation because of the larger potential use of energy-management devices (EMDs, reducing power consumption during non-retail hours by raising the temperature of the displayed goods), the use of volume and not display area as the reference metric, the storage and display of non-perishable foodstuffs, the pull-down capacity to working temperature of products loaded at ambient temperature, and so forth.

2. The Australian standard has been segmented for drinks cabinets rather than beverage coolers, because beverage coolers are unsuitable for cabinets that could contain perishable beverages or foodstuffs. To adapt these beverage coolers to suit the perishable foodstuffs, manufacturers can ship them from the factory in "perishable mode" (with the EMD disabled). Hence, it is difficult to distinguish beverage coolers from RDCs based on their appearance.
3. In the U.S., these products are classified as CRE with self-condensing units designed for pull-down temperature applications.
4. China's standard has separate MEPS for beverage cooler cabinets.

Refrigerated vending machines

Refrigerated vending machines are self-contained refrigerated systems designed to accept consumer payments or tokens to dispense pre-packed beverages and/or food at temperatures from 2°C to 12°C without on-site labor/intervention. They also have a modular structure with only selected zones refrigerated. These products are roughly estimated to constitute 5%–10% of the global CRE market [2]. In the EU in 2014, refrigerated vending machines accounted for 9% of stocks and 2% of energy use in the market that includes refrigerated cabinets, beverage coolers, and small ice-cream freezers [13]. In 2008, refrigerated vending machines in the U.S. accounted for 39% of stocks and 11% of energy use in the commercial refrigeration market that includes refrigerated cabinets, condensing units, compressor racks, and vending machines [14]. Several economies (China, EU, Japan, U.S., etc.) have energy-efficiency standards in place for these products. The standard IEC 63252: 2020 is available for performance rating and testing.

RDCs with integral (plug-in, self-contained) vs. remote condensing

Globally, RDC demand is shifting from large supermarkets to smaller supermarkets and convenience stores, which is increasing the demand for integral condensing RDCs. In Australia, remote cabinets (i.e., supermarket applications) had a roughly 20% share of the refrigerated cabinet market in 2015 [22]. In the U.S., remote condensing supermarket refrigeration systems (display cases, compressor racks, and condensers) accounted for 52% in 2008 of total energy consumption in commercial refrigeration, of which compressor racks and condensers represented 66% [14].

There are clear differences in system design and ambient conditions with condensing units. Integral condensing RDCs reject heat indoors, while the opposite is true for refrigeration systems with remote condensers. Heat rejected from integral condensing RDCs increases the burden on the air-conditioning system, and the overall power consumption of the building can be reduced by rejecting that heat outdoors. Integral condensing RDCs are sometimes space constrained and tend to have smaller heat exchangers [22]. If an integral condensing RDC that rejects heat into the conditioned space were compared to an RDC of equal duty and function with a remote condensing unit that rejects heat externally, an allowance for the heat rejection treatment would need to be included in the total energy calculation, taking into account the additional air conditioner operating time or energy required to remove the heat added by the integral RDC on hot days less the energy savings or free heating on cold days [22]. In regions where colder weather would cancel out hotter weather, such as Australia and New Zealand, the heat rejection portion can be assumed to be insignificant [22]. The technologies employed in larger systems (remote units) can be designed efficiently with multiple cabinets and better controls and may not be economically feasible for smaller systems (integral units).

Integral and remote RDCs have been segmented in energy-efficiency standards in China and the U.S. An adjustment factor to account for the difference in energy consumption is used in the EU regulation (2019/2024). Although the Australian standard differentiates integral and remote units, the MEPS for both types are the same.

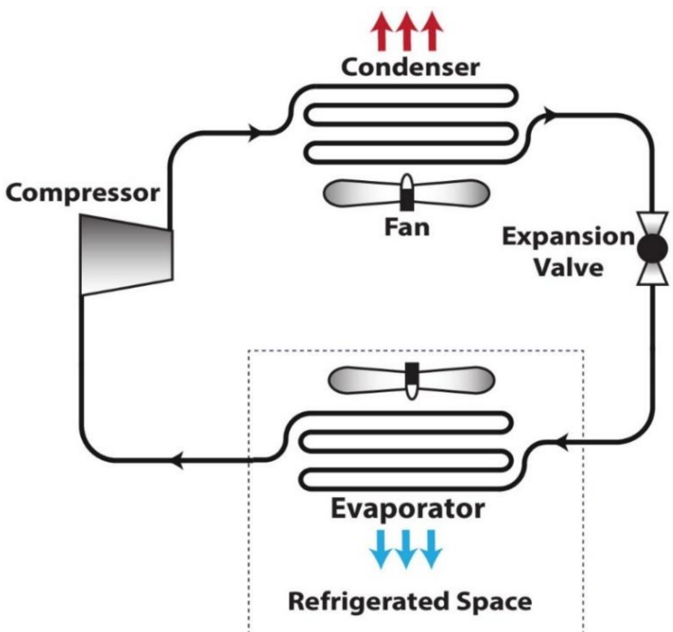
Open cabinets vs. closed cabinets

Open refrigerated cabinets consume more energy than their closed counterparts. The largest consumption of refrigeration system energy in supermarket settings is attributed to open RDCs, such as traditional meat and dairy cabinets, which are subject to much higher heat loads than RDCs with transparent doors [23]. Retrofitting open RDCs with transparent doors is one method of decreasing this energy consumption. Adding doors or lids to refrigerated cabinets can lower energy consumption by different amounts depending on RDC type and food items stored (e.g., a 60% reduction for a bottle cooler [24]).

China and the U.S. have segmented open and closed RDCs in energy-efficiency standards. In Australia and the EU, MEPS levels are imposed irrespective of whether a cabinet is closed or open, with the goal of driving the RDC market toward energy-efficient designs. The Guidelines are using this approach, but countries that have product categories similar to those in China or the U.S. can get insights from this supporting information. Annex B offers a comparison of product classes in the Guidelines and regional standards.

3. Energy-Efficiency Technologies, Designs, Costs, and Benefits

Currently, a large majority of CRE is primarily based on the vapor-compression cycle and its variations. Figure 9 shows a basic vapor-compression cycle consisting of four main components: condenser, compressor, evaporator, and expansion device. The refrigerant circulates through the evaporator at a relatively low pressure, extracting heat from the refrigerated space as it undergoes vaporization. After leaving the evaporator, the vapor is compressed to a higher pressure by the compressor, which converts electrical energy into mechanical work. In the condenser, the refrigerant condenses as it rejects heat to the ambient air. An expansion valve (pressure-drop device) at the condenser outlet lowers the pressure of the refrigerant as it circulates back to the evaporator. In addition, several other components (fans, insulation, defrost heaters, controls, lighting, etc.) are used to ensure that the refrigeration system performs optimally and reliably.



Source: authors' work

Figure 9. Schematic of the vapor-compression cycle

This section highlights the energy-saving design options related to various components of the basic vapor-compression cycle. Some alternative refrigeration cycles with higher energy efficiency are also described. The design of CRE (size, configuration, operating temperature, ambient conditions, etc.) may vary significantly depending on the application. Therefore, the economic feasibility of these energy-saving design options may also vary for different types of applications. In general, there are more opportunities for incorporating energy-saving designs into larger systems with remote condensing units, compared to smaller integral units.

Finally, the refrigeration industry is currently in the process of phasing out HFC refrigerants owing to their relatively high GWP. For optimal performance, transitioning new low-GWP replacements into refrigeration systems requires redesigning the equipment for these new refrigerants. This transition can also serve as an opportunity to use more energy-efficient designs and achieve higher system performance.

3.1 Component-level energy-saving design options

Compressors

Innovations in computational fluid dynamics (CFD) modeling and advanced manufacturing in recent decades have enabled tremendous advancements in compressor technology. Newer designs can operate with much lower compression energy demand through the use of high-efficiency motors, strict manufacturing tolerances, high-quality lubricants, and designs with lower internal leakage and heat loss from friction.

Although many different types of compressors exist, the compressors used in the refrigeration industry broadly fall into two categories: reciprocating and rotary compressors. Reciprocating compressors use a piston driven by a crankshaft connected to a motor. Rotary compressors (scroll compressors, screw compressors, etc.) [3] achieve compression through rotation of internal components. Traditionally, reciprocating compressors have been used in the refrigeration industry owing to their versatility and lower cost. However, rotary compressors have fewer moving parts and therefore are generally more efficient compared to reciprocating compressors. Reciprocating compressors are commonly used for self-contained refrigeration systems, while high-efficiency rotary compressors are deployed in larger refrigeration systems with remote condensers.

In addition to using a high-efficiency compressor design, energy consumption can be reduced by adding a variable-speed drive and improved controls to the compressor. Variable-speed compressors operate at a range of speeds and can better match the cooling load demand, greatly reducing the energy loss that occurs for fixed-speed units during on-off operation. Variable-speed compressors also exhibit higher efficiency—that is, a higher coefficient of performance (COP)—at part-load conditions, because the heat exchangers in the system are generally sized for full-load conditions. When the compressor is operating at reduced speed, pressure losses in the heat exchangers are relatively low, which results in more efficient operation.

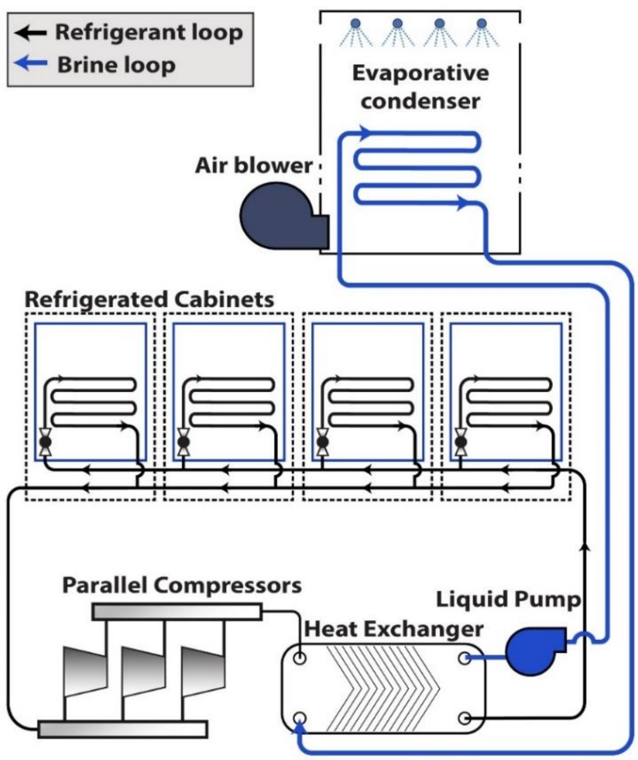
Heat exchangers

The effectiveness of the condenser and evaporator plays a critical role in the overall efficiency of the refrigeration system. Improving heat transfer in the condenser and evaporator can minimize the heat exchanger temperature differences and consequently reduce the compression power required to operate. On the refrigerant side, heat transfer can be enhanced by using tubes with internal surface enhancements (such as microfin tubes), heat exchangers with a higher number of smaller-diameter tubes, and improved heat exchanger circuitry design. Typically, the heat transfer rate on the refrigerant side is orders of magnitude higher than on the air side, primarily

[3] The rotary compressors here do not specifically refer to rotary vane compressors. Scroll compressors fall under the category of rotary compressor because of their rotational mechanism.

owing to the comparatively poor thermophysical properties of air. Therefore, fins are used to increase the surface area available for air to transfer heat. Additionally, fin patterns (such as wavy, louvered, slit, etc.) are stamped on the fins to promote turbulence. However, a tradeoff exists between enhancing heat transfer via increased surface area and increasing fan power consumption from increased air-side pressure drop. Both must be considered and optimized.

In addition to optimizing the condenser effectiveness, evaporative condensers may be used to achieve even higher performance (Figure 10). Generally, this is only a feasible option for supermarket refrigeration systems with remote condensing units. In this configuration, sprinklers spray water onto the condenser surface. The water droplets vaporize by extracting heat from the condenser surface and produce a cooling effect. The heat transfer coefficients during latent cooling are much higher compared to those exhibited by airflow alone. As a result, the refrigeration system performs more efficiently as well. However, evaporative cooling is most effective in warm and dry climates and may not be suitable for humid climates.



Source: authors' work based on [25]. Note that the dominant mechanism of cooling is evaporation, not convection. See the cited reference for details.

Figure 10. Schematic of a supermarket refrigeration system with a secondary brine loop and remote evaporative condenser

Another opportunity to enhance system performance is through the use of microchannel condensers. Microchannel heat exchangers are typically constructed out of aluminum. The refrigerant flows in parallel flattened tubes that are further divided into smaller channels (hydraulic diameter less than 1 mm). Microchannel heat exchangers benefit from the large ratio of surface area to volume and therefore have higher effectiveness compared to fin-and-tube heat exchangers. Microchannel heat exchangers are also more compact and can minimize refrigerant charge, which is important for systems that have flammable refrigerants as working fluids.

Controls

The use of sophisticated advanced control systems has enabled significant efficiency improvement for commercial refrigeration systems. Examples of improved control technology include electronic expansion valves (EEVs), controllers to regulate the compressor speed to match the cooling load, Internet of Things (IoT)-based controls that allow setback of cabinet temperatures, on-demand defrost system control, and anti-sweat heater control. These control systems monitor system operation with the aid of temperature and pressure sensors and adjust component characteristics accordingly. For example, EEVs adjust the refrigerant mass flow rate in the system based on the superheat temperature in the evaporator, ensuring that pressure lift in the system is minimized and, consequently, compressor power consumption is reduced. However, the cost of EEV systems can prohibit their implementation in integral refrigeration systems. EEV use is more common in large remote systems.

Fans/motors

Fans consume electricity to move air across the heat exchangers. The airflow rate requirements are generally determined based on the full system design and may not be reduced without adversely affecting system performance. For this reason, many past research studies have been dedicated to reducing fan motor power consumption without affecting shaft power output. Some successful efforts accomplish this by using high-efficiency motors or improving fan blade design. Electronically commutated motor (ECM, also known as brushless direct current [DC] motor) fans are among the most consequential and revolutionary motor technologies in the last century. ECM motors can have efficiencies as high as 90%, much higher than predecessors such as shaded-pole motors (typically less than 20%) and permanent split capacitor (PSC) motors (50%–70%) [26]. Further power reduction may be obtained using variable-speed control of fan motors.

Cabinet airflow/insulation

The cooling load and power consumption of a refrigeration system increase as a result of heat loss in the refrigerated space and ambient air infiltration into the refrigerated space. The heat loss can be minimized by using thicker insulation with a lower conductivity or through the use of vacuum insulated panels (VIPs). Similarly, ambient air infiltration can be reduced by customizing airflow in the refrigerated space using:

- Strip/night curtains
- Air curtains
- Automatic door closers
- Shelf risers and weir plates
- Baffles
- Rerouted airflow ducts

Defrost

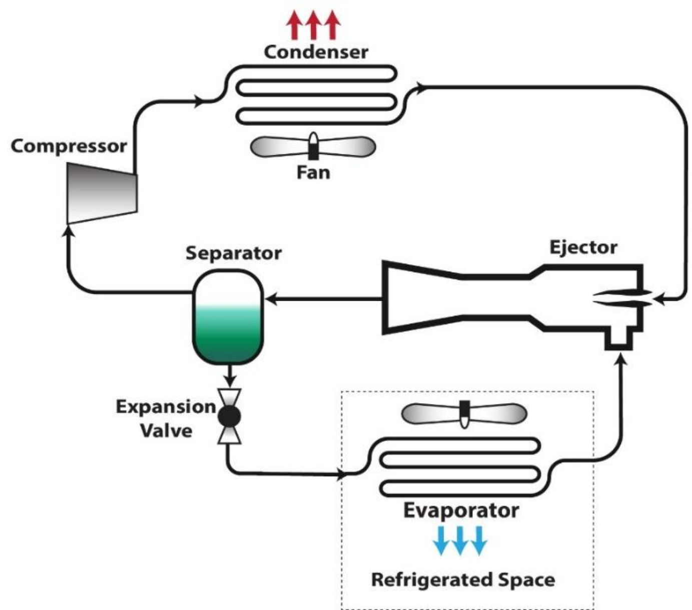
Intermittent defrosting is critical for continuous and reliable operation of a refrigeration system. The accumulated frost adds thermal resistance to heat transfer in the refrigerated space, which increases system power consumption. Traditionally, defrosting has been accomplished using techniques such as off-cycle defrost and electric defrost. Although these methods are cost-effective from a manufacturing perspective and easy to implement, they are relatively energy inefficient. Conversely, techniques such as hot-gas defrost and reverse cycle are more energy efficient and more expensive. Improved control systems that can detect frost also offer an opportunity to reduce energy consumption compared with regularly scheduled defrost sessions.

3.2 Energy savings from alternative refrigeration cycles

This section reviews some of the alternative refrigeration cycles shown in the literature to improve system performance. Although all the cycles discussed below have been demonstrated to improve the performance of refrigeration systems in the laboratory and research and development projects, their widespread adoption in emerging economies remains gradual.

Ejector-enhanced vapor-compression cycle

An ejector is an energy converter with no moving parts. It can be employed in refrigeration systems to reduce the compression work by recovering some of the energy losses that occur in an expansion valve [27]. **Error! Reference source not found.** is a schematic of the basic ejector-e nhanced vapor-compression cycle. In the literature, ejectors have been shown to boost the COP of a CO_2 supermarket refrigeration system by 5%–17% [28]. Although ejectors are versatile and simple in many ways, their implementation requires significant research and development. Of particular significance are geometrical designs of the nozzles and diffuser in the ejector, which require CFD analysis to optimize the fluid flow.



Source: authors' work

Figure 11. Schematic of the ejector-enhanced vapor-compression cycle

Subcooling cycles

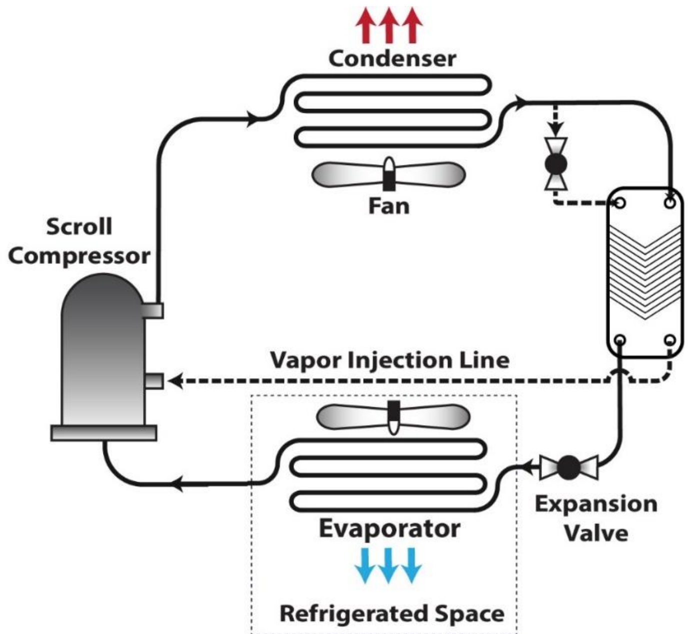
Past research on vapor-compression cycles has shown that cooling capacity and system efficiency can be increased by further subcooling the liquid condensate after it leaves the condenser [24]. This helps minimize the pressure losses observed in the expansion valve and increase overall cooling capacity in the evaporator. There are two different ways this can be achieved:

- *Suction line heat exchanger:* In this configuration, the condensate leaving the condenser is further subcooled by redirecting the cold vapor from the evaporator outlet to an intermediate heat exchanger (Figure 12). However, a tradeoff exists between the benefits from subcooling and the increase in compressor power from additional superheat at its inlet. Hence, this configuration may be favorable only for certain refrigerants. Klein et al. [30] extensively investigated the impact of adding a suction line heat exchanger for a wide range of refrigerants used in the heating, ventilation, air-conditioning, and refrigeration (HVAC&R) industry. They found that the refrigerants R404A, R290, and R600 benefited from suction line heat exchangers, while these heat exchangers adversely affected R32 and R717.

- *Mechanical subcooling:* An alternative way to increase subcooling at the condenser outlet is through use of an additional dedicated refrigeration system. Although this configuration is beneficial for all refrigerants, it is commonly used for transcritical CO_2 refrigeration systems [31, 32].

Vapor injection

Vapor injection is a commonly used method that falls into the category of multistage compression cycles. These cycles reduce the irreversibility during compression by introducing vapor, liquid, or two-phase injections at intermediate pressures. This decreases the compression power requirements without affecting the cooling capacity of the system [33]. Two common configurations of the vapor-injection cycle are the flash-tank and subcooler (Figure 12) vapor-injection cycles. Scroll compressors are best suited for this type of application.

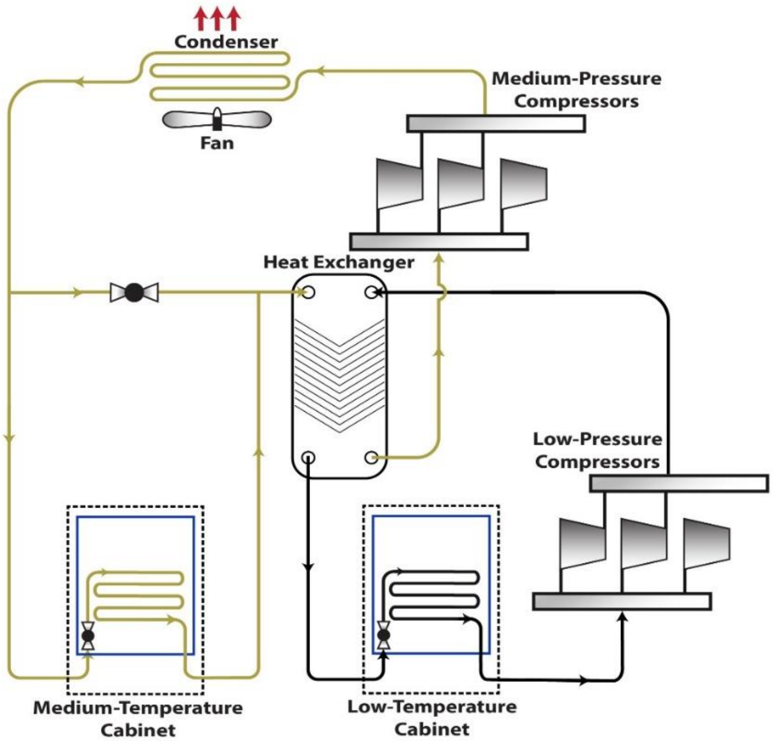


Source: authors' work

Figure 12. Schematic of the subcooler vapor-injection system

Cascade systems

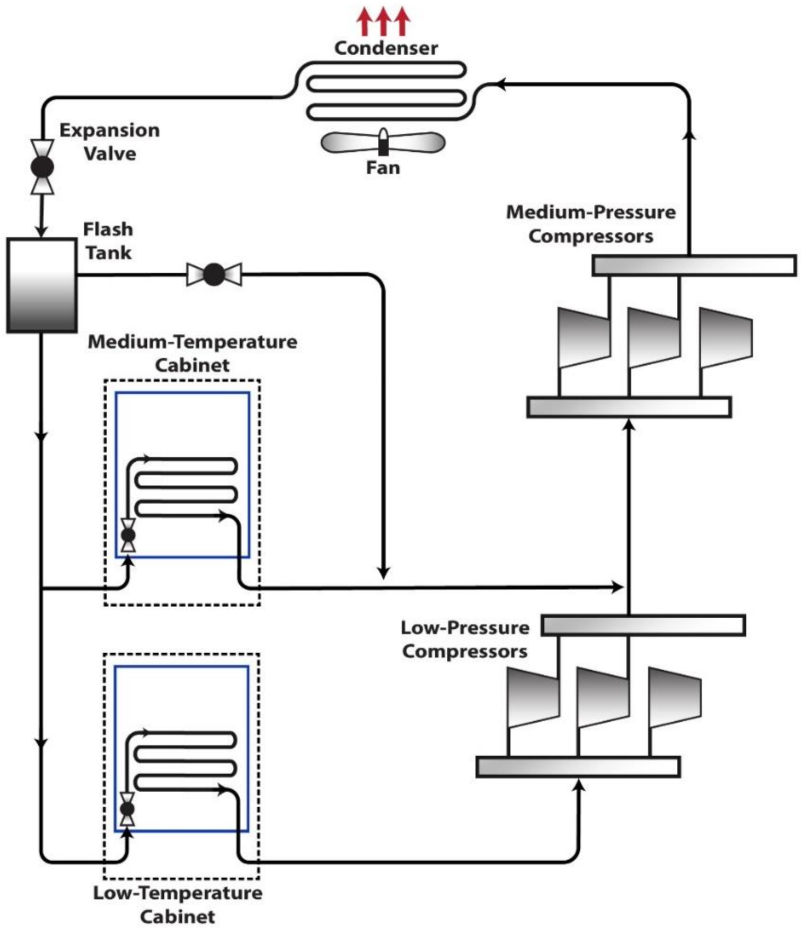
Cascade systems combine a medium-temperature refrigeration system and a low-temperature refrigeration system using a common cascade heat exchanger. Figure 13 shows that the medium-temperature refrigeration system is used to extract the heat rejected by the low-temperature refrigeration system. Currently, R134a and CO_2 (R744) are commonly used as fluids for the medium- and low-temperature refrigeration systems. With this configuration, the low-temperature refrigeration system operates more efficiently owing to the enhanced heat transfer in the cascade heat exchanger. Compared to single-stage systems, 15% to 20% energy savings are typically observed for these systems [29].



Source: authors' work based on [27]
Figure 13. Schematic of the cascade refrigeration system

Booster systems

In the past decade, booster systems with CO_2 (R744) working fluid have become an increasingly popular choice for supermarkets in developed economies [29]. CO_2 (R744) is an attractive refrigerant choice owing to its widespread availability (mostly found in Australia, Europe, and North America), low cost, and lower GWP [31]. As shown in Figure 14, booster systems consist of a medium-temperature display case and a low-temperature display case, along with two different sets of compressors. They have the advantage of being relatively simple and cheap compared to cascade systems.



Source: authors' work based on [29]

Figure 14. Schematic of a booster refrigeration system

Table 10 summarizes energy-saving design options for commercial refrigeration systems, along with the estimated additional costs. For integral refrigeration systems, significant performance improvement can be achieved through high-efficiency variable-speed compressors, improved controls, ECM fans, and thicker insulation. Some alternative refrigeration cycles—such as the subcooling cycle, ejector-enhanced refrigeration cycle, and vapor-injection cycle—may be employed for additional performance benefits. The energy-saving opportunities for supermarket refrigeration systems are even greater. For larger systems, it may be cost-effective to employ techniques such as evaporative condensing and parallel compression for higher performance. Because these systems reject heat outdoors, they ease the load on the building HVAC&R system. In developed economies, there has been a recent shift to using CO_2 as a working fluid owing to its decreased environmental impact compared to HFC refrigeration. This has resulted in adoption of advanced configurations such as booster and cascade refrigeration systems.

Table 10. Overview of energy-saving design options for commercial refrigeration systems

Component	Option	Potential Efficiency Improvement	Indicative Additional Cost	Applicable to
Fan/motors	PSC fan motor for evaporator	<15%	<5%	All
	PSC fan motor for condenser	<5%	1%	Integral
	ECM fan motor for evaporator	2%-35%	<5%	All
	ECM fan motor for condenser	<15%	1.5%	Integral
	Optimized cabinet airflow	*5%*	*<10%*	*All*
	Variable-speed drive	*10%*	*15%*	*All*
Cabinet doors	High-performance door with low infiltration	20%-45%	5%-10%	Transparent doors
Cabinet lighting	Super T8 lighting	<2.5%	<1%	Vertical no door units
	Light-emitting diode (LED) lighting	10%-35%	1.5%	Vertical
	LED lighting with occupancy sensors	5%-40%	5%-20%	Vertical
Insulation	Night curtains	5%	<5%	Vertical no door units
	Increase cabinet insulation thickness by 1/2 inch	<10%	<5%	All
	VIPs	<25%	30%-90%	All
	Pipe insulation	*<5%*	*N/A*	*All*
Heat exchanger	Optimized evaporator design	<5%	<2%	All
	Optimized condenser design	5%-12.5%	<3%	Integral
	Optimized air fins	*10%*	*<0%*	*All*
Compressors	High-efficiency reciprocating compressor	5%-10%	<1.5%	Integral
	Variable-speed drive	*40%*	*2 × non-inverter*	*All*
	Motor efficiency controllers	*10%*	*N/A*	*All*
Control	*Dynamic demand controllers*	*40%*	*Variable*	*All*
	EEVs	*20%*	*<20%*	*All*
	Improved evaporator pressure control	*2% per K increase*	*1.5%-35%*	*All*
Leak minimization	*Improved leak tightness*	*20%*	*10%*	*All*
	Leak detection	*15%*	*10%*	*All*
Refrigerant	*High-efficiency refrigerant*	*Variable*	*N/A*	*All*
	Refrigerants with nano-particles	*20%*	*10%*	*All*
Defrost	*Hot gas, reverse cycle*	*5%*	*<5%*	*Freezers*
	Off-cycle	*10%*	*<0%*	*Refrigerator*
	On-demand control	*10%*	*<5%*	*All*
Others	*Radiant reflectors*	*8%*	*<0%*	*All*
	Improved glazing	*5%*	*5%*	*All*
	Anti-sweat heater control	*<5%*	*<0%*	*All*
	Refrigerant line trim heaters	*10%-25%*	*<0%*	*All*

See the cited references for details and the baseline system specifications that correspond to design options in Table 10. For example, the Technical Support Document of the U.S. Department of Energy [3] assumes shaded-pole motors, T8 lighting, standard single-speed hermetic compressor, etc. as the baseline (or lowest-efficiency) technologies. Source: [3]. Gray and italic cells are based on analysis from [34–36].

3.3 Cost of improving energy efficiency: Examples from the U.S.

Establishing new MEPS or improving existing MEPS removes inefficient or the least energy-efficient products from the market and encourages manufacturers and suppliers to deploy more efficient products. This subsection provides two examples of the incremental manufacturing cost associated with energy-efficiency improvement in two equipment classes from the U.S. market: (1) vertical integral refrigerators with transparent doors (VCT.SC.M), and (2) horizontal integral freezers with transparent doors (HCT.SC.L). These two classes include widely available beverage coolers and ice-cream freezers.

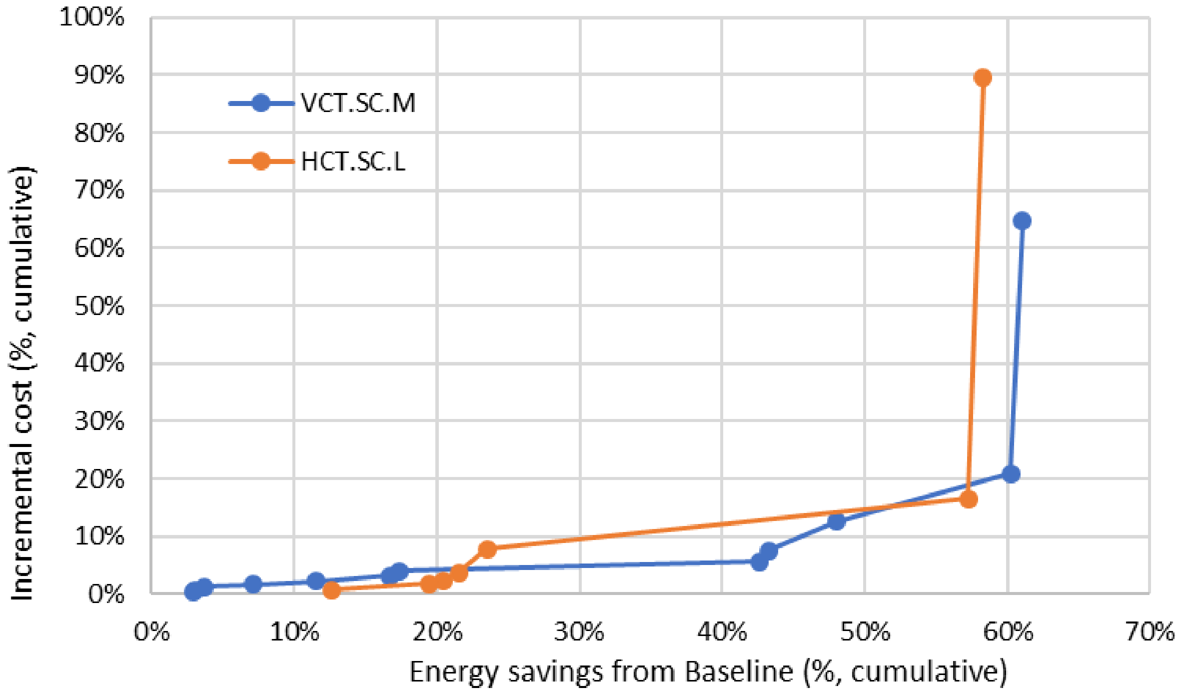
The U.S. MEPS for these two equipment classes seem to be competitive (see Section 4), hence the cost-effective savings potential estimated for these products in the U.S. can provide useful insights for other markets, although this type of cost analysis needs to be updated with region-specific information. Table 11 presents an overview of the energy-savings options and associated costs for the product classes, based on the U.S. technical support document for CRE [3]. Estimated costs and energy savings are shown as percentage reductions in electricity demand compared to the baseline products.

Figure 15 shows the cost increase of increasing energy savings calculated based on the data in Table 11. The chart presents the least-cost combinations of the design options achieving the target savings. Up to 22% improvement in the baseline energy consumption levels of both units (coming from efficient compressor, condenser, and evaporator options) incurs a cost increase of less than 4%. Energy savings for the vertical system (VCT.SC.M) can be increased to 40%–50% (adding efficient or LED lighting options) with a total cost increase of approximately 5.5% to 12.5%. In contrast, high-performance transparent (glass) doors with low infiltration provide the next largest savings for the horizontal system (HCT.SC.L) (~60%), but the overall cost increase remains below 20%. The VIP option offers negligible savings for both units but a large cost increase.

Table 11. Incremental cost of efficient components and designs for VCT.SC.M and HCT.SC.L

Vertical integral refrigerators with transparent doors (VCT.SC.M)					
Component	**Design option**	**Efficiency improvement (%)**	**Incremental cost (%)**	**Efficiency improvement (%, cumulative)**	**Incremental cost (%, cumulative)**
Compressor	High-efficiency reciprocating compressor	2.9%	0.3%	2.9%	0.3%
Heat exchanger	Optimized evaporator design	0.1%	0.4%	3.0%	0.7%
Fan motor	PSCs for condenser	0.7%	0.5%	3.7%	1.2%
Heat exchanger	Optimized condenser design	3.6%	0.5%	7.1%	1.7%
Fan motor	PSC for evaporator	4.7%	0.5%	11.5%	2.3%
	ECM (brushless DC) for evaporator	10.3%	1.4%	16.7%	3.1%
	ECM (brushless DC) for condenser	1.5%	1.4%	17.3%	4.0%
Lighting	High-efficiency lighting	30.6%	1.6%	42.6%	5.6%
Insulation	1/2 inch (1.27 cm) additional thickness	1.0%	1.8%	43.2%	7.5%
Lighting	LED lighting + occupancy sensors	36.4%	6.8%	48.0%	12.6%
Door	High-performance door with low infiltration	23.5%	8.2%	60.2%	20.9%
Insulation	VIP	2.0%	43.8%	61.0%	64.7%
Horizontal integral freezers with transparent doors (HCT.SC.L)					
Component	**Design option**	**Efficiency improvement (%)**	**Incremental cost (%)**	**Efficiency improvement (%, cumulative)**	**Incremental cost (%, cumulative)**
Heat exchanger	Optimized condenser design	12.6%	0.7%	12.6%	0.7%
Compressor	High-efficiency reciprocating compressor	7.9%	1.0%	19.5%	1.8%
Fan motor	PSC for condenser	1.2%	0.6%	20.4%	2.4%
	ECM (brushless DC) for condenser	2.5%	2.0%	21.5%	3.7%
Insulation	1/2 inch (1.27 cm) additional thickness	2.5%	4.1%	23.5%	7.8%
Door	High-performance door with low infiltration	44.1%	8.8%	57.2%	16.6%
Insulation	VIP	7.5%	72.9%	58.3%	89.5%

VCT.SC.M: vertical closed transparent with self-contained condensing unit for medium temperature
HCT.SC.L: horizontal closed transparent with self-contained condensing unit for low temperature
Source: [3]



Note: Individual savings of components are multiplied when calculating the total electricity savings potential of a design combination. Baseline daily energy consumptions for VCT.SC.M and HCT.SC.L are based on [1] (ANSI/ASHRAE 72: 2005 and ANSI/AHRI 1200: 2010) and used as 14.4 kWh/yr and 2.28 kWh/yr, respectively.[4]

Figure 15. Cumulative cost increase vs. energy savings by design options

[4] AHRI is the Air Conditioning, Heating, and Refrigeration Institute; ANSI is the American National Standards Institute; and ASHRAE is the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

4. Energy Performance Requirements and Market Availability of Energy-Efficient Equipment

4.1 CRE energy consumption data and assumptions

The expected market and technology transition via standards and labels in major economies provides an important policy signal to manufacturers that also sell to markets that are the target of the Guidelines: those with outdated, unenforced, or no MEPS and labels. A common set of requirements will help manufacturers prepare to offer products that can be sold in a larger set of markets, with the aim of unlocking greater economies of scale so energy-efficient solutions are widely accessible. Market availability, cost, and benefits of equipment are some of the key considerations that must be assessed in the policy-development process. The following context on some key developments may be informative as countries consider the direction of global markets, but it does not replace the need for a robust assessment of local conditions and the aims of stakeholders in the market. Table 12 summarizes the data used in this analysis. This analysis also includes the UK Energy Technology List (ETL) that defines high-performance criteria, aiming to identify the top 10%–25% performing products in the market.

Table 12. CRE energy consumption data

	Australia	EU	U.S.
Data sources	- 424 models from registration database (screened out of 1,360 entries)[a]	- 145 models from Eurovent (remote RDCs, screened out of 288 entries)[a] - 185 models from Topten EU (integral)	- 6,104 models from compliance database (screened out of 27,135 entries)[a]
RDCs	Integral 214 models Remote 31 models	Integral 53 models Remote 145 models	Integral 1,904 models Remote 3,196 models
RSCs	Integral 163 models	Integral 101 models	Integral 672 models
Small ice-cream freezers	2 models	8 models	Not defined 45 models selected from HCT.SC.L (up to 600 L)
Scooping cabinets	10 models	Not available	Not defined
Drink cabinets or beverage coolers	14 models	23 models	Not defined 49 models selected from VCT.SC.M
Refrigerated vending machines	Not applicable	1 model	46 models

[a] The preliminary analysis considers only one model for multiple models that have the same specifications in the reported parameters on brand or manufacturer, dimensions, and energy consumption, except for model name.

Normalization of energy consumption to ISO 23953

The most commonly used test standards to evaluate energy consumption in CRE are ISO 23953 (e.g., in Australia, New Zealand, China, EU) and ANSI/ASHRAE 72 & ANSI/AHRI 1200 (U.S.). While energy consumption in CRE with an integral condensing unit is measured in accordance with a standard, energy consumption in refrigerated cabinets with a remote condensing unit is calculated based on measurement for the cabinet and calculation for the remote condensing unit. Table 13 shows CRE energy consumption defined in ANSI/AHRI 1200 and ISO 23953. The Guidelines refer to ISO 23953.

Table 13. CRE energy consumption defined in ANSI/AHRI 1200 and ISO 23953

	ANSI/AHRI 1200	ISO 23953
Integral	Total daily energy consumption (TEC)	TEC = direct electrical energy consumption (DEC)
Remote	Calculated daily energy consumption (CDEC) = CEC + FEC + LEC + ACEC + DEC + PEC	TEC = REC + DEC REC: refrigeration daily electrical energy consumption for cabinets with remote condensing unit DEC = FEC + LEC + ACEC + DFEC + PEC +CPEC

CEC: compressor energy consumption; FEC: fan energy consumption; LEC: lighting energy consumption; ACEC: anti-condensate energy consumption; DFEC: defrost energy consumption; PEC: condensate evaporator pan energy consumption; CPEC: pumping electrical energy consumption

These two standards are different in many respects. The effects of some differences between test standards on measurement or calculation results can be predicted or estimated, whereas other factors are difficult to estimate or are less important. The assumptions used in this analysis to convert declared energy consumptions of systems in different standards are based on previous studies [4, 11, 17, 22, 37-39] that conducted benchmarking between standards and additional consultation with experts; hence, they should be regarded as *indicative,* and not as exact conversion factors. Key elements considered in these studies include test room temperature and humidity, product temperature, door/lid opening regime, lighting regime, loading configuration/material, and so forth. Particularly for RDCs with remote condensing units, at an identical cooling capacity and evaporating temperature, the calculated energy consumption for refrigeration is much higher under the ISO 23953 standard (defined as REC in Table 13) than under the ANSI/AHRI 1200 standard (defined as CEC in Table 13, see [11] and [38] for more details).

Table 14 summarizes the assumptions used in this analysis for normalization of RDCs to ISO 23953. Table 15 summarizes the assumptions used in this analysis for normalization of RSCs to ISO 22041.

Table 14. Assumptions used for normalization to ISO 23953 in the preliminary analysis

Equipment Class in the Guidelines[a]				U.S. Equipment Class[b]	ANSI/ASHRAE 72: 2005 & ANSI/AHRI 1200: 2010	Normalized to ISO 23953: 2015[c]
Integral	Horizontal	Chilled	RDC-IHC	HZO.SC.M	100%	103.9%
				SOC.SC.M	100%	99.6%
		Frozen	RDC-IHF	HZO.SC.L	100%	96.3%
				SOC.SC.L	100%	92.3%
	Vertical	Chilled	RDC-IVC	VOP.SC.M	100%	101.6%
				SVO.SC.M	100%	106.0%
		Frozen	RDC-IVF	HZO.SC.L	100%	96.5%
				SOC.SC.L	100%	100.7%
Remote	Horizontal	Chilled	RDC-RHC	HZO.RC.M	100%	144.7%
				SOC.RC.M	100%	139.9%
				HCT.RC.M	100%	222.1%
		Frozen	RDC-RHF	HZO.RC.L	100%	124.2%
				SOC.RC.L	100%	123.4%
				HCT.RC.L	100%	124.6%
	Vertical	Chilled	RDC-RVC	VOP.RC.M	100%	143.0%
				SVO.RC.M	100%	149.5%
				VCT.RC.M	100%	260.6%
		Frozen	RDC-RVF	VOP.RC.L	100%	120.9%
				SVO.RC.L	100%	126.8%
				VCT.RC.L	100%	133.8%

a. IHC: integral horizontal chilled; IHF: integral horizontal frozen; IVC: integral vertical chilled; IVF: integral vertical frozen; RHC: remote horizontal chilled; RHF: remote horizontal frozen; RVC: remote vertical chilled; RVF: remote vertical frozen

b. HZO: horizontal open; SOC: service over counter; HCT: horizontal closed transparent; VOP: vertical open; SVO: semi-vertical open; VCT: vertical closed transparent; SC: self-contained condensing unit; RC: remote condensing unit; M: medium temperature; L: low temperature

c. For example, the first row should read that the estimated energy consumption of a U.S. HZO.SC.M classified product under ISO 23953 is 1.039 times (103.9%) as high as the U.S. standard.

Table 15. Assumptions used for normalization to ISO 22041 in the preliminary analysis

Equipment Class in the Guidelines				U.S. Equipment Class[a]	ANSI/ASHRAE 72: 2005 & ANSI/AHRI 1200: 2010	Normalized to ISO 22041: 2019
Integral	Horizontal (Counter)	Chilled	RSC-IHC	HCS.SC.M	100%	120.0%
		Frozen	RSC-IHF	HCS.SC.L	100%	127.2%
	Vertical	Chilled	RSC-IVC	VCS.SC.M	100%	129.5%
		Frozen	RSC-IVF	VCS.SC.L	100%	129.7%

a. HCS: horizontal closed solid; VCS: vertical closed solid

4.2 Energy-efficiency requirements

Maximum energy consumption requirements

Maximum energy consumption (EC_{max}) requirements (daily or annual), e.g., reference annual energy consumption (RAEC) or standard annual energy consumption (SAEC), are typically determined in a linear relationship with TDA or volume (net or gross). EC_{max} requirements for RDCs (Australia, EU, and U.S.), drink cabinets (Australia), and scooping cabinets (Australia and EU) are based on TDA, while those for storage cabinets, ice-cream freezers (Australia and EU), beverage coolers (EU), and refrigerated vending machines (EU and U.S.) are based on volume (net, gross, or equivalent volume, which is net volume normalized by factors that depend on the M-package temperature class and test room climate class [CC]).

Energy efficiency index (EEI) calculations

An EEI is generally defined as actual energy consumption measured under laboratory conditions, e.g., TEC over the standard energy consumption or EC_{max}, which typically coincides with MEPS. MEPS and labeling requirements in Australia, China, and the EU are set in EEIs as defined in the standards. Table 16 shows an example of EEI calculations in the standards of these three economies.

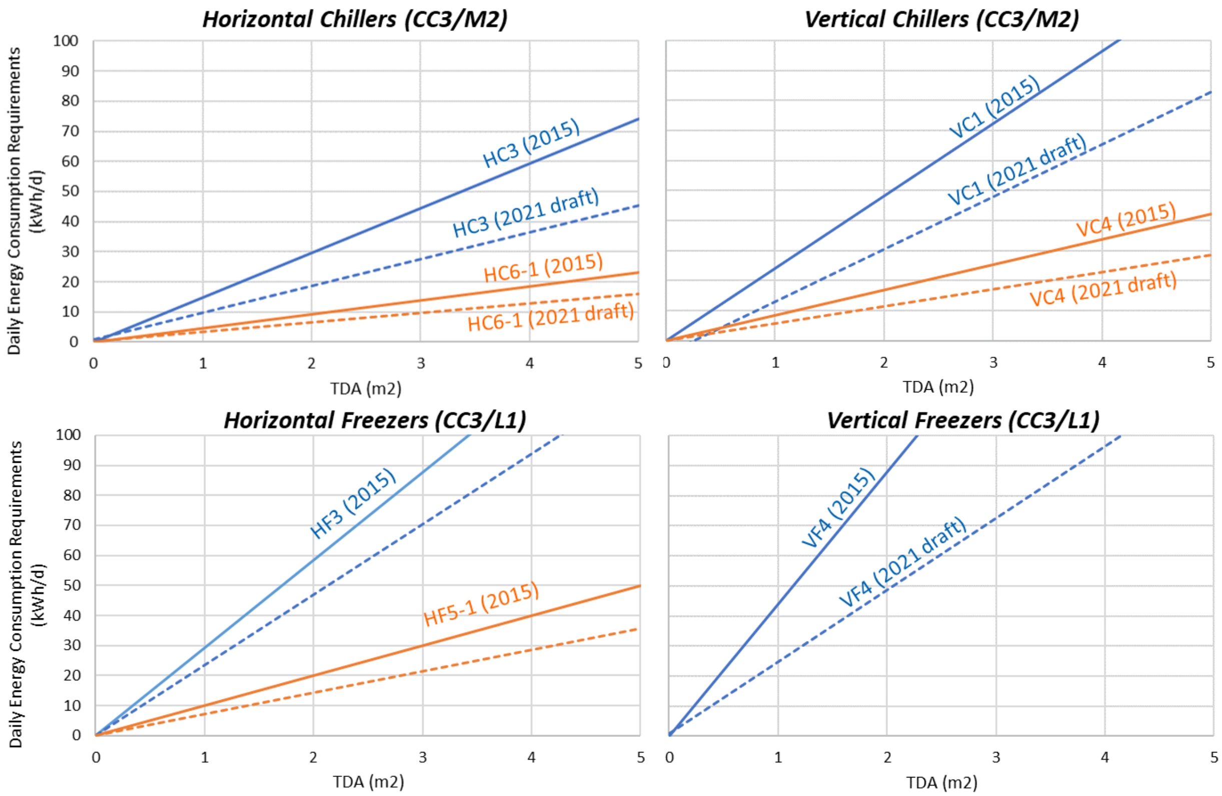
Table 16. EEI calculations for a hypothetical CRE

	Australia	EU	China
Product type	Integral vertical refrigerator		
CC	CC3 dry bulb (°C) = 25, relative humidity (%) = 60		
M-package temperature class	M1 (highest temperature of warmest M-package colder than or equal to +5°C & lowest temperature of coldest M-package warmer than or equal to -1°C)		
TDA	1 m^2		
TEC	10 kWh/d		
RAEC (or SAEC)	(9.1+9.1xTDA) x 365	(9.1+9.1xTDA) x P x C x 365 P=1.1 for integral, 1.0 for remote; C=1.15 for M1 (1.00 for M2, 0.82 for H1&H2)	(17.77+9.1xTDA) x K x CC x F x 365 K=1.1 for M1; CC=1 for CC3; F=1 for cabinets with fan
EEI	$\frac{10 \times 365}{(9.1 + 9.1 \times 1) \times 365} \times 100 = 55$	$\frac{10 \times 365}{(9.1 + 9.1 \times 1) \times 1.1 \times 1.15 \times 365} \times 100 = 43$	$\eta = \frac{10 \times 365}{(17.77+9.1 \times 1) \times 1.1 \times 1.0 \times 365} \times 100\% = 34\%$
MEPS	EEI_{AU} = 130	EEI_{EU} = 100	EEI_{CN} = 100%

Note that the China standard defines the EEI in percentage.

Draft revision of China energy-efficiency standards for integral refrigerated cabinets

China's MEPS for refrigerated cabinets with self-contained condensing units are under revision. Although the standard has many equipment classes, the four charts in Figure 16 show RDCs that have the highest and lowest energy consumption requirements. The improvement rate varies by size (i.e., TDA). Energy consumption requirements for RDCs (at TDA 2–3 m^2) in the 2021 draft[5] are about 17%–50% more stringent, by product categories, compared to the 2015 MEPS.



HC3: chilled, open, wall-site; HC5-1: chilled, glass lid, wall site (4 solid walls), HC6-1: chilled, glass lid, island (4 solid walls), HF3: frozen, open, wall-site; HF5-1: frozen, glass lid, wall site (4 solid walls); VC1: chilled, semi-vertical; VC4: chilled, glass door; and VF4: frozen, glass door.

Figure 16. 2021 revision draft of China's MEPS for RDCs

Energy consumption requirements for RDCs in China and the U.S. vary by subproduct classes (particularly between open and closed RDCs), while those in Australia and the EU have no or a certain range of variations depending on temperature classes (for example, see Annex B for detailed product categories). As standards in China and the U.S. have more product classes than those in Australia and the EU, MEPS in China and the U.S. are more stringent for some types of products while less stringent for other types compared to other economies. The Australian 2021 and EU 2021/2023 MEPS for RDCs seem to be the levels that efficient open RDCs and closed RDCs can meet.

Energy consumption requirements in the Guidelines

[5] The China standard is under revision at the time of this analysis. The draft version 4 of the standard revision has been analyzed in this document.

The Guidelines are designed for developing and emerging economies to implement around 2024. Given existing regional standards and energy-efficiency improvement opportunities, the low-efficiency requirements align with the Australian 2021 or EU 2021 MEPS. The intermediate- and high-efficiency requirements in the Guidelines (30% and 60% more stringent, respectively, than the low-efficiency requirements) are comparable with or more stringent than levels in the current regional standards (Table 17).

Table 17. Summary of RDC EEI requirements in the Guidelines

<table>
<tr><th colspan="4">Equipment Category</th><th>Equipment Class Code</th><th>Low Efficiency (High EEI)</th><th>Intermediate Efficiency (Intermediate EEI)</th><th>High Efficiency (Low EEI)</th></tr>
<tr><td rowspan="8">RDC</td><td rowspan="4">Integral</td><td rowspan="2">Horizontal</td><td>Chiller</td><td>RDC-IHC</td><td>130
[AU 2021]</td><td>90
[EU 2023]</td><td>50</td></tr>
<tr><td>Freezer</td><td>RDC-IHF</td><td>130
[AU 2021]</td><td>90
[EU 2023]</td><td>50
[China draft 2021, HF5-1]</td></tr>
<tr><td rowspan="2">Vertical</td><td>Chiller</td><td>RDC-IVC</td><td>130
[AU 2021]</td><td>90
[EU 2023]</td><td>50</td></tr>
<tr><td>Freezer</td><td>RDC-IVF</td><td>130
[AU 2021]</td><td>90
[EU 2023)</td><td>50</td></tr>
<tr><td rowspan="4">Remote</td><td rowspan="2">Horizontal</td><td>Chiller</td><td>RDC-RHC</td><td>130
[AU 2021]</td><td>90
[EU 2023,
U.S. HCT 2017]</td><td>50</td></tr>
<tr><td>Freezer</td><td>RDC-RHF</td><td>130
[AU 2021]</td><td>90
[EU 2023,
U.S. HZO 2017]</td><td>50
[U.S. HCT 2017]</td></tr>
<tr><td rowspan="2">Vertical</td><td>Chiller</td><td>RDC-RVC</td><td>100
[EU 2021]</td><td>75
[EU 2023]</td><td>50
[U.S. VCT 2017]</td></tr>
<tr><td>Freezer</td><td>RDC-RVF</td><td>130
[AU 2021,
EU 2021]</td><td>90
[EU 2023]</td><td>50
[U.S. VCT 2017]</td></tr>
</table>

[ ] represents regional MEPS roughly comparable with the Guidelines requirements.

Table 18 and Figure 17 show RDC TEC requirements at 2.5 m^2 in TDA for all subproduct categories. See Annex D for detailed information on each product category. Because TEC requirements for RDCs are expressed in a linear equation which depends on TDA, differences in the TEC requirements between regional standards vary by size, i.e., TDA. Also, the typical RDC size varies by product type and market, for example, roughly in the range of 1.5–5 m^2 in TDA.

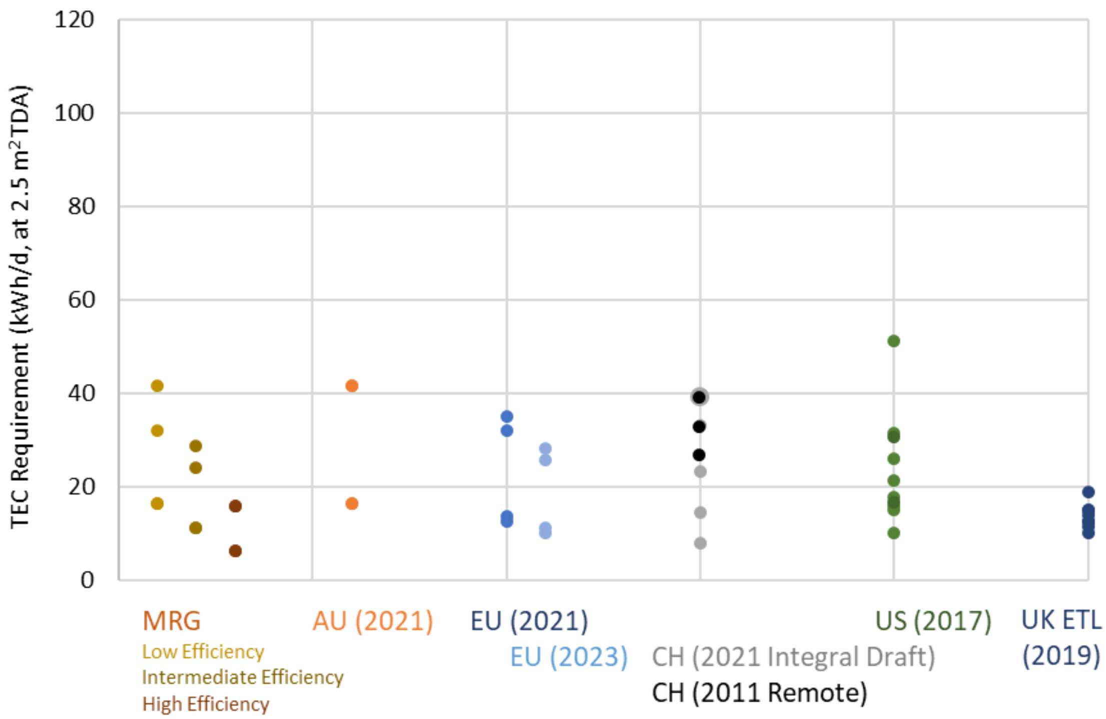
Table 18. RDC TEC requirements at 2.5 m[2] in TDA

		TEC (kWh/d, at 2.5 m^2 TDA)					
		MRG (2024)[a]	Australia (2021)	EU (2021/2023)	China (integral: 2021 draft/remote: 2011)[b]	U.S. (2017)[c]	UK ETL (2019)
Chiller (Refrigerator)	RDC-IHC	16.2 (L) 11.2 (M) 6.2 (H)	16.2	13.7/11.0	23.3 (HC3) 7.9 (HC5-1)	14.9 (HZO.SC.M) 25.9 (SOC.SC.M)	15.0 (M0) 12.5(M1) 11.25 (M2) 10.0 (H1/H2)
	RDC-RHC	16.2 (L) 11.2 (M) 6.2 (H)	16.2	12.5/10.0	32.6 (RS7) 26.6 (RS9)	17.8 (HZO.RC.M) 16.7 (SOC.RC.M) 9.9 (HCT.RC.M)	
	RDC-IVC	41.4 (L) 28.7 (M) 15.9 (H)	41.4	35.0/28.0	39.3 (VC1) 14.3 (VC4)	21.3 (SVO.SC.M) 51.0 (VOP.SC.M)	18.75 (M0) 15.0(M1) 13.75 (M2) 12.5 (H1/H2)
	RDC-RVC	31.9 (L) 23.9 (M) 15.9 (H)	41.4	31.9/25.5	38.8 (RS3) 33.1 (RS4)	31.3 (SVO.RC.M) 30.5 (VOP.RC.M) 15.7 (VCT.RC.M)	
Freezer	RDC-IHF	37.3 (L) 25.8 (M) 14.4 (H)	37.3	32.7/26.2	58.7 (HF3) 17.9 (HF5-1)	56.0 (HZO.SC.L) 29.2 (SOC.SC.L)	25.0 (L1) 21.25(L2) 20.0 (L3)
	RDC-RHF	37.3 (L) 25.8 (M) 14.4 (H)	37.3	29.8 (2021) 23.8 (2023)	39.2 (RS13) 34.4 (RS14)	31.2 (SOC.RC.L) 26.9 (HZO.RC.L) 11.7 (HCT.RC.L)	
	RDC-IVF	64.2 (L) 44.4 (M) 24.7 (H)	64.2	61.3 (2021) 49.1 (2023)	59.9 (VF4)	117.0 (SVO.SC.L) 112.1 (VOP.SC.L)	28.75 (L1) 27.5(L2) 27.5 (L3)
	RDC-RVF	64.2 (L) 44.4 (M) 24.7 (H	64.2	55.8 (2021) 44.6 (2023)	132.7 (RS12) 72.3 (RS19)	83.7 (SVO.RC.L) 79.9 (VOP.RC.L) 21.1 (VCT.RC.L)	

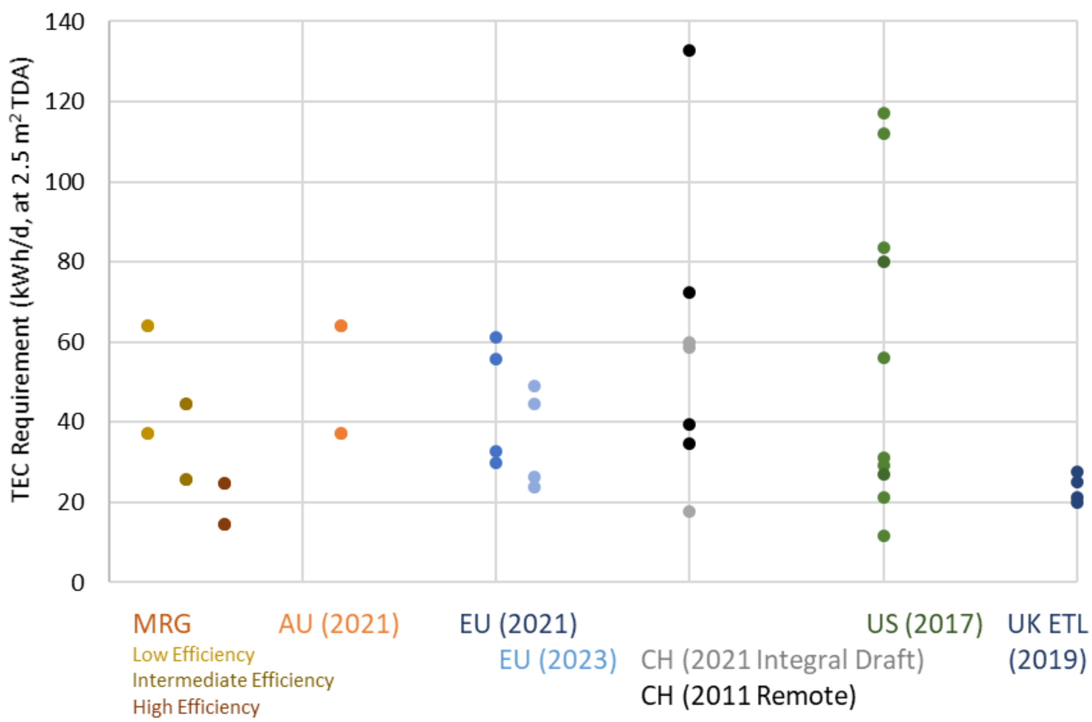
a. MRG: Guidelines; L: low efficiency; M: intermediate efficiency; H: high efficiency.

b. China's draft standard for integral refrigerated cabinets is based on ISO 23953: 2015. China's standard for remote RDCs is based on ISO 23953: 2005.

c. Estimated to values under ISO 23953 at the conditions of CC3 and package temperature M2 or L1, in accordance with Table 14, except for UK ETL criteria.



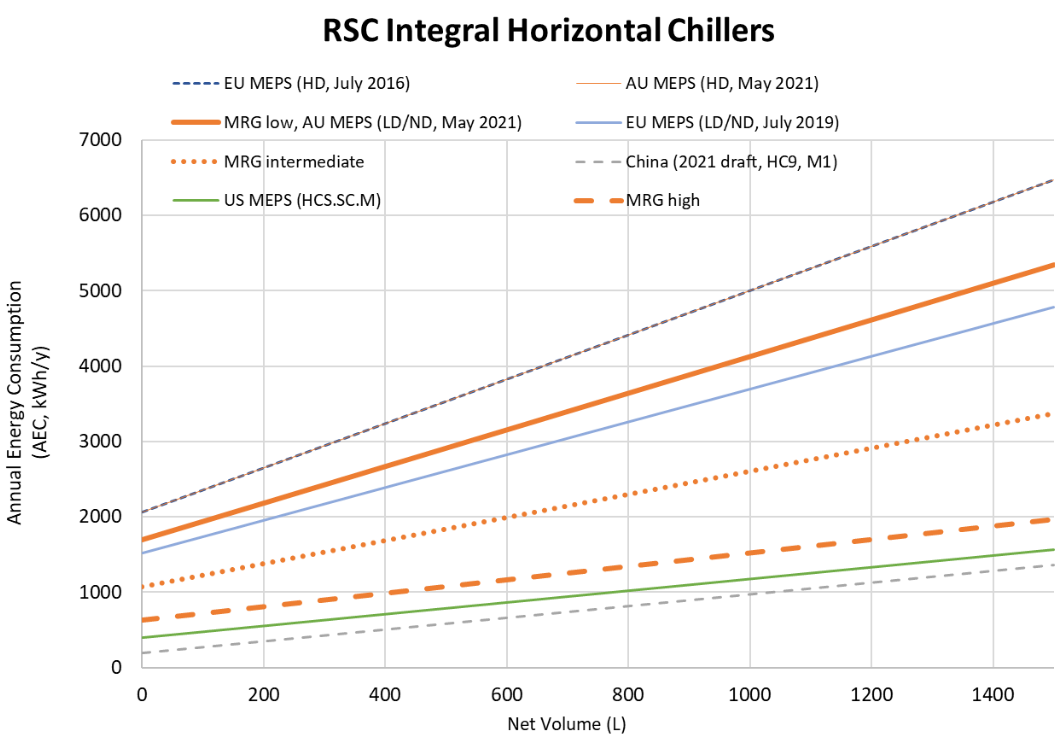
(a) Chiller (Refrigerator)



(b) Freezer

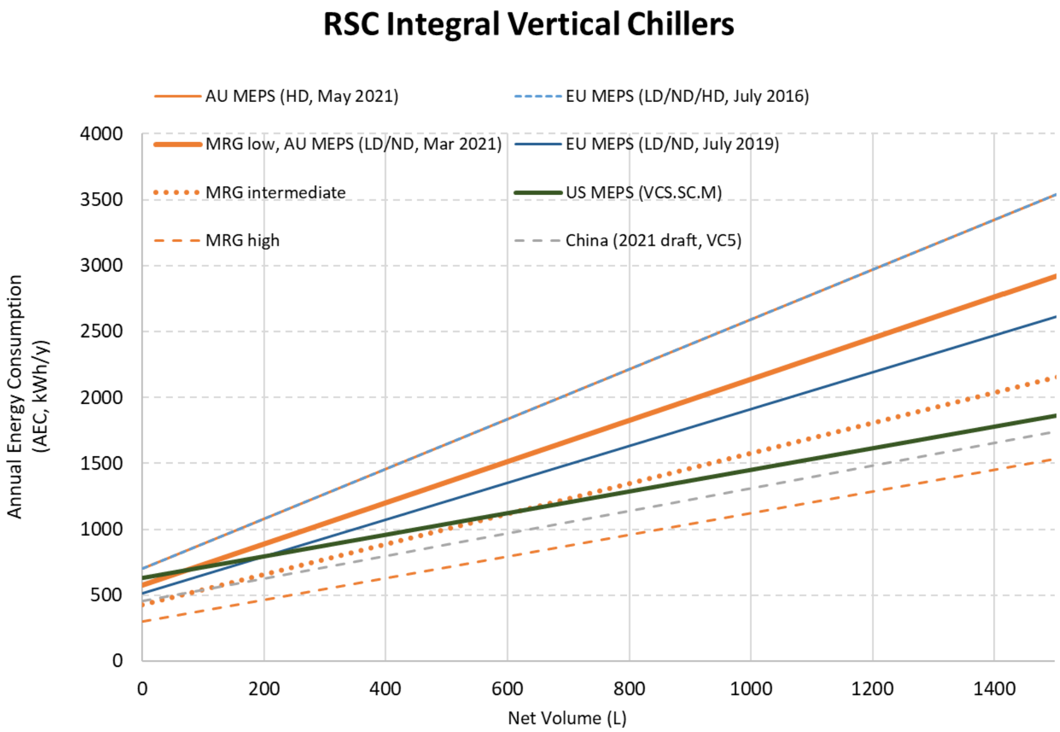
Figure 17. Graphical comparison of RDC TEC requirements at 2.5 m² TDA in Table 18

Energy consumption requirements for RSCs, which are all closed cabinets, in China and the U.S. vary little, while those in Australia and the EU have a very wide gap between horizontal (or counter)[6] and vertical types—so there is a wide gap between Australia/EU and China/U.S. in horizontal RSCs (Figure 18). China's standards for RSCs are based on ISO 23953. Although RSCs in the Guidelines are covered by ISO 22041 (previously EN 16825), this is largely consistent with ISO 23953 for RDCs but with a modified door opening sequence [22]. Also, the reported energy consumption of commercially available horizontal RSCs in Australia and the EU is much lower, by up to 85%–89%, than the MEPS levels (Figure 19 and Figure 20).



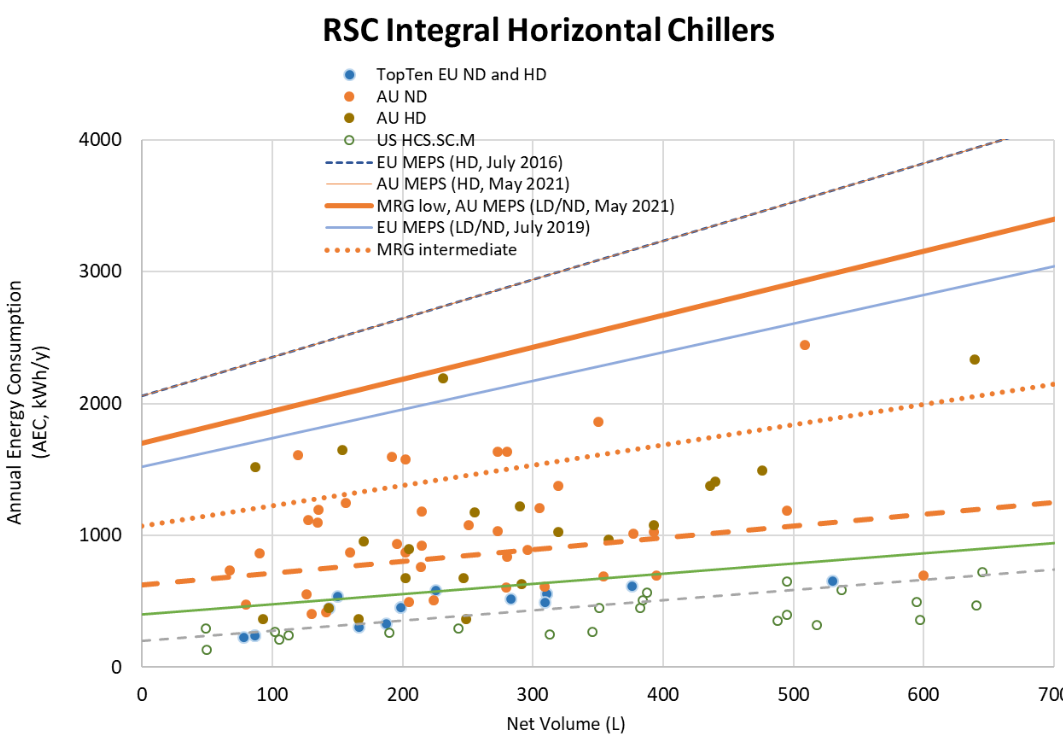
(a) Horizontal Chiller (Refrigerator)

[6] The Australian standard defines an RSC is horizontal if it has an overall height, when determined in accordance with EN 16825, of no greater than 1,050 mm; and vertical otherwise. ISO 22041 (former EN 16825) the Guidelines and the EU standard refer to defines counter cabinet as RSC, having overall height lower than 1,050 mm, with one or more front doors or drawers accessing the same compartment.



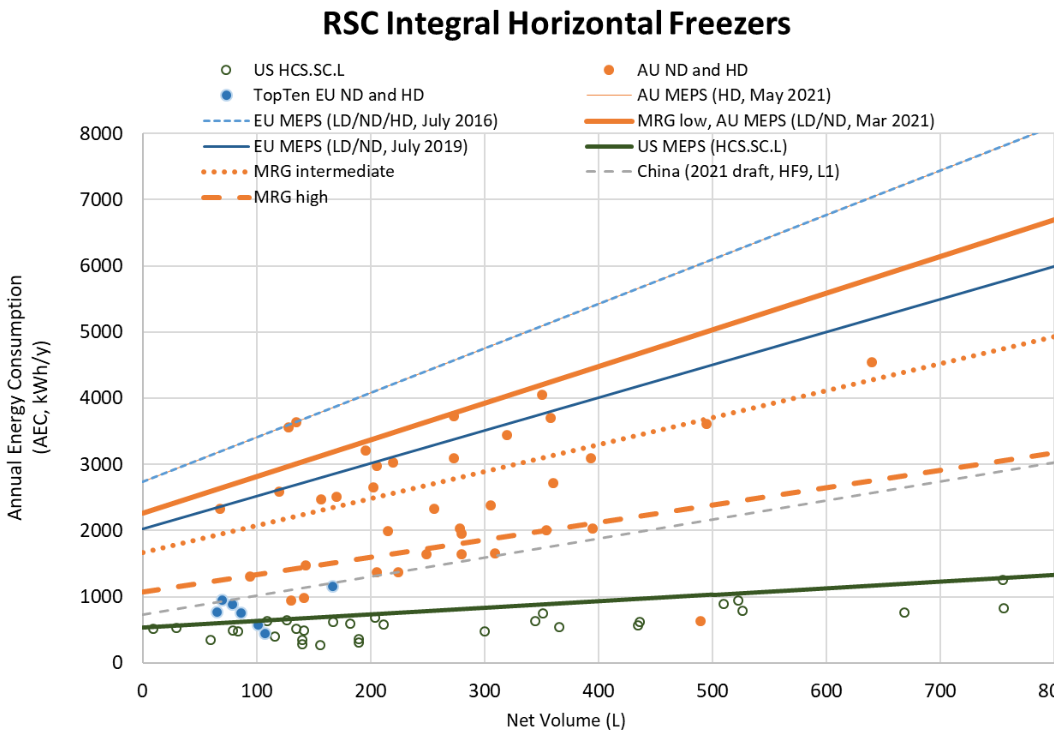
(b) Vertical Chiller (Refrigerator)

Figure 18. Energy consumption requirements for RSC refrigerators (horizontal and vertical)



See Annex D for more details.

Figure 19. Energy consumption requirements and market data for RSC horizontal refrigerators



See Annex D for more details.

Figure 20. Energy consumption requirements and market data for RSC horizontal freezers

The low-efficiency requirements in the Guidelines align with the Australian 2021 MEPS for light duty (LD) and normal duty (ND). The intermediate- and high-efficiency requirements in the Guidelines (26% and 47% more stringent, respectively, for vertical types, and 26%–33% and 53%–63% more stringent, respectively, for horizontal types compared with the low-efficiency requirements) are comparable with levels in the other regional standards (Table 19).

Table 19. Summary of RSC EEI requirements

Equipment Category				Equipment Class Code	Low Efficiency (High EEI)	Intermediate Efficiency (Intermediate EEI)	High Efficiency (Low EEI)
RSC	Integral	Horizontal (Counter)	Chiller	RSC-IHC	95 [AU 2021, LD/ND]	60	35 [U.S. HCS 2017, CH 2021 draft HC9, UK ETL]
			Freezer	RSC-IHF	95 [AU 2021, LD/ND]	70 [UK ETL]	45 [CH 2021 draft, HF9]
		Vertical	Chiller	RSC-IVC	95 [AU 2021, LD/ND]	70	50 [U.S. VCS 2017, CH 2021 draft VC5, UK ETL]
			Freezer	RSC-IVF	95 [AU 2021, LD/ND]	70 [U.S. VCS 2017, CH 2021 draft VF5]	50 [UK ETL]

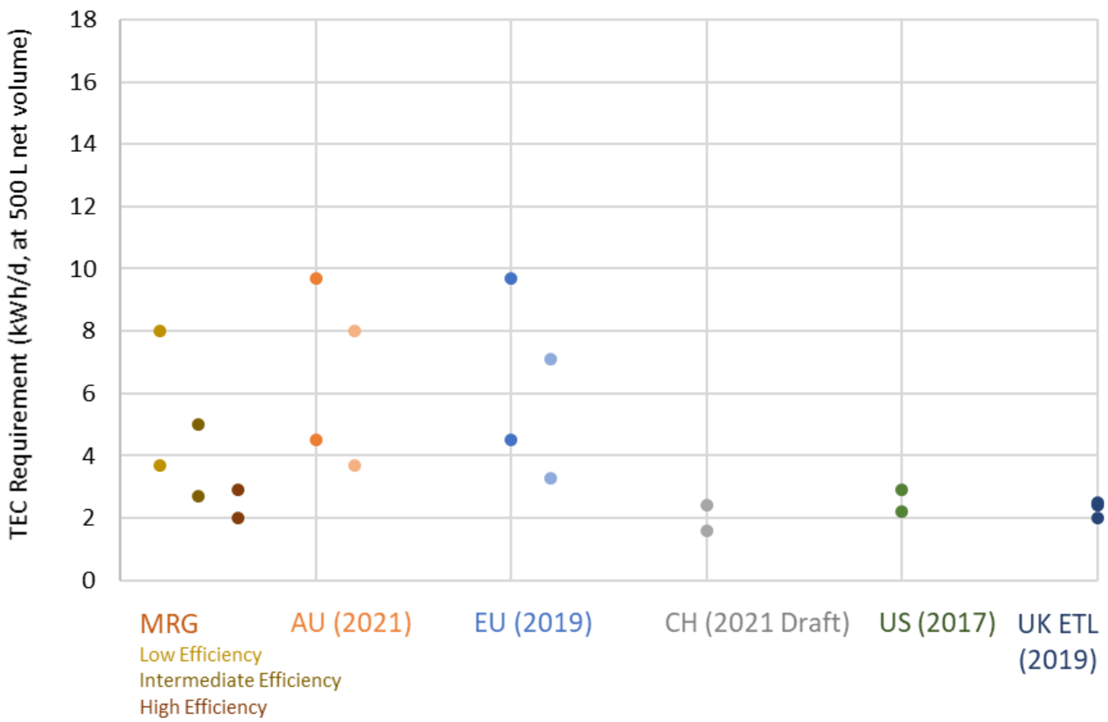
[ ] represents regional MEPS roughly comparable with the Guidelines requirements.

As TEC requirements for RSCs are expressed in a linear equation which depends on net volume, differences in the TEC requirements between regional standards vary by size. Also, typical RSC size varies by product type and market, for example, roughly 200–1,000 L in net volume. Table 20 and Figure 21 show RSC TEC requirements at 500 L in net volume for all subproduct categories. See Annex D for detailed information for each product category.

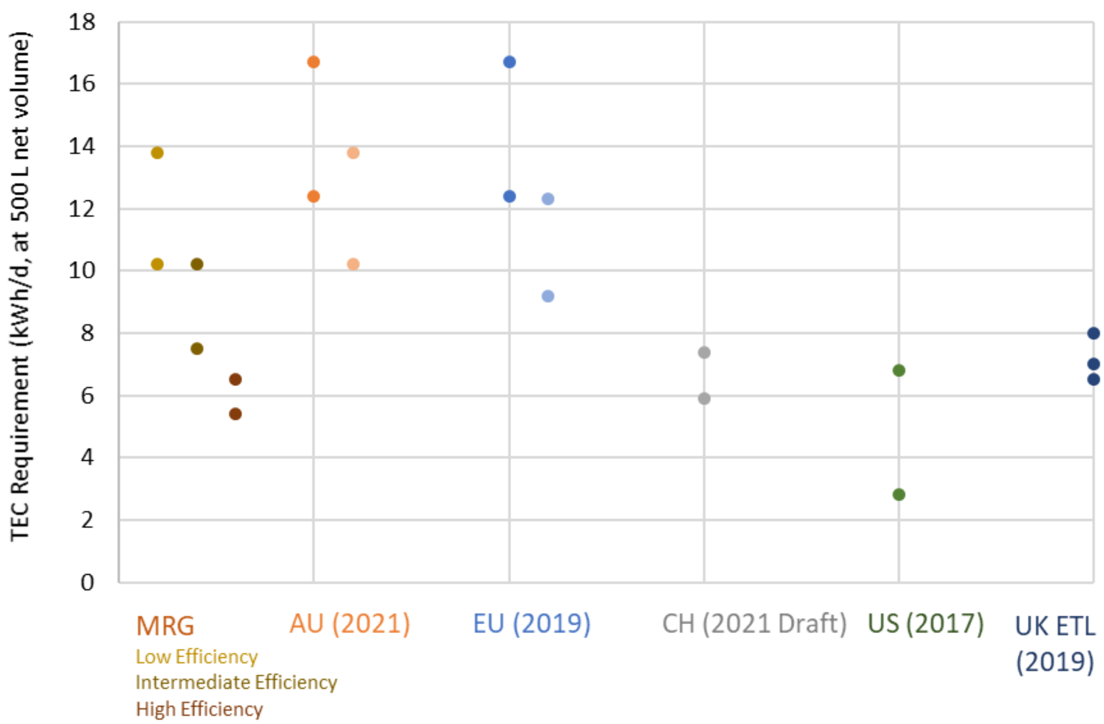
Table 20. RSC TEC requirements at 500 L in net volume (kWh/d)

	MRG (2024)[a]	Australia (2021)	EU (2019)	China (Draft 2021)	U.S. (2017)[c]	UK ETL (2019)
RSC-IHC	8.0 (L) 5.0 (M) 2.9 (H)	9.7 (HD)[b] 8.0 (LD/ND)	9.7 (HD) 7.1 (LD/ND)	1.6 (HC9)	2.2 (HCS.SC.M)	2.5
RSC-IVC	3.7 (L) 2.7 (M) 2.0 (H)	4.5 (HD) 3.7 (LD/ND)	4.5 (HD) 3.3 (LD/ND)	2.4 (VC5)	2.9 (VCS.SC.M)	2.4 (double door) 2.0 (single door)
RSC-IHF	13.8 (L) 10.2 (M) 6.5 (H)	16.7 (HD) 13.8 (LD/ND)	16.7 (HD) 12.3 (LD/ND)	5.9 (HF9)	2.8 (HCS.SC.L)	8.0
RSC-IVF	10.2 (L) 7.5 (M) 5.4 (H)	12.4 (HD) 10.2 (LD/ND)	12.4 (HD) 9.2 (LD/ND)	7.4 (VF5)	6.8 (VCS.SC.L)	7.0 (double door) 6.5 (single door)

a. MRG: Guidelines; L: low efficiency; M: intermediate efficiency; H: high efficiency.
b. LD: light duty; ND: normal duty; HD: heavy duty
c. Estimated to values under ISO 22041 conditions of CC 4 and package temperature M1 (for chillers) or L1 (freezers), in accordance with Table 15.



(a) Chiller (Refrigerator)



(b) Freezer

Figure 21. Graphical comparison of RSC TEC requirements at 500 L net volume in Table 20

Energy consumption requirements for beverage coolers (or similar products), small ice-cream freezers (or similar products), and refrigerated vending machines in China and the U.S. are assessed to be more stringent than requirements for similar products in Australia and the EU. The low-efficiency requirements in the Guidelines are more stringent than the Australia MEPS, or align with the EU 2021 MEPS. The intermediate- and high-efficiency requirements in the Guidelines (30% and 50%–60% more stringent, respectively, than the low-efficiency requirements) are comparable with or more stringent than levels in the current regional standards (Table 21). This is mainly because the energy consumption of the other equipment commercially available is assessed to be much lower than each regional MEPS (see Figure 22c and Annex D).

Table 21. Summary of EEI requirements of other equipment

Equipment Category	Equipment Class Code	Low Efficiency (High EEI)	Intermediate Efficiency (Intermediate EEI)	High Efficiency (Low EEI)
Refrigerated drinks cabinet (beverage cooler)	RDC-BC	100	70	40
Ice-cream freezer cabinet	RDC-ICF	100 [EU 2021]	70 [EU 2023]	50
Refrigerated scooping cabinet	RDC-SC	100	70	50
Refrigerated vending machine	RVM	100 [EU 2021]	70 [China 2019]	50 [U.S. 2019]

[ ] represents regional MEPS roughly comparable with the Guidelines requirements.

As TEC requirements for other equipment are expressed in a linear relationship which depends on TDA or net volume, differences in the TEC requirements between regional standards vary by size. Also, their typical sizes vary by product type and market. Table 22 shows TEC requirements of other equipment at selected sizes. See Annex D for detailed information for each product category.

Table 22. Summary of TEC requirements for other equipment at selected sizes

	Net Volume or TDA	kWh/d				
		MRG (2024)	**Australia (2021)**	**EU (2021/2023)**	**China (Draft 2021 or 2019)**	**U.S. (2017 or 2019)**
RDC-BC	300 L or 1 m^2	6.7 (L)[a] 4.7 (M)[a] 2.7 (H)[a]	8.7[a]	4.0/3.2	1.4 (draft 2021)	2.2 (VCT.SC.M)[b] 2.2 (PD.SC.M) (2017)
RDC-ICF	300 L	3.7 (L) 2.6 (M) 1.9 (H)	4.8	3.8/2.4	3.2 (draft 2021)	2.7 (HCT.SC.L)[c] (2017)
RDC-SC	300 L	28.6 (L) 20.0 (M) 14.3 (H)	37.2	43.2/34.6	NA	NA
RDC-RVM	800 L	7.3 (L) 5.1 (M) 3.7 (H)	NA	7.3–9.9[d] (2021)	4.3–4.6[e] (2019)	3.7–3.9 (2019)[f]

a. kWh/d for 1 m^2 of TDA. The energy consumption requirement for drink cabinets is based on TDA (m^2).
b. Estimated to values under ISO 23953 conditions of CC 3 and package temperature M2.
c. Estimated to values under ISO 22043 conditions of CC A (max) and package temperature C1.
d. Category 1, 2, and 3 considered.
e. Class A and class B considered.
f. Class A and class B considered. No normalization has been made. Class A vending machines (for which the whole interior space is fully cooled) in the U.S. are identical in principle to glass-front machines or called spiral vending machines, the majority of the EU market. Hence, the data are considered roughly comparable, although there remains uncertainty on how the ASHRAE 32.1 test method is interpreted in the U.S. for testing spiral vending machines [38].

4.3 Best available technology

At the time of this analysis, the best available technology (BAT) in the selected markets (Australia, Europe, and the U.S.) for refrigerating equipment in terms of TEC per TDA or net volume (Vn) is identified in Table 23 and Table 24. These products do not necessarily have the lowest EEI defined as annual energy consumption (AEC) per SAEC.

Table 23. BAT energy consumption (most efficient in TEC/TDA) in RDCs

		TEC/TDA (kWh/d/m²)	TDA (m²)	TEC (kWh/d)[a]	AEC (kWh/y)	EEI_{MRG}[b]	Market
Chiller (Refrigerator)	RDC-IHC	2.3 2.4	0.54 1.36	1.2 3.3	448 1,212	22 39	U.S. EU
	RDC-IVC	2.1 2.1	1.45 3.91	3.0 8.2	1,113 3,006	14 18	AU EU
	RDC-RHC	0.6 1.2	4.58 0.62	2.9 0.7	1,052 271	15 13	U.S. U.S.
	RDC-RVC	1.9 2.2	2.87 6.72	5.6 14.9	2,036 5,454	16 21	U.S. AU
	RDC-BC	0.9	0.34	0.3	110	12	EU
Freezer	RDC-IHF	2.8 2.9	0.71 1.73	2.0 4.9	714 1,799	18 23	U.S. EU
	RDC-IVF	5.0 6.2	1.77 1.68	8.9 10.3	3,249 3,796	25 31	EU EU
	RDC-RHF	3.6 4.0	2.42 2.84	8.8 11.3	3,216 4,117	32 35	U.S. U.S.
	RDC-RVF	6.4 6.4	7.24 8.06	46.3 51.4	16,889 18,764	33 33	U.S. U.S.

a. Measured or estimated to values under ISO 23953 at the conditions of CC3 and package temperature M2 or L1.

b. EEI based on the Guidelines' requirements.

Table 24. BAT energy consumption (most efficient in TEC/100-L) in RSCs

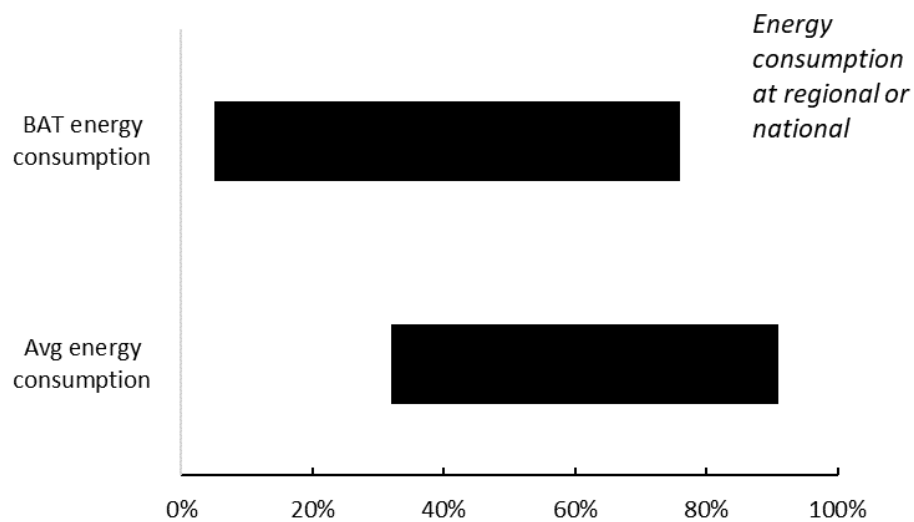
		TEC/100-L (kWh/d/100-L)	TEC (kWh/d)[a]	AEC (kWh/y)	EEI_{MRG}[b]	Market
Chiller	RSC-IHC	0.16 0.17	1.2 2.8	429 1,034	13 19	U.S. U.S.
	RSC-IVC	0.13 0.13	3.0 3.2	1,091 1,179	30 31	U.S. U.S.
	RDC-BC	0.16 0.19	0.3 1.5	125 540	10 21	EU EU
Freezer	RSC-IHF	0.23 0.24	2.1 2.3	756 822	12 12	U.S. U.S.
	RSC-IVF	0.24 0.39	3.3 2.2	1,208 786	18 22	U.S. U.S.
	RDC-ICF	0.30 0.41	0.9 1.2	329 438	24 33	EU EU

a. For RSCs, estimated to values under ISO 22041 at the conditions of CC4 and package temperature M2 or L1. For RDC-ICF, measured to values under ISO 22043 at the conditions of CC B and package temperature L1.

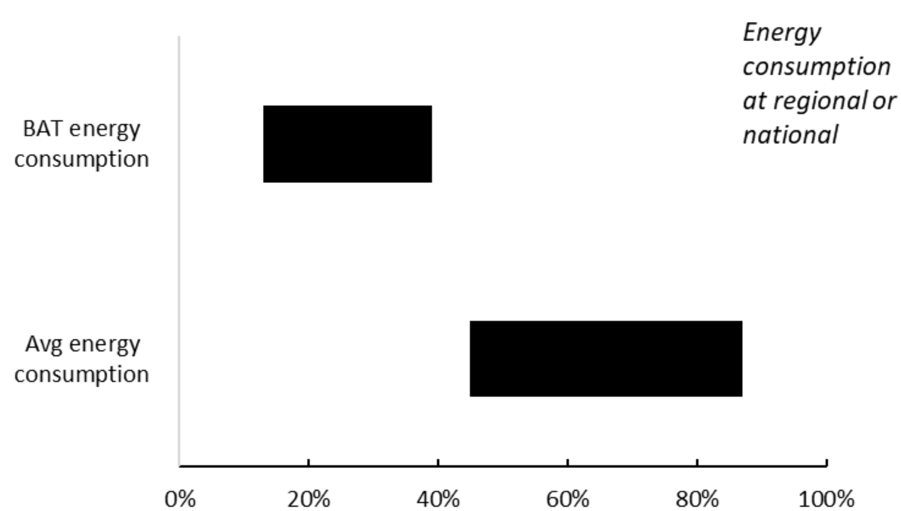
b. EEI based on the Guidelines' requirements.

Energy-efficient CRE systems, as defined in the U4E Model Regulation Guidelines, are commercially available. The following findings are based on analysis of energy consumption data described in Table 12:

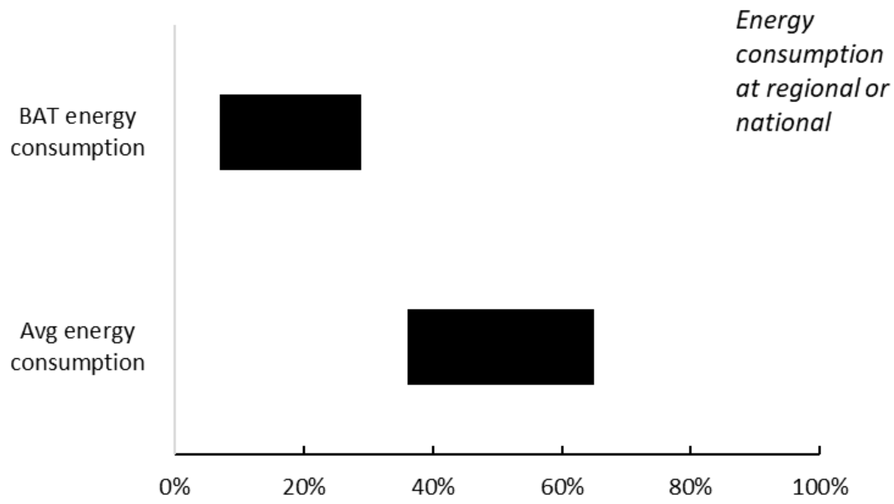
- The average energy consumption of RDCs is lower by 9%–68% than each regional or national MEPS. The most efficient systems consume 23%–95% less energy than each regional or national MEPS (Figure 22a).
- The average energy consumption of RSCs is lower by 13%–55% than each regional or national MEPS. The most efficient systems consume 61%–87% less energy than each regional or national MEPS (Figure 22b).
- The average energy consumption of drink cabinets/beverage coolers is lower by 35%–64% than each regional or national MEPS. The most efficient systems consume 71%–93% less energy than each regional or national MEPS (see Figure 22c).



(a) RDCs



(b) RSCs



(c) Drink cabinets/beverage coolers

See Annex D for more details.

Figure 22. Energy consumption of commercially available CRE systems compared with regional MEPS

5. Low-GWP Refrigerant Options

Combining the transition toward higher efficiency with the transition toward low-GWP refrigerants would allow the industry to exploit synergies in redesigning equipment and retooling manufacturing lines to pursue both paths simultaneously for a more cost-effective transition, as well as enable the market to accelerate GHG emissions reduction.

International mandates, such as the Kigali Amendment to the Montreal Protocol and the F-Gas regulation 517/2014 in Europe [40], continue to aggressively phase down high-GWP HFC refrigerants owing to their environmental impact. For commercial refrigeration specifically, the F-Gas regulation 517/2014 prohibits use of HFC refrigerants with GWP higher than 2,500 in all new equipment in the EU market after January 1, 2020. After January 1, 2022, all new integral refrigeration equipment will be required to use refrigerants with GWP below 150. Similarly, the GWP of foam blowing agents is limited to a maximum value of 150 beyond the year 2020. In the U.S., several states (led by California) are aiming to reduce HFC emissions to 40% below 2013 levels by 2030 [24]. The Guidelines, requiring refrigerants and foam blowing agents to meet GWP 150 or lower, are well aligned with international policy trends and the global goal of achieving sustainable refrigeration through approaches related to the Montreal Protocol.

These mandates ban the use of refrigerants R404A (GWP 3,922) and R134a (GWP 1,300), which are currently widely deployed in both self-contained and remote condensing refrigeration systems. These strict GWP targets have compelled the refrigeration industry to shift its focus from non-flammable HFC refrigerants to other refrigerants including hydrocarbons (HCs), CO_2, hydrofluoroolefins (HFOs), and mixtures of HFCs and HFOs. Figure 23 shows an overview of the refrigerants used in commercial refrigeration and their proposed replacements. HCs include natural, non-toxic refrigerants such as R600a (isobutane) and R290 (propane), which have ultra-low GWPs (< 30) [31]. R600a and R290 have found early adoption in Europe owing to their higher energy efficiency compared to other working fluids. However, HC refrigerants are highly flammable (classified by ASHRAE as A3 [41]), so their use is currently limited to small, self-contained refrigeration systems with a low refrigerant charge. Reinforced safety regulations and adequate training for technicians and practitioners can help the deployment of these refrigerants.

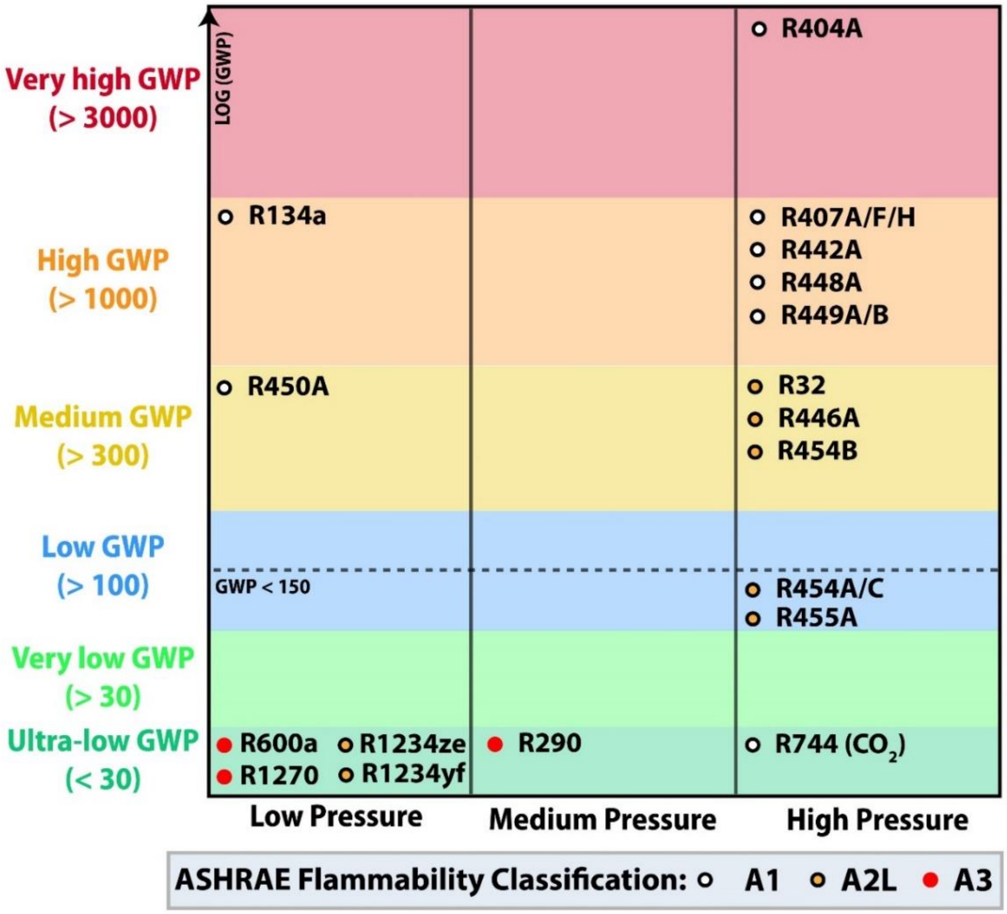
For larger supermarket refrigeration systems, R744 (CO_2) is being widely deployed across Europe and in California in the U.S. R744 (GWP = 1) is an attractive working fluid because of its low GWP, non-toxicity, and widespread availability. In addition, R744 has been researched extensively in the past, so there are very few technical barriers to its increased penetration. However, there are higher equipment costs associated with these systems, which require higher-pressure compressors and the use of advanced system configurations such as transcritical booster systems or cascade systems [31].

Alternatively, HFOs are being considered for application in integral commercial refrigeration systems. HFOs, such as R1234ze and R1234yf, have ultra-low GWPs (< 30) [31, 41]. In addition, they are generally less flammable (classified by ASHRAE as A2L [41]) and can serve as alternatives to HCs in refrigeration systems in areas restricted by regional safety codes.

For large supermarket systems, new blends of HFC/HFOs are being proposed to replace R404A. The composition of these blends can be tailored so they have similar thermodynamic properties as R404A, a lower GWP than R404A, and lower flammability compared to pure HFOs. New synthetic unsaturated HFCs, also known as HFOs, also have zero ozone depletion potential and low GWP. However, they have an unknown degradation pathway, flammability, and/or toxicity implications, so further evaluation of potential impacts is needed [31, 43]. Currently, non-flammable refrigerant blends (classified by ASHRAE as A1 [38]) with GWP as low as 1,360 (R448A) are available. Alternatively, to comply with F-Gas regulation 517/2014 [40] and for an even greater reduction in GWP, A2L refrigerant blends such as R454C (GWP = 146) and R455A (GWP = 146) can be used.

Although these new HFO and HFC/HFO refrigerants can meet the GWP targets set by international mandates, some critics have suggested that policymakers also consider the environmental impact of manufacturing and degradation in the atmosphere [42]—emphasizing the use of natural refrigerants (such as HCs and R744), which have a lower GWP and a lower manufacturing carbon footprint. Additionally, the use of GWP on a 100-year horizon has also been criticized for underestimating the actual near-term environmental impact of refrigerants. Instead, shorter time horizons (e.g., 20 years) have been recommended. As discussed earlier, HCs and R744 are already being used in the commercial refrigeration sector. The Guidelines are based on GWP on a 100-year horizon currently used in regional policy making and the Montreal Protocol.

As highlighted above, selecting the appropriate refrigerant requires a range of different considerations, including the environmental impact, flammability, material compatibility, energy efficiency, size of the system, cost of the system, and so forth [43]. In particular, both natural refrigerants and HFO refrigerants have potential to meet the targets set by international mandates, although concerns over their safe adoption and manufacturing carbon footprint still must be addressed along with related safety standards.



Source: authors' work based on [24, 43, 44]

Figure 23. GWP values, flammability classifications, and operating pressures of the refrigerants used in commercial refrigeration and their proposed replacements

References

[1] International Institute of Refrigeration (IIR, 2019). The Role of Refrigeration in the Global Economy. https://iifiir.org/en/fridoc/the-role-of-refrigeration-in-the-global-economy-2019-142028

[2] Japan Air Conditioning, Heating & Refrigeration News (JARN, 2020). World Refrigeration Equipment Market. September 24, 2020.

[3] United States Department of Energy (U.S. DOE, 2014). Technical Support Document: Energy Efficiency Program for Consumer Products and Commercial And Industrial Equipment – Commercial Refrigeration Equipment. https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=28

[4] Tait, Jeremy, Judith Evans, and Marie Baton (2014). Analysis of specific issues regarding EU policy proposals for DG ENER Lot 12 Commercial Refrigeration Including 'best-in-world' requirements; integral/remote cabinets; representative cabinets; reducing 'gaming'; impact on SMEs; comments on Eurovent proposals of 1 September 2014. Final Report. Prepared by Tait Consulting Limited, RD&T, and CLASP Europe. https://www.clasp.ngo/wp-content/uploads/2021/01/2014_11_Lot-12-Commercial-Refrigeration-Specific-Issues.pdf

[5] The Department of the Environment and Energy, Australia (2017). Decision RIS: Refrigerated display and storage cabinets. https://www.energyrating.gov.au/sites/default/files/documents/Decision_RIS_Commercial_Refrigeration_FINAL.pdf

[6] International Copper Association (ICA, 2021). Production of commercial refrigeration equipment for China in 2018. Provided to authors.

[7] CLASP and PWC (2020). Standards and Labeling Policy for Deep freezer. https://www.clasp.ngo/wp-content/uploads/2021/01/Standards-and-Labeling-Policy-for-Deep-Freezers.pdf

[8] Alliance for an Energy Efficient Economy (AEEE, 2021). India Commercial Refrigeration Market Estimate. Provided to authors.

[9] IIR (2021). The Carbon Footprint of the Cold Chain. 7th Informatory Note on Refrigeration and Food. https://iifiir.org/uploads/store/document/45137/file/d631b44d09d6310558108312cc8103f9.pdf

[10] IIR (2021). The Carbon Footprint of the Cold Chain - Methodological Annex. 7th Informatory Note on Refrigeration and Food. https://iifiir.org/uploads/store/document/45141/file/29d856c2c8f7a3584a80d68c8f22873a.pdf

[11] Waide, Paul, Sietze van der Sluis, and Thomas Michineau (2014). CLASP Commercial refrigeration equipment: mapping and benchmarking. Prepared by Waide Strategic Efficiency Ltd, Saint Trofee and Cemafroid. https://www.clasp.ngo/wp-content/uploads/2021/01/2014-02_Commercial-Refrigeration-Equipment-Mapping-and-Benchmarking.pdf

[12] Bio Intelligence Service (2007). Preparatory Studies for Eco-design Requirements of EuPs - Lot 12 Commercial refrigerators and freezers. Final Report. December 2007. https://www.eceee.org/static/media/uploads/site-2/ecodesign/products/commercial-refrigerators-freezers/finalreport-lot12.pdf

[13] Moons, Hans, Alejandro Villanueva, Maria Calero, Fulvio Ardente, Fabrice Mathieux, Nicola Labanca, Paolo Bertoldi, Oliver Wolf (2014). Ecodesign for Commercial Refrigeration. Preparatory study update Final report. https://www.applia-europe.eu/images/Library/Ecodesign_for_commercial_refrigerators_2013.pdf

[14] Goetzler, William, Shalom Goffri, Sam Jasinski, Rebecca Legett, Heather Lisle, Aris Marantan, Matthew Millard, Daniel Pinault, Detlef Westphalen, and Robert Zogg (2009). Energy Savings Potential and R&D Opportunities for Commercial Refrigeration. Prepared by Navigant Consulting, Inc. for U.S. Department of Energy. https://www1.eere.energy.gov/buildings/pdfs/commercial_refrigeration_equipment_research_opportunities.pdf

[15] Kemna, René, Pepijn Wesselman, Roy van den Boorn, Martijn van Elburg, Jeremy Tait, Claus Barthel, and Christian Jensen (2021). Review Study Phase 1.1 & 1.2 Technical Analysis PRELIMINARY DRAFT INTERIM REPORT for Professional Refrigeration. Prepared by VHK, Tait Consulting Wuppertal Institute, and Viegand Maagøe. https://www.ecoprorefrigeration.eu/downloads/20210618_Professional%20refrigeration%20review%20study_Preliminary%20draft%20interim%20report_Webversion.pdf

[16] Energy Foundation China (2021). Scoping Study on Mitigation Potential of Refrigeration and Air Conditioning Products In China. https://www.efchina.org/Reports-en/report-cip-20210119-en

[17] Mark Ellis & Associates and Tait Consulting Limited (2013). Technical Evaluation of National and Regional Test Methods for Commercial Refrigeration Products. Super-efficient Equipment and Appliance Deployment (SEAD). https://superefficient.org/publications/technical-evaluation-of-national-and-regional-test-methods-for-commercial-refrigeration-equipment

[18] European Commission (2019). Commission Regulation (EU) 2019/2024 of 1 October 2019 laying down ecodesign requirements for refrigerating appliances with a direct sales function pursuant to Directive 2009/125/EC of the European Parliament and of the Council. *Offical Journal of European Union.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2019.315.01.0313.01.ENG

[19] Commonwealth of Australia (2020). Greenhouse and Energy Minimum Standards (Refrigerated Cabinets) Determination 2020. https://www.legislation.gov.au/Details/F2020L01014

[20] New Zealand Government (2020). Energy Efficiency (Energy Using Products) Amendment Regulations 2020. https://www.legislation.govt.nz/regulation/public/2020/0305/latest/whole.html

[21] European Commission (2019). Impact Assessment. Commission Staff Working Document. https://ec.europa.eu/transparency/documents-register/detail?ref=SWD(2019)352&lang=en

[22] Commonwealth of Australia (2020). Greenhouse and Energy Minimum Standards (Refrigerated Cabinets) Determination 2020_EXPLANATORY STATEMENT. https://www.legislation.gov.au/Details/F2020L01014/Explanatory%20Statement/Text

[23] Navigant Consulting, Inc (2013). Guide for the Retrofitting of Open Refrigerated Display Cases with Doors. Prepared for: Better Buildings Alliance Building Technologies Office Office of Energy Efficiency and Renewable Energy U.S. Department of Energy. https://www1.eere.energy.gov/buildings/commercial/pdfs/cbea_open_case_retrofit_guide.pdf

[24] Technology and Economic Assessment Panel (TEAP, 2020). Report of The Technology and Economic Assessment Panel - Volume 2: Decision Xxxi/7 - Continued Provision of Information on Energy-Efficient and Low-Global-Warming-Potential Technologies. United Nations Environment Programme (UNEP). https://ozone.unep.org/sites/default/files/assessment_panels/TEAP_dec-XXXI-7-TFEE-report-september2020.pdf

[25] International Energy Agency (IEA, 2003). IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1 – Executive Summary. Compiled by Van D. Baxter, Oak Ridge National Laboratory. https://technicalreports.ornl.gov/cppr/y2003/rpt/117000.pdf

[26] U.S. DOE (2009). Energy Savings Potential and RD&D Opportunities for Commercial Refrigeration. Building Technologies Office. https://www.energy.gov/eere/buildings/downloads/energy-savings-potential-and-rdd-opportunities-commercial-refrigeration.

[27] Sarkar, Jahar (2012). Ejector enhanced vapor compression refrigeration and heat pump systems — A review. *Renewable & Sustainable Energy Reviews.*, vol. 16, no. 9, pp. 6647–6659. DOI: 10.1016/j.rser.2012.08.007.

[28] Hafner, Armin., Sven Försterling, and Krzysztof Banasiak (2014). Multi-ejector concept for R-744 supermarket refrigeration. *International Journal of Refrigeration*, vol. 43, pp. 1–13, Jul. 2014, doi: 10.1016/j.ijrefrig.2013.10.015.

[29] Park, Chasik, Hoseong Lee, Yunho Hwang, and Reinhard Radermacher (2015). Recent

advances in vapor compression cycle technologies. *International Journal of Refrigeration*, vol. 60, pp. 118–134. DOI: 10.1016/j.ijrefrig.2015.08.005.

[30] Klein, S. A., D. T. Reindl, and K. Brownell (2000). Refrigeration system performance using liquid-suction heat exchangers. *International Journal of Refrigeration*, vol. 23, no. 8, pp. 588–596. DOI: 10.1016/S0140-7007(00)00008-6.

[31] UNEP (2019). Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee - 2018 ASSESSMENT. https://ozone.unep.org/sites/default/files/2019-04/RTOC-assessment-report-2018_0.pdf

[32] Mota-Babiloni, Adrián, Joaquín Navarro-Esbrí, Ángel Barragán-Cervera, Francisco Molés, Bernardo Peris, and Gumersindo Verdú (2015). Commercial refrigeration – An overview of current status. *International Journal of Refrigeration*, vol. 57, pp. 186–196. DOI: 10.1016/j.ijrefrig.2015.04.013.

[33] Lee, Hoseong, Sarah Troch, Yunho Hwang, and Reinhard Radermacher (2016). LCCP evaluation on various vapor compression cycle options and low GWP refrigerants. *International Journal of Refrigeration*, vol. 70, pp. 128–137. DOI: 10.1016/j.ijrefrig.2016.07.003.

[34] Abdelaziz, Omar, Nigel Cotton, and Pierre Cazelles (2020). Guidance Report on net benefits and cost for energy efficient refrigeration design options. United Nations Industrial Development Programme (UNIDO) and Kigali Cooling Efficiency Program (K-CEP). https://www.renenergyobservatory.org/api/documents/22223292/download/Guidance%20Report%20on%20net%20benefits%20and%20cost%20for%20different%20energy%20efficient%20refrigeration%20design%20options%20Final%20200720.pdf

[35] TEAP (2019). Report of The Technology and Economic Assessment Panel - Volume 4: Decision XXX/5 Task Force Report on Cost and Availability of Low-GWP Technologies/Equipment that Maintain/Enhance Energy Efficiency. UNEP. https://ozone.unep.org/sites/default/files/2020-07/TEAP_May-2019_Task_Force_Report_on_Energy_Efficiency.pdf

[36] Foster, Alan, Edward Hammond, Tim Brown, Judith Evans, and Graeme Maidment (2018). Technological options for retail refrigeration. International Institute of Refrigeration/ London South Bank University. https://openresearch.lsbu.ac.uk/item/8688y.

[37] Tait, Jeremy (2015). Notes on DG ENER Lot 12 regulatory proposals: Supermarket cabinets and beverage cabinets - Policy thresholds for the various temperature classes; stringency of proposed thresholds; coverage of minor cabinet types; definition for corner cabinets; stringency of beverage cooler thresholds; initial review of small ice cream cabinets. Supported by Judith Evans, RD&T.

[38] Tait, Jeremy (2014). Analysis of EU policy proposals for DG ENER Lot 12 Commercial Refrigeration including comparison with policy thresholds and product data from other regions. With technical support from Judith Evans, RD&T. https://www.eceee.org/static/media/uploads/site-2/ecodesign/products/commercial-

refrigerators-freezers/clasp-2014-11-analysis-eu-policy-proposals-dgenerlot12-regional-comparisons.pdf

[39] Tait Consulting limited (2012). Performance Data Normalisation Methodology for Professional Storage Cabinets. DRAFT Version 0.5: 15 June 2012.

[40] European Commission (2014). 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. *Official Journal of European Union*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2014.150.01.0195.01.ENG

[41] ASHRAE (2017). *2017 ASHRAE handbook: Fundamentals*. Atlanta, GA: American Society of Heating, Refrigeration and Air-Conditioning Engineers.

[42] Environmental Coalition on Standards (ECOS, 2021). Briefing: One step forward, two steps back A deep dive into the climate impact of modern fluorinated refrigerants. https://ecostandard.org/wp-content/uploads/2021/09/ECOS-briefing-on-HFO-production-and-degradation_final3.pdf

[43] McLinden, Mark O., Christopher J. Seeton, and Andy Pearson (2020). New refrigerants and system configurations for vapor-compression refrigeration. *Science*. 2020, doi: 10.1126/science.abe3692.

[44] UNEP Ozone Secretariat (2015). FACT SHEET 4 Commercial Refrigeration Fact Sheets on HFCs and Low GWP Alternatives. https://ozone.unep.org/sites/ozone/files/Meeting_Documents/HFCs/FS_4_Commercial_Refrigeration_Oct_2015.pdf.

Annex A. Types of refrigerated cabinets in China

Table A1. Types of refrigerated display cabinets with integral condensing units in China

	Chiller	ISO 23953	China (GB 26920.2)	Freezer	ISO 23953	China (GB 26920.2)
Horizontal	Chilled, serve-over counter open service access	IHC1	HC1	Frozen, serve-over counter open service access	IHF1	HF1
	Chilled, serve-over counter with integrated	IHC2	HC2			HF2
	Chilled, open, wall site	IHC3	HC3	Frozen, open, wall site	IHF3	HF3
	Chilled, open, island	IHC4	HC4	Frozen, open, island	IHF4	HF4
	Chilled, glass lid, wall site	IHC5	HC5-1 (4 solid walls)	Frozen, glass lid, wall site	IHF5	HF5-1 (4 solid walls)
			HC5-2 (3 glass walls)			HF5-2 (3 glass walls)
			HC5-3 (only front glass wall)			HF5-3 (only front glass wall)
	Chilled, glass lid, island	IHC6	HC6-1 (4 solid walls)	Frozen, glass lid, island	IHF6	HF6-1 (4 solid walls)
			HC6-2 (4 glass walls)			HF6-2 (4 glass walls)
			HC6-3 (only front glass wall)			HF6-3 (only front glass wall)
	Chilled, serve-over counter closed service	IHC7	HC7	Frozen, serve-over counter closed service access	IHF7	
	Chilled, serve-over counter with integrated storage closed service access	IHC8	HC8			
Vertical	Chilled, semi-vertical	IVC1	VC1	Frozen, semi-vertical	IVF1	VF1
	Chilled, multi-deck	IVC2	VC2	Frozen, multi-deck	IVF2	VF2
	Chilled, roll-in	IVC3	VC3	Frozen, roll-in		VF3
	Chilled, glass door	IVC4	VC4	Frozen, glass door	IVF4	VF4
Combined	Chilled, open top, open	IYC1	YC1	Frozen, open top, open	IYF1	YF1
	Chilled, open top, glass lid	IYC2	YC2	Frozen, open top, glass lid	IYF2	YF2
	Chilled, glass door top, open	IYC3	YC3	Frozen, glass door top,	IYF3	YF3
	Chilled, glass door top, glass lid bottom	IYC4	YC4	Frozen, glass door top, glass lid bottom	IYF4	YF4
	Multi-temperature, open top,				IYM5	
	Multi-temperature, open top,				IYM6	
	Multi-temperature, glass door top, open bottom				IYM7	
	Multi-temperature, glass door top, glass lid bottom				IYM8	

Source: Author's work

Table A2. Types of refrigerated display cabinets with remote condensing units in China

Cabinet type	Model	Description	Classification		
Medium-temperature cabinets					
Open multi-level upright (high)	RS1	Medium-temperature-multi-level cabinet, air curtain length 1.5–1.9 m; cabinet height 2.2–2.5 m, depth 0.6–1.2 m	Non-illuminated shelf	Illuminated shelf	
Open multi-level upright (medium)	RS2	Medium-temperature-multi-level cabinet, air curtain length 1.0–1.5 m; cabinet height 1.8–2.19 m, depth 0.6–1.2 m	Non-illuminated shelf	Illuminated shelf	
Open multi-level upright (low)	RS3	Medium-temperature-multi-level cabinet, air curtain length 0.8–1.2 m; cabinet height 0–1.79 m, depth 0.6–1.2 m	Non-illuminated shelf	Illuminated shelf	
Enclosed self-service storage	RS4	Multiple shelves, glass door; cabinet height 1.8–2.2 m, depth 0.6–1.2 m	Solid door	Glass door	
Enclosed self-service storage: lower counter	RS5	Multiple shelves, glass door; cabinet height 0–1.79 m, depth 0.6–1.2 m	Solid door	Glass door	
With front single-layer flat glass	RS6	Medium-temperature single-level cabinet with flat glass at the front and sliding door at the back; cabinet height 1.25–1.4 m, depth 0.8–1.2 m; two subtypes according to the arrangement of the coils of its evaporator	Direct-cooling calandria	Fan coil	
With front double- or multi-layer flat glass	RS7	Medium-temperature double- or multi-level cabinet with flat glass at the front and sliding door at the back; cabinet height 1.25–1.4 m, depth 0.8–1.2 m; two subtypes according to the arrangement of the coils of its evaporator	Direct-cooling calandria	Fan coil	
With front single-layer curved glass	RS8	Medium-temperature-single-level cabinet with curved glass at the front and sliding door at the back; cabinet height 1.25–1.4 m, depth 0.8–1.2 m; two subtypes according to the arrangement of the coils of its evaporator	Direct-cooling calandria	Fan coil	
With front double- or multi-layer curved glass	RS9	Medium-temperature-double- or multi-level cabinet with curved glass at the front and sliding door at the back; cabinet height 1.25–1.4 m, depth 0.8–1.2 m; two subtypes according to the arrangement of the coils of its evaporator	Direct-cooling calandria	Fan coil	
Upright with glass structure visible on four sides	RS10	Cabinet height 2.2–2.5 m (high), 1.8–2.9 m (medium), 0–1.79 m (low)	High	Medium	Low

Low-temperature cabinets

Open multi-level upright (medium)	RS11	Low-temperature multi-level cabinet, air curtain length 1.0–1.5 m; cabinet height 1.8–2.19 m, depth 0.6–1.2 m	No classification	
Open multi-level upright (low)	RS12	Low-temperature multi-level cabinet, air curtain length 0.6–1.0 m; cabinet height 0–1.79 m, depth 0.6–1.2 m	No classification	
Single-width open	RS13	Low-temperature self-service open cabinet with horizontal air curtain (length 0.75–0.85 m) at the opening	With solid envelope	With glass envelope
Double-width open	RS14	Low-temperature self-service open cabinet with horizontal air curtain (length 2 × (0.75–0.85 m)) at the opening	With solid envelope	With glass envelope
Enclosed self-service storage (high)	RS15	Low-temperature, cabinet height 2.2–2.8 m, depth 0.6–1.2 m	Solid door	Glass door
Enclosed self-service storage (medium)	RS16	Low-temperature, cabinet height 1.8–2.19 m, depth 0.6–1.2 m	Solid door	Glass door
Enclosed self-service storage (low)	RS17	Low-temperature, cabinet height 0–1.79 m, depth 0.6–1.2 m	Solid door	Glass door
Composite with glass door in upper part and open lower part	RS18	Cabinet height 1.8 – 2.2 m, with glass door in the upper part and open lower part	No classification	
Enclosed self-service storage with glass structure visible on four sides (high)	RS19	Low-temperature, glass door, cabinet height 2.2–2.8 m, depth 1.9–2.1 m	No classification	
Enclosed self-service storage with glass structure visible on four sides (medium)	RS20	Low-temperature, glass door, cabinet height 1.8–2.19 m, depth 1.9–2.1 m	No classification	

Source: [9]

Annex B. Comparison of product categorizations in selected economies

Model Regulation Guidelines (Preliminary)					International	Australia & New Zealand		EU	US	
Purpose	Condensing Unit	Configuration	Temperature	Test Standard	ISO Types	Product Group	Group Code	Product Group	Product Group	Group Code
Display	Integral	Horizontal	Refrigerator (Chiller)	ISO 23953	IHC3, IHC4 IHC5, IHC6 IHC1, IHC2, IHC7, IHC8	Integral, Horizontal Cabinets RDC-chiller (1)	IRH	Horizontal supermarket refrigerator cabinets (5)	Horizontal Open, Self-contained, MT Horizontal Closed Transparent, Self-contained, MT Service Over Counter, Self-contained, MT	HZO.SC.M HCT.SC.M SOC.SC.M
			Freezer	ISO 23953 ISO 22043 EN16838	IHF3, IHF4 IHF5, IHF6 IHF1, IHF7 IHF5, IHF6 -	Integral, Horizontal Cabinets RDC-freezer (2) Ice-cream freezer cabinet (5)	IFH IFH-5 GSC or ISC	Horizontal supermarket freezer cabinets (7) Ice-cream freezers (2) Gelato-scooping cabinets (3)	Horizontal Open, Self-contained, LT or IT Horizontal Closed Transparent, Self-contained, LT or IT Service Over Counter, Self-contained, LT or IT	HZO.SC.L HZO.SC.I HCT.SC.I HCT.SC.I SOC.SC.L
		Vertical	Refrigerator (Chiller)	ISO 23953	IVC1, IYC1 IVC2, IYC2 IVC3, IYC3 IVC4, IYC4 -	Integral, Vertical Cabinets RDC-chiller (7) Drinks cabinets (11)	IRV IRV-4 (Glass door)	Vertical and combined supermarket refrigerator cabinets (4) Beverage coolers (1) Roll-in cabinets (8)	Vertical Open, Self-contained, MT Vertical Closed Transparent, Self-contained, MT Semivertical Open, Self-contained, MT Pull-Down	VOP.SC.M VCT.SC.M SVO.SC.M PD.SC.M
			Freezer	ISO 23953	IVF1, IYF1 IVF2, IYF2 IVF4, IYF4	Integral, Vertical Cabinets RDC-freezer (8)	IFV	Vertical and combined supermarket freezer cabinets (6)	Vertical Open, Self-contained, LT or IT Vertical Closed Transparent, Self-contained, LT or IT Semivertical Open, Self-contained, LT ot IT	VOP.SC.L VOP.SC.I VCT.SC.L VCT.SC.I SVO.SC.L SVO.SC.I
	Remote	Horizontal	Refrigerator (Chiller)	ISO 23953	RHC3, RHC4 RHC5, RHC6 RHC1, RHC2, RHC7, RHC8	Remote, Horizontal Cabinets RDC-chiller (12)	RRH	Horizontal supermarket refrigerator cabinets (5)	Horizontal Open, Remote, MT Horizontal Closed Transparent, Remote, MT Service Over Counter, Remote, MT	HZO.RC.M HCT.RC.M SOC.RC.M
			Freezer	ISO 23953	RHF3, RHF4 RHF5, RHF6 RHF1, RHF7	Remote, Horizontal Cabinets RDC-freezer (13)	RFH	Horizontal supermarket freezer cabinets (7)	Horizontal Open, Remote, LT or IT Horizontal Closed Transparent, Remote, LT or IT Service Over Counter, Remote, LT or IT	HZO.RC.L HZO.RC.I HCT.RC.I HCT.RC.I SOC.RC.L SOC.RC.I
		Vertical	Refrigerator (Chiller)	ISO 23953	RVC1, RYC1 RVC2, RYC2 RVC3, RYC3 RVC4, RYC4	Remote, Vertical cabinets RDC-chiller (14)	RRV, RRV-2	Vertical and combined supermarket refrigerator cabinets (4) Roll-in cabinets (8)	Vertical Open, Remote, MT Vertical Closed Transparent, Remote, MT Semivertical Open, Remote, MT	VOP.RC.M VCT.RC.M SVO.RC.M
			Freezer	ISO 23953	RVF1, RYF1 RVF2, RYF2, RVF4, RYF3, RYF4	Remote, Vertical Cabinets RDC-freezer (15)	RFV	Vertical and combined supermarket freezer cabinets (6)	Vertical Open, Remote, LT or IT Vertical Closed Transparent, Remote, LT or IT Semivertical Open, Remote, LT or IT	VOP.RC.L VOP.RC.I VCT.RC.L VCT.RC.I SVO.RC.L SVO.RC.I

H: horizontal; V: vertical

Annex C. Notes on Products not Covered by the Guidelines

There are other commercial refrigeration products that appear to be growing in use, depending on the market. Energy-efficiency and test standards for these products are available only in a few economies, or they are currently in development.

Automatic commercial ice makers

These products are refrigeration systems that make and harvest ice and may include a means for storing and dispensing ice. They are typically found in hotels, restaurants, health care facilities, and educational settings. Batch-type ice makers operate with alternating freezing and harvesting periods and typically produce cube-type ice. Continuous-type ice makers continually freeze and harvest ice at the same time and primarily produce flake or nugget ice.

In the U.S., these products accounted in 2008 for about 11% of stocks and 7% of energy use in the commercial refrigeration market that includes refrigerated cabinets, condensing units, compressor racks, vending machines, and walk-in coolers and freezers [12]. The U.S. MEPS for automatic commercial ice makers went into effect in 2018. The minimum amount of water necessary to produce 45 kg (100 pounds) of ice is 45 kg (12 gallons). However, additional water is consumed with batch-type machines, largely due to any remaining water often being purged after harvest cycles. Performance evaluation includes the following:

- Ice harvest rate (kg/24 hr)
- Energy consumption rate (kWh/45 kg of ice)
- Ice hardness factor (%, for continuous type ice makers only)
- Potable water use rate (L/45 kg of ice, for batch type ice makers only)
- Condenser water use rate (L/45 kg of ice)

In China, annual sales of ice makers grew at a year-over-year rate of 20%–30%, to 240,000 units in 2019 [2]. China's standards for CRE cover RDCs with remote condensing units (Part 1, 2011), refrigerated cabinets with self-contained condensing units (Part 2, 2015, under revision), and refrigerated vending machines (Part 3, 2019). Commercial ice makers are likely the next product group to be added to the standard.

Walk-in coolers and freezers

In the U.S., walk-in coolers and freezers are defined as having an enclosed, refrigerated space, sufficiently large to be stepped into but no larger than 3,000 square feet (279 m^2), and capable of storing foodstuffs at temperatures from +5°C (41°F) to -18°C (-0.4°F). In 2008, these products accounted for about 7% of stocks and 16% of energy use in the commercial refrigeration market that includes refrigerated cabinets, condensing units, compressor racks, vending machines, and ice makers [12]. In the U.S. and Canada, MEPS for walk-in coolers and freezers went into effect in 2020. Resources for performance evaluation include the following:

- AHRI 1250: 2020 Standard for Performance Rating of Walk-in Coolers and Freezers
- EN 16855-1: 2017 Walk-in Cold Rooms - Definition, Thermal Insulation Performance and Test Methods - Part 1: Prefabricated Cold Room Kits
- EN 16855-2: 2018 Walk-in Cold Rooms - Definition, Thermal Insulation Performance and Test Methods - Part 2: Customized Cold Rooms
- prEN 17432 Packaged Refrigerating Units for Walk-In Cold Rooms - Classification, Performance and Energy Consumption Testing

Laboratory-grade refrigerators, vaccine refrigerators

These products are refrigeration cabinets used for storing non-volatile reagents and biological specimens at set-point temperatures, typically marketed through laboratory equipment supply stores for laboratory or medical use. Most temperature-sensitive vaccines, such as influenza vaccines, require cold storage between 2°C and 8°C, except a few vaccines require storage at ultra-low temperatures (e.g., -80°C cold chain).

The U.S. ENERGY STAR program provides criteria for general-purpose, high-performance laboratory-grade refrigerators/freezers as well as ultra-low temperature freezers:

- Laboratory-grade refrigerator: 0°C and 12°C (32°F and 53.6°F)
- Laboratory-grade freezer: -40°C and 0°C (-40°F and 32°F)
- Ultra-low-temperature laboratory-grade freezer: -70°C and -80°C (-94°F and -112°F)

In the EU, laboratory equipment is typically designed to operate at temperatures much lower than those defined in Regulation (EU) 2015/1095. These cabinets are under consideration separately.

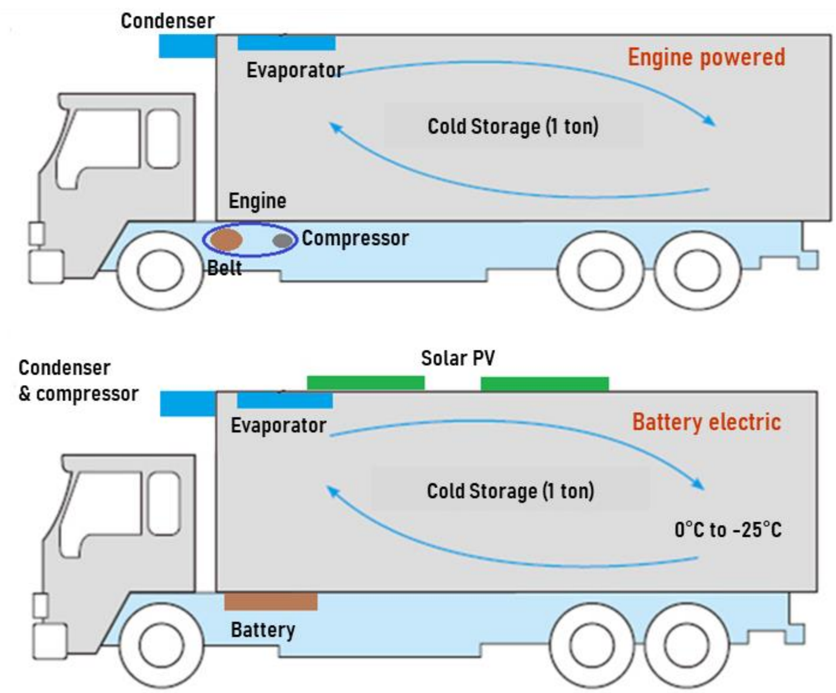
Resources for performance evaluation include the following:

- U.S. ENERGY STAR Program Requirements for Laboratory-Grade Refrigerators and Freezers
- IEC 60335-2-89, Particular Requirements for Commercial Refrigerating Appliances with an Incorporated or Remote Refrigerant Unit or Motor-Compressor
- IEC 61010-2-011 Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use

- The World Health Organization (WHO) provides comprehensive guidelines for performance, quality, and safety of refrigeration equipment, vehicles, and cold chain, https://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/

Transport refrigeration systems

These refrigeration systems are typically powered by internal combustion engines (mostly diesel fueled) designed to control the environment of temperature-sensitive products that are transported in trucks and refrigerated trailers. For example, compared to conventional diesel-engine-powered systems, battery-electric, energy-efficient (using variable-speed compressors, advanced controls, etc.) refrigerated trucks offer major benefits, reducing roughly 50% of emissions due to energy and refrigerant use. Integrating renewable energy can also improve access (Figure C1). Additional alternatives to conventional refrigeration approaches, such as integrating phase change materials, are being explored for certain applications.



Source: THERMAL MASTER

Figure C1. Conceptual diesel-engine and battery-electric transport refrigeration systems

Resources for performance evaluation include the following:

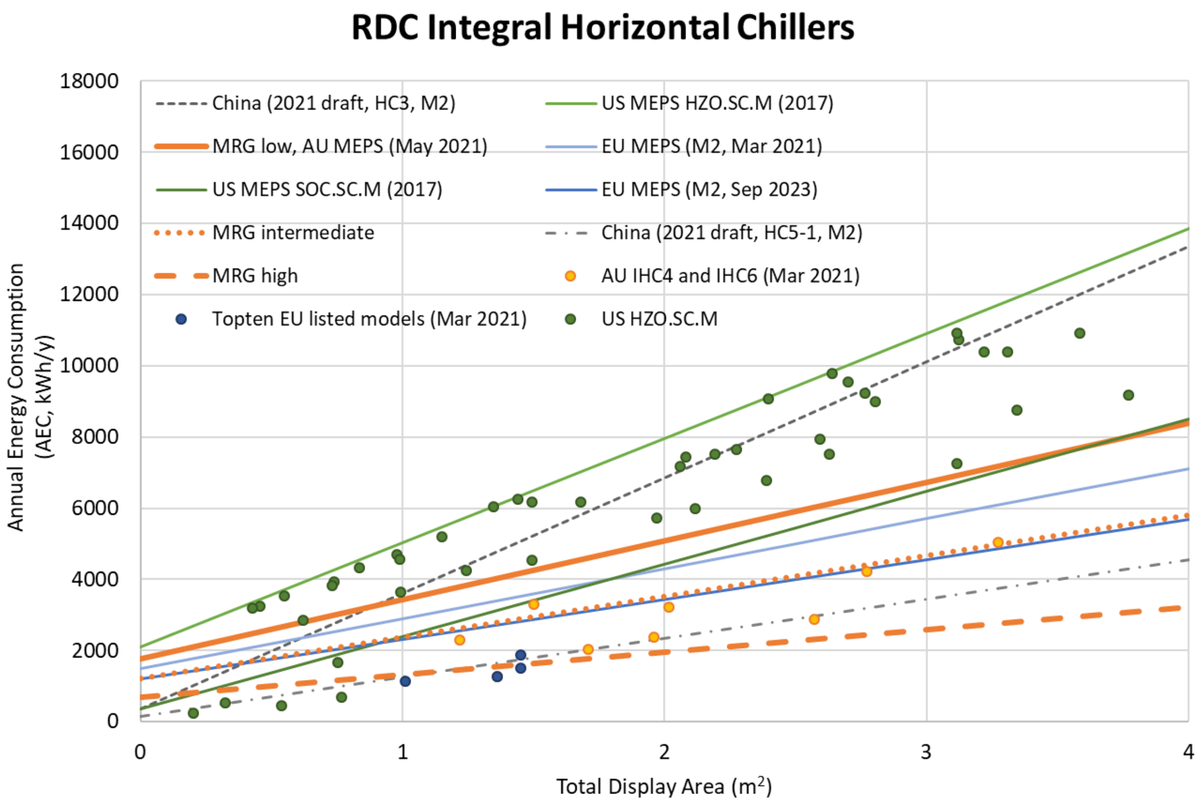
- ANSI/AHRI 1110-2013 Standard for Performance Rating of Mechanical Transport Refrigeration Units

- Transport of Perishable Foodstuffs (ATP Certificate). The UN Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for Such Carriage. https://unece.org/atp-handbook

Off-grid cold storage

- Solar direct-drive refrigerator means a DC-supply refrigerator designed for direct connection with a photovoltaic (PV) panel, generally containing an integrated thermal and/or electric battery to allow autonomous operation during the night.
- Weak-grid refrigerator means a refrigerator designed for intermittent alternating-current power supply, generally containing an integrated thermal and/or electrical battery allowing autonomous operation during periods when power supply is lacking.
- Global Lighting and Energy Access Partnership (Global LEAP) integrated test methods for off-grid refrigerators are based on IEC 62552 (household refrigerating appliances), 62124, and 60335-2-24.
- Other resources for performance evaluation include the following:
  - WHO/PQS/E003/RF05-VP.4: Refrigerator or Combined Refrigerator and Water-Pack Freezer: Solar Direct Drive Without Battery Storage
  - IEC 62124: 2004: Photovoltaic (PV) Stand Alone Systems – Design Verification

Annex D. CRE Energy Consumption and Regional MEPS by Equipment Class



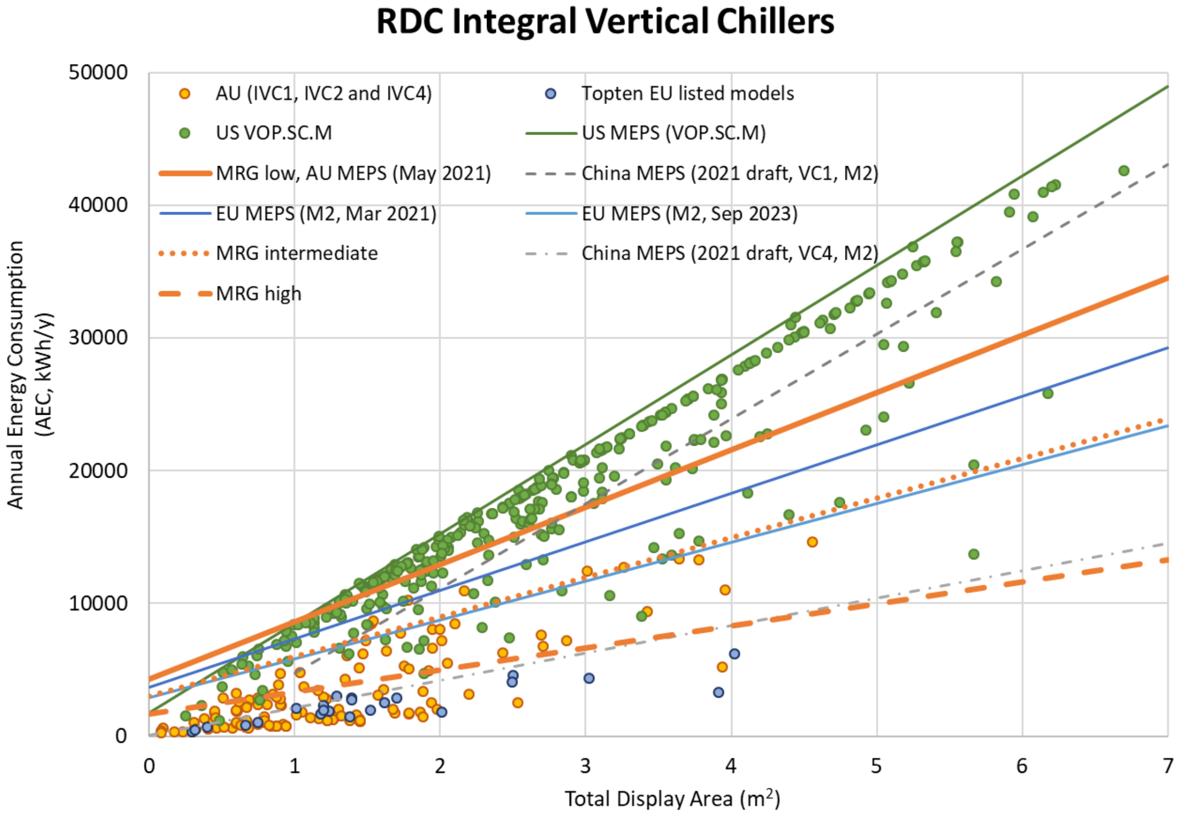
	Number of models	Average TDA	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/TDA	EEI
		m^2	kWh/d	kWh/y	kWh/d/m^2	
AU (IHC4, IHC6)[b]	9	2.04	7.69	2806	3.76	EEI_{AU} 41-101
EU (Topten EU)[c]	4	1.32	3.75	1368	2.85	EEI_{EU} 35-49
U.S. (HZO.SC.M)	45	1.87	16.96[d]	5955	9.09	EEI_{US} 9-100

a. AU and EU data have been adjusted to the M2 condition. U.S. data have been adjusted to ISO 23953 (CC3 and M2).

b. HC4: chilled, open-island; HC6: chilled, glass-lid island.

c. Topten EU lists energy-efficient models.

d. HZO.SC.M: horizontal open, self-contained condensing, medium temperature.



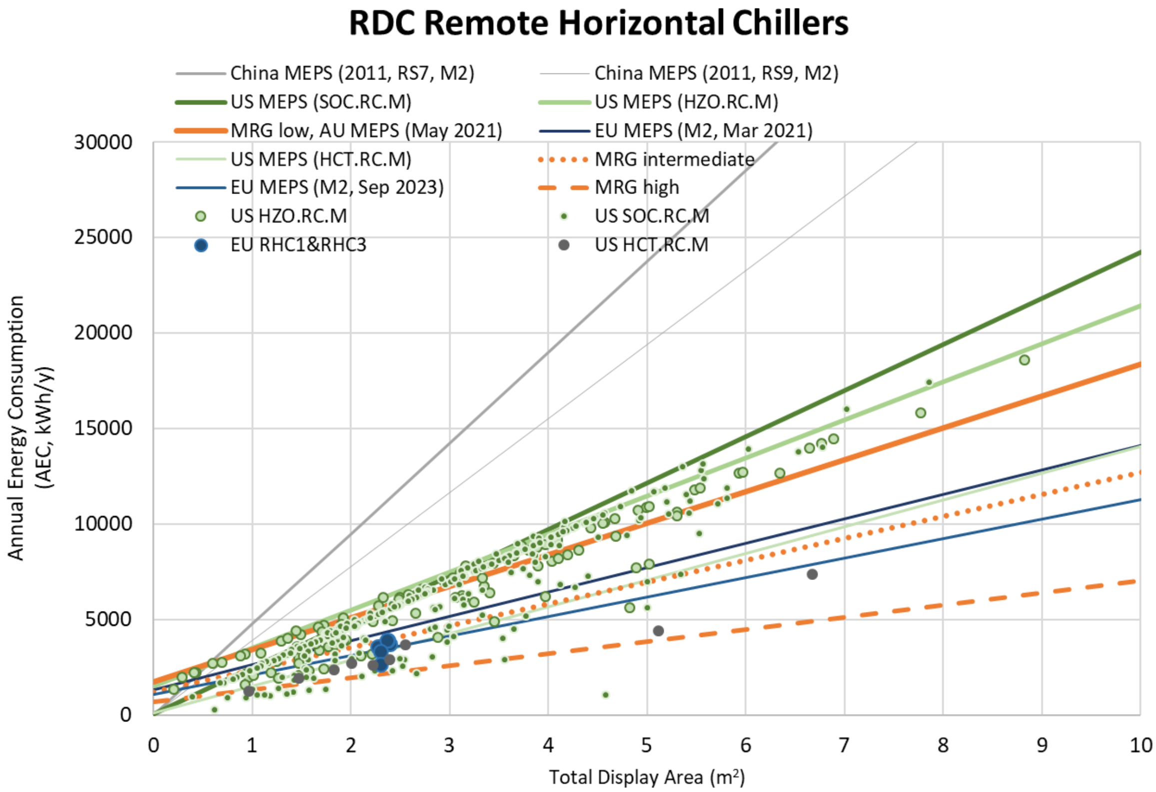
	Number of models	Average TDA	Average TEC$_{adj}$[a]	Average AEC$_{adj}$	Average TEC$_{adj}$/TDA	EEI
		m^2	kWh/d	kWh/y	kWh/d/m^2	
AU (IVC1, IVC2, IVC 4)[b]	129	1.30	9.09	3317	6.97	EEI$_{AU}$ 7-123
EU (Topten EU)[c]	22	1.59	6.04	2204	3.81	EEI$_{EU}$ 6-32
U.S. (VOP.SC.M)[d]	354	2.76	48.86	17833	17.70	EEI$_{US}$ 23-100

a. AU and EU data have been adjusted to the M2 condition. U.S. data have been adjusted to ISO 23953 (CC3 and M2).

b. VC1: chilled, semi-vertical; VC2: chilled, multi-deck; VC4: chilled, glass door.

c. Topten EU lists energy-efficient models.

d. VOP.SC.M: vertical open, self-contained condensing, medium temperature.

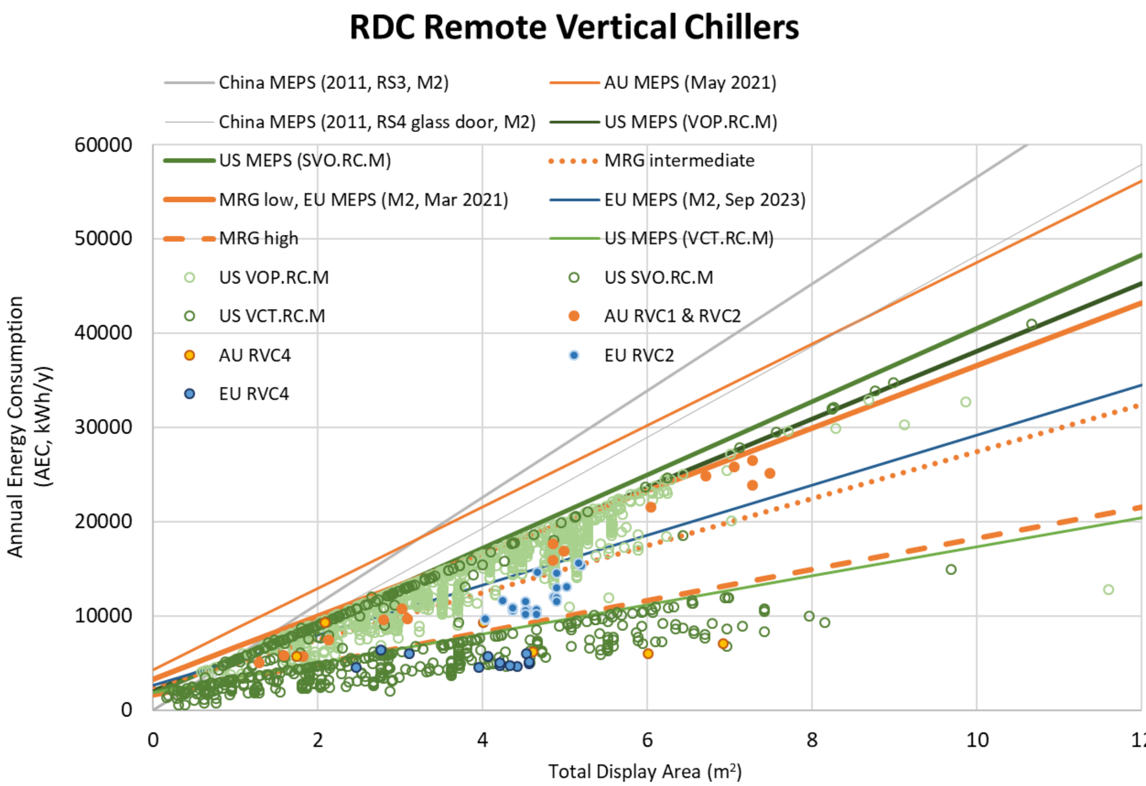


	Number of models	Average TDA	Average TEC$_{adj}$[a]	Average AEC$_{adj}$	Average TEC$_{adj}$/TDA	EEI
		m^2	kWh/d	kWh/y	kWh/d/m^2	
EU (RHC1, RHC3)[b]	8	2.32	12.11	4421	5.2	EEI$_{EU}$ 62-90
U.S. (HZO.RC.M)[c]	106	3.07	17.58	6416	5.7	EEI$_{US}$ 47-100
U.S. (SOC.RC.M)[c]	310	2.73	15.77	5757	5.8	EEI$_{US}$ 9-100
U.S. (HCT.RC.M)[c]	9	2.80	8.90	3250	3.2	EEI$_{US}$ 61-100

a. EU data have been adjusted to the M2 condition. U.S. data have been adjusted to ISO 23953 (CC3 and M2).

b. HC1: chilled, serve-over counter open service access; HC3: chilled, open, wall site.

c. HZO.RC.M: horizontal open, remote condensing, medium temperature; SOC.RC.M: service over counter, remote condensing, medium temperature; HCT.RC.M: horizontal closed transparent, remote condensing, medium temperature.

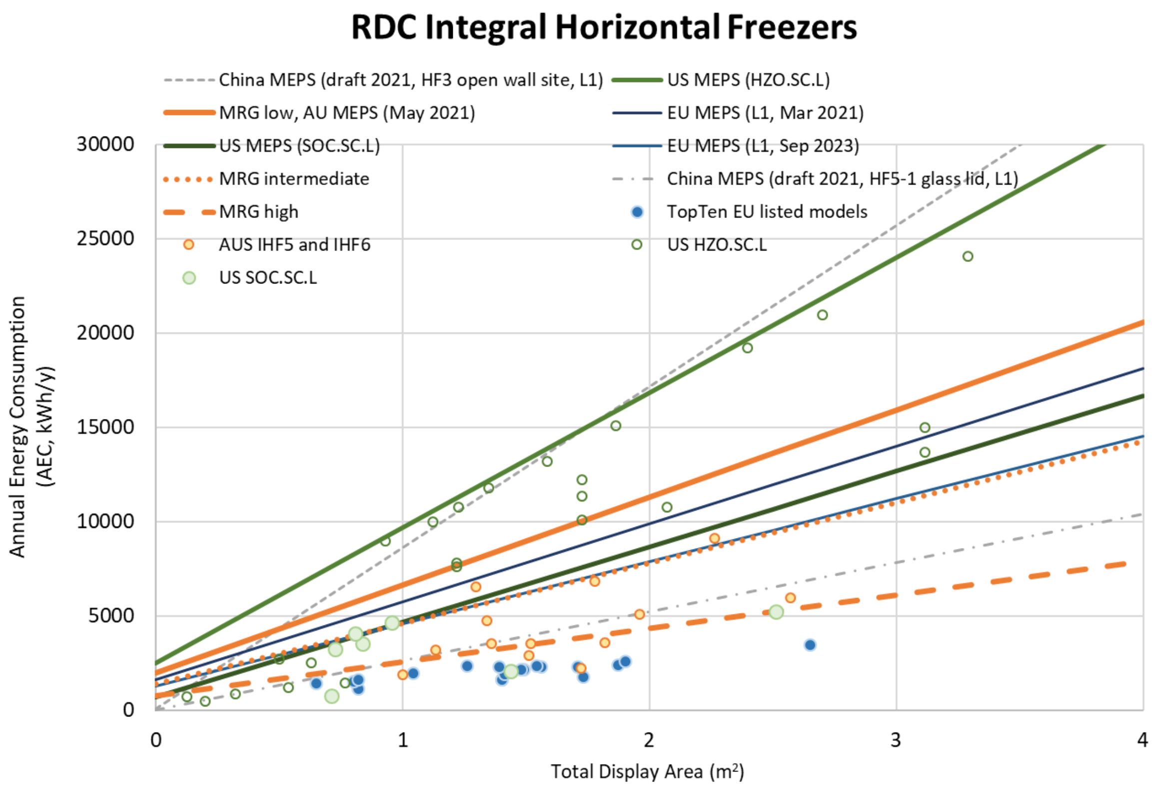


	Number of models	Average TDA	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/TDA	EEI
		m^2	kWh/d	kWh/y	kWh/d/m^2	
AU (RVC2)[b]	5	5.85	51.12	18659	8.7	EEI_{AU} 81-97
EU (RVC2)[b]	19	4.58	31.14	11367	6.8	EEI_{EU} 55-66
U.S. (VOP.RC.M)[c]	923	3.60	30.18	13320	7.4	EEI_{US} 24-100
U.S. (SVO.RC.M)[c]	881	3.38	36.39	13281	10.8	EEI_{US} 32-100
AU (RVC4)[b]	6	4.23	19.08	6966	4.5	EEI_{AU} 37-78
EU (RVC4)[b]	13	3.99	21.51	7850	5.4	EEI_{EU} 36-71
U.S. (VCT.RC.M)[c]	360	3.08	13.87	5064	4.5	EEI_{US} 24-100

a. AU and EU data have been adjusted to the M2 condition. U.S. data have been adjusted to ISO 23953 (CC3 and M2).

b. VC2: chilled, multi-deck; VC4: chilled, glass door.

c. VOP.RC.M: vertical open, remote condensing, medium temperature; SVO.RC.M: semi-vertical open, remote condensing, medium temperature; VCT.RC.M: vertical closed transparent, remote condensing, medium temperature.



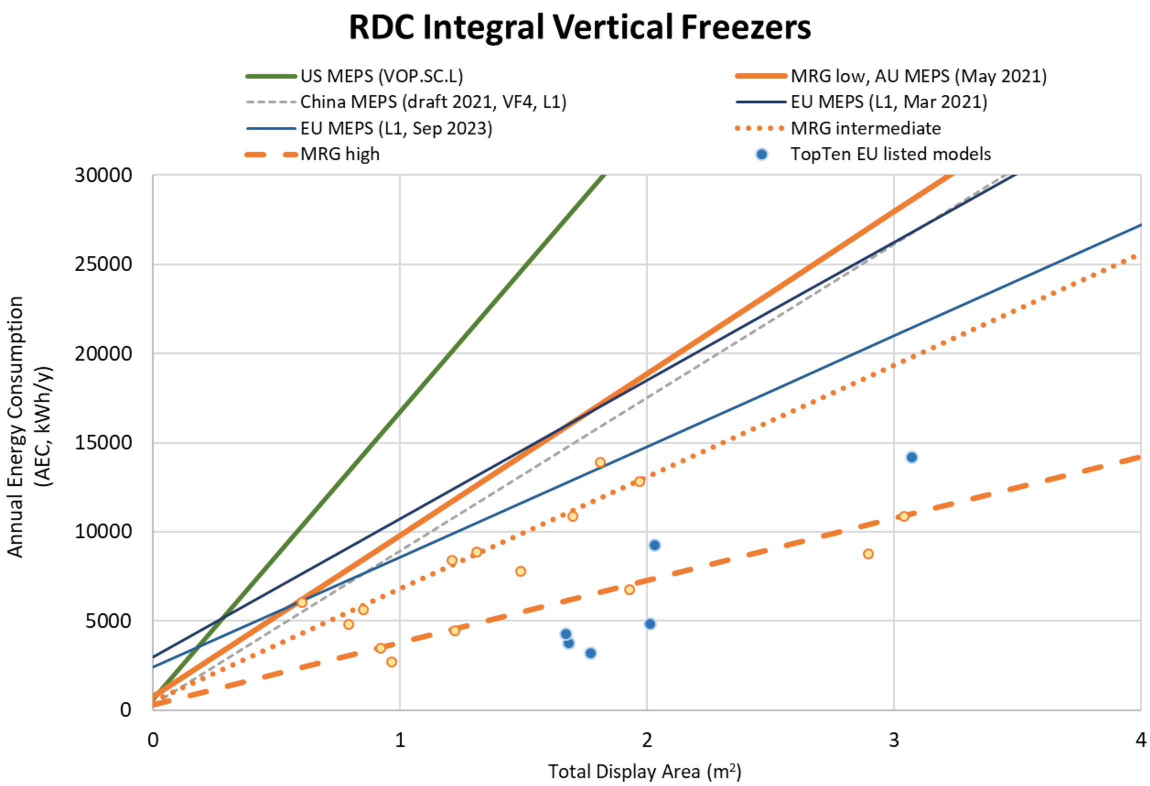
	Number of models	Average TDA	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/TDA	EEI
		m^2	kWh/d	kWh/y	kWh/d/m^2	
AU (IHF5, IHF6)[b]	13	1.64	12.48	4555	7.6	EEI_{AU} 29-106
EU (Topten)[c]	19	1.42	5.67	2071	4.0	EEI_{EU} 21-35
U.S. (HZO.SC.L)[d]	27	1.83	33.95	12393	18.6	EEI_{US} 13-98
U.S. (SOC.SC.L)[d]	7	1.14	8.52	3111	7.5	EEI_{US} 20-95

a. AU and EU data have been adjusted to the L1 condition. U.S. data have been adjusted to ISO 23953 (CC3 and L1).

b. HF5: frozen, glass lid, wall site; HF6: frozen, glass lid, island

c. Topten EU lists energy-efficient models.

d. HZO.SC.L: horizontal open, self-contained condensing, low temperature; SOC.SC.L: service over counter, self-contained condensing, low temperature.

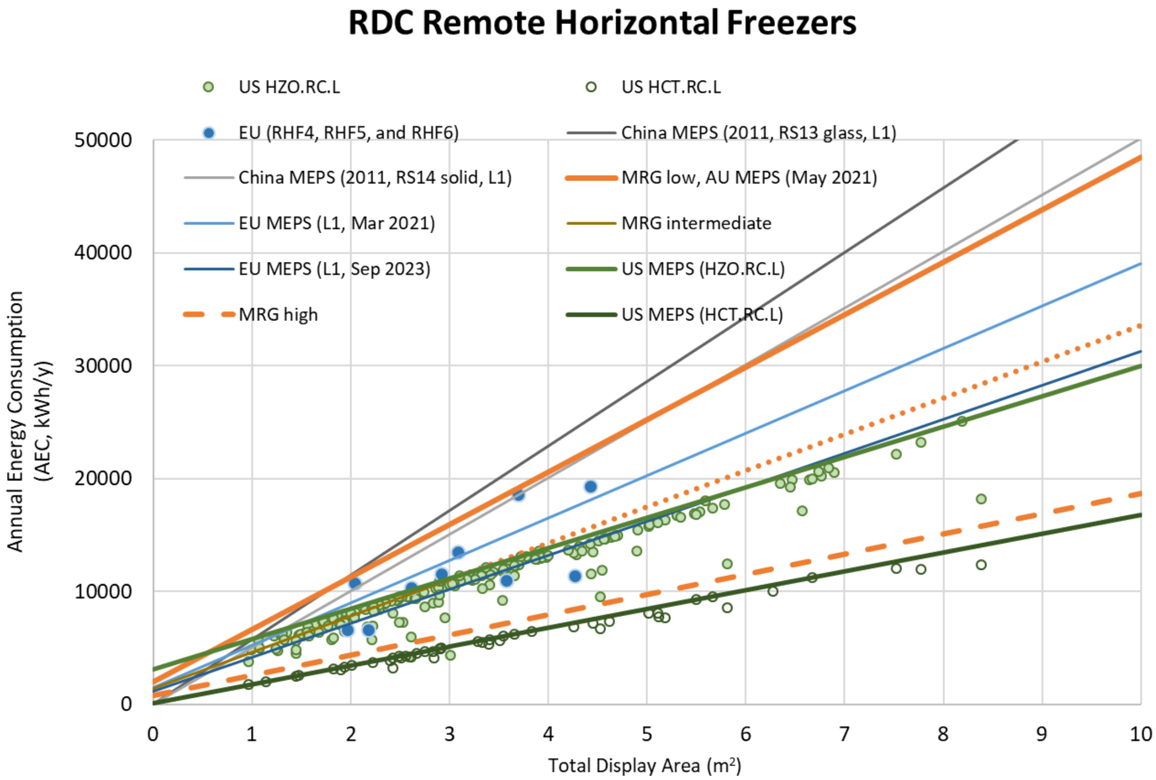


	Number of models	Average TDA	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/TDA	EEI
		m^2	kWh/d	kWh/y	$kWh/d/m^2$	
AU (IVF4)[b]	15	1.51	21.26	7758	14.0	EEI_{AU} 38-127
EU (Topten)[c]	6	2.04	18.14	6621	8.9	EEI_{EU} 19-53

a. AU and EU data have been adjusted to the L1 condition. U.S. data have been adjusted to ISO 23953 (CC3 and L1).

b. VF4: frozen, glass door

c. Topten EU lists energy-efficient models.



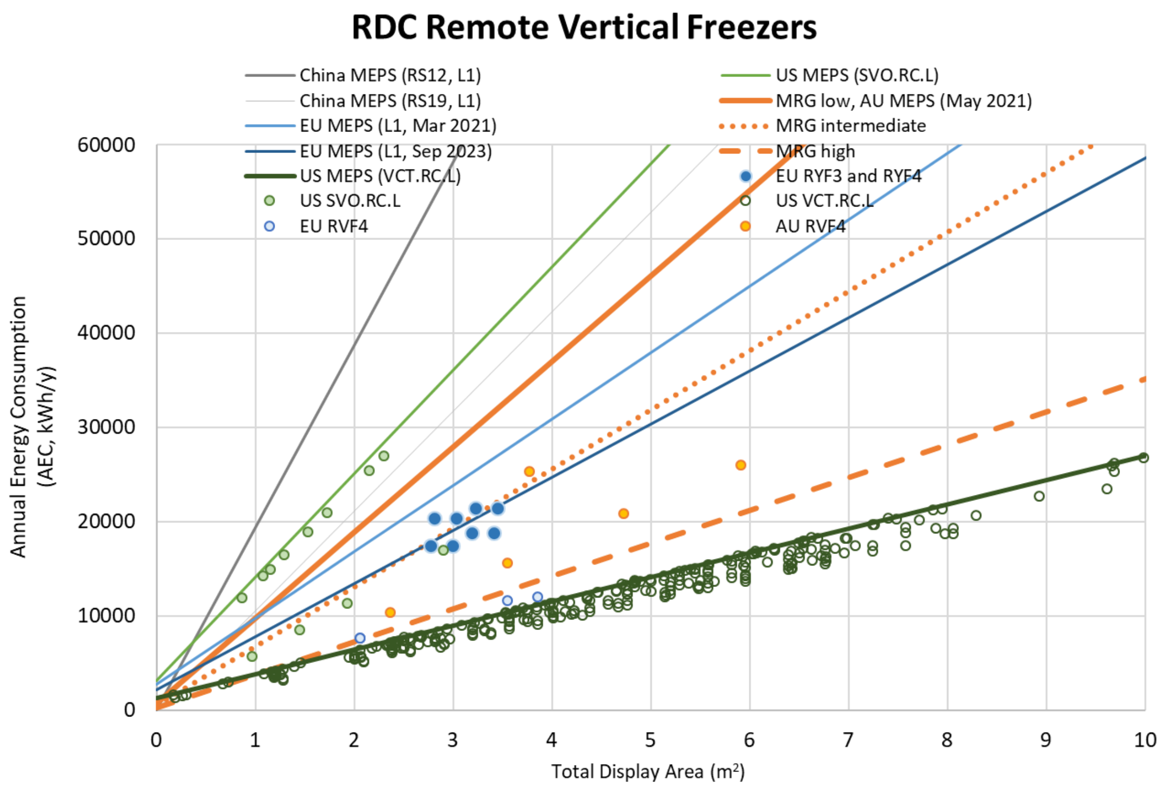
	Number of models	Average TDA	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/TDA	EEI
		m^2	kWh/d	kWh/y	kWh/d/m^2	
EU (RHF3, RHF4, RHF5, RHF6)[b]	10	3.07	32.80	11970	10.7	EEI_{EU} 67-116
U.S. (HZO.RC.L)[c]	174	3.32	29.92	10923	9.0	EEI_{US} 39-100
U.S. (HCT.RC.L)[c]	47	3.66	16.18	5906	4.4	EEI_{US} 77-100

a. AU and EU data have been adjusted to the L1 condition. U.S. data have been adjusted to ISO 23953 (CC3 and L1).

b. HF3: frozen, open, wall site; HF4: frozen, open, island; HF5: frozen, glass lid, wall site; HF6: frozen, glass lid, island

c. Topten EU lists energy-efficient models.

d. HZO.RC.L: horizontal open, remote condensing, low temperature; HCT.RC.L: horizontal closed transparent, remote condensing, low temperature.

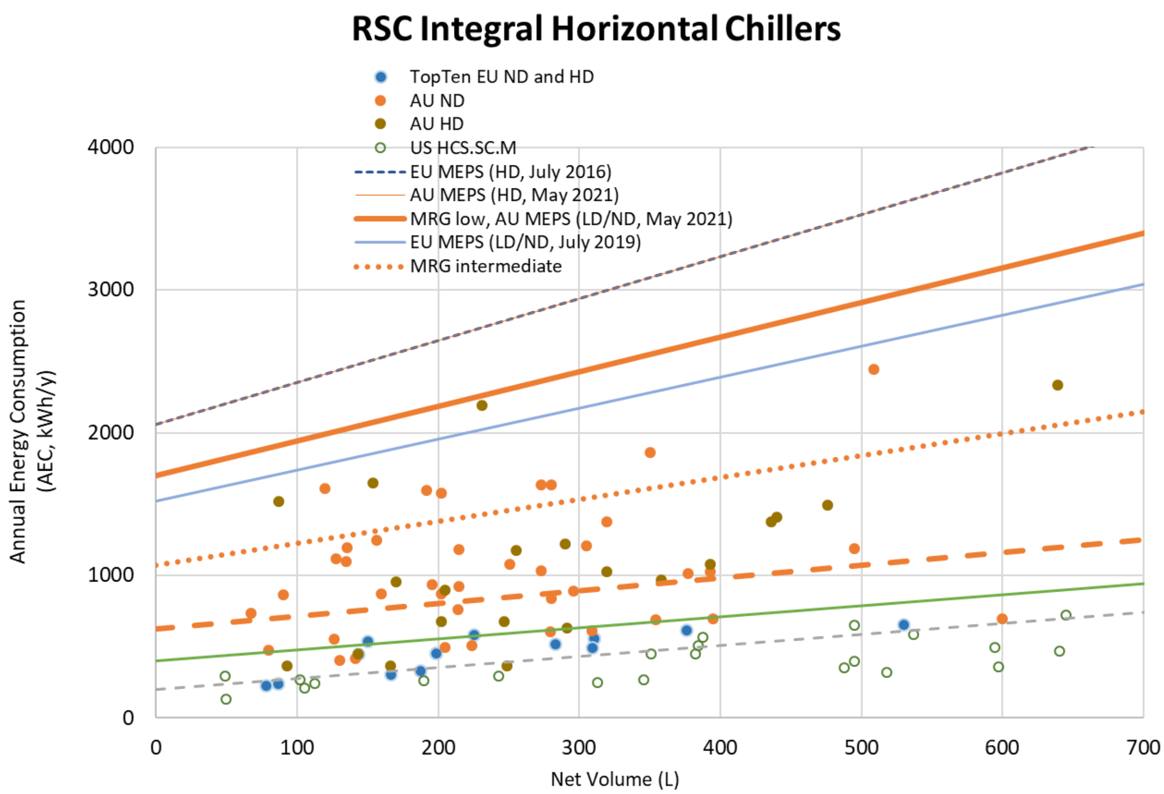


	Number of models	Average TDA	Average TEC$_{adj}$[a]	Average AEC$_{adj}$	Average TEC$_{adj}$/TDA	EEI
		m^2	kWh/d	kWh/y	kWh/d/m^2	
AU (RVF4)[b]	8	3.11	53.47	19517	17.2	EEI$_{AU}$ 36-94
EU (RVF4)[b]	4	2.88	26.80	9783	9.3	EEI$_{EU}$ 40-45
EU (RYF3, RYF4)[b]	6	5.59	59.92	21872	10.7	EEI$_{EU}$ 78-101
U.S. (SVO.RC.L)[c]	12	1.61	43.94	16039	27.3	EEI$_{US}$ 41-95
U.S. (VCT.RC.L)[c]	284	4.82	34.74	12681	7.2	EEI$_{US}$ 71-100

a. AU and EU data have been adjusted to the L1 condition. U.S. data have been adjusted to ISO 23953 (CC3 and L1).

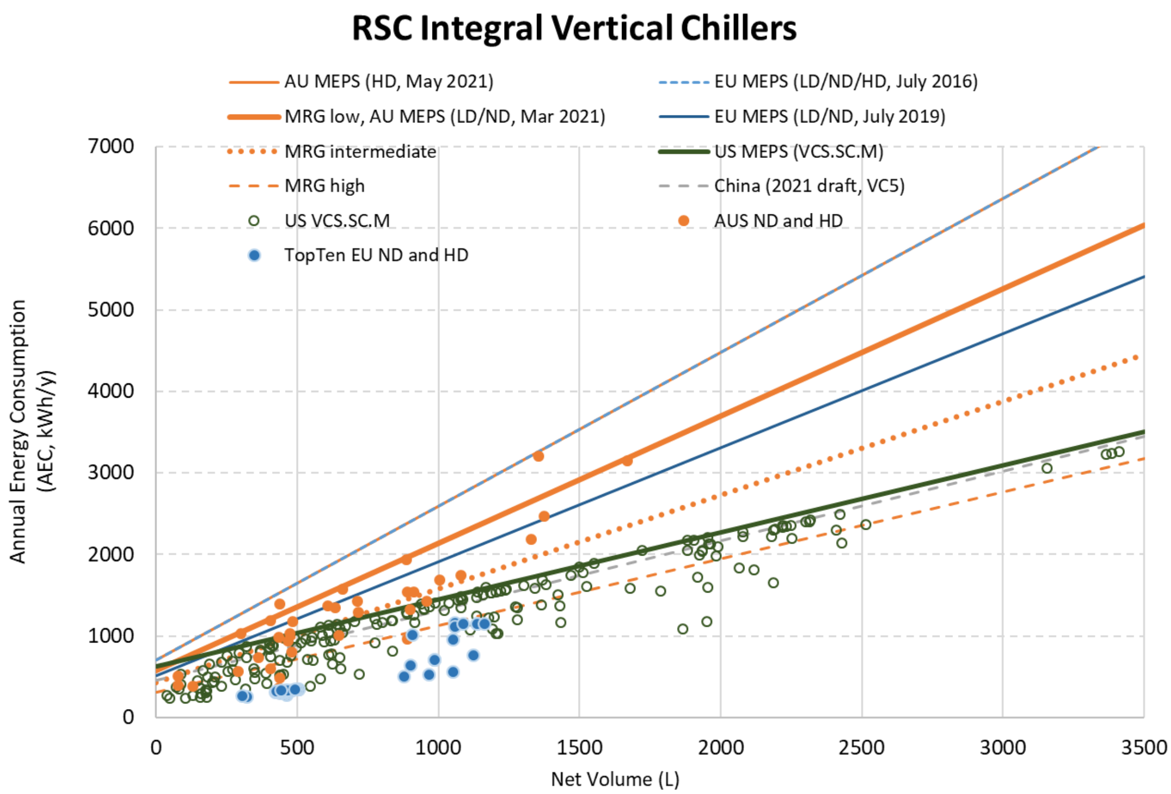
b. VF4: frozen, glass door; YF3: frozen, glass door top, open bottom; YF4: frozen, glass door top, glass lid bottom

c. SVO.RC.L: semi-vertical open, remote condensing, low temperature; VCT.RC.L: vertical closed transparent, remote condensing, low temperature.



	Number of models	Average Net Volume	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/Net Volume	EEI
		L	kWh/d	kWh/y	kWh/d/m^3	
AU (ND/HD)[b]	59	259	2.87	1046	11.0	EEI_{AU} 15-92
EU (Topten, ND/HD)[c]	16	227	1.24	453	5.5	EEI_{EU} 11-25
U.S. (HCS.SC.M)[d]	25	416	1.42	517	3.4	EEI_{US} 37-100

a. U.S. data have been estimated for ISO 22041 (CC4 and M1).
b. ND: normal duty; HD; heavy duty
c. Topten EU lists energy-efficient models
d. HCS.SC.M: horizontal closed solid, self-contained condensing, medium temperature.



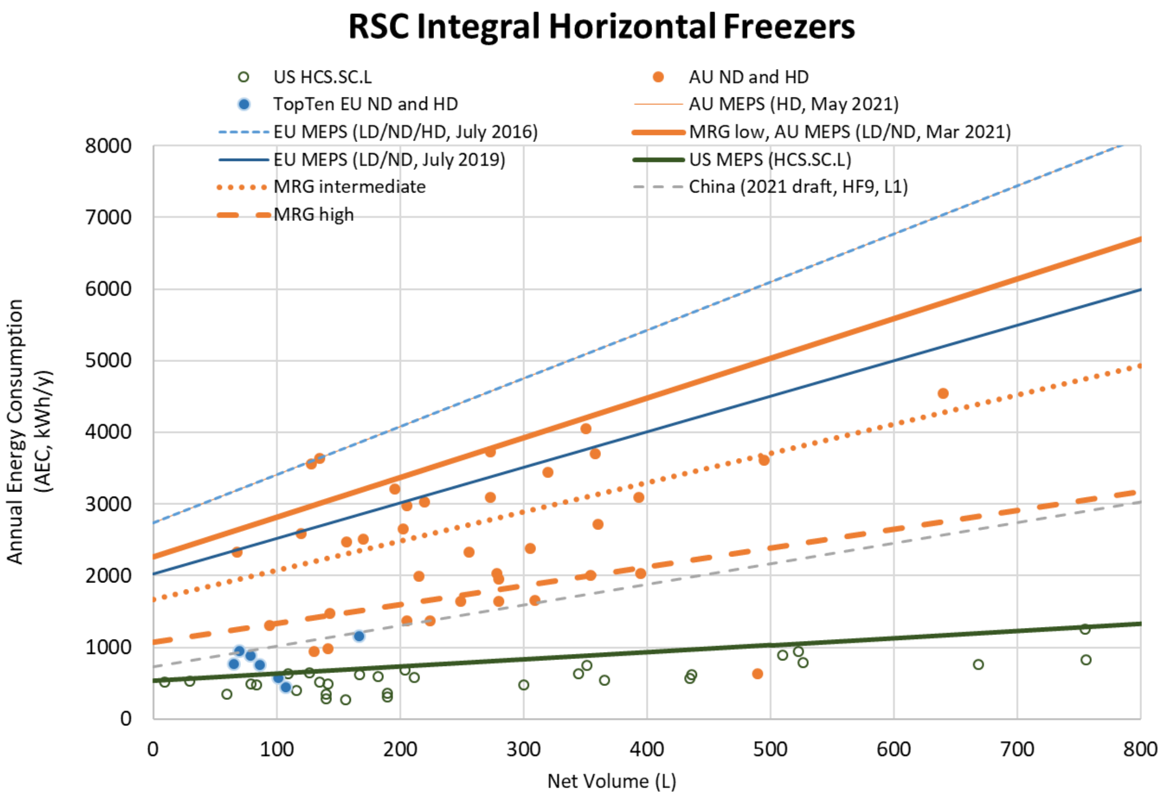
	Number of models	Average Net Volume	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/Net Volume	EEI
		L	kWh/d	kWh/y	kWh/d/m^3	
AU (ND/HD)[b]	34	674	3.52	1286	5.2	EEI_{AU} 28-113
EU (Topten, ND/HD)[c]	37	683	1.51	552	2.2	EEI_{EU} 21-50
U.S. (VCS.SC.M)[d]	180	1046	3.40	1241	3.3	EEI_{US} 32-100

a. U.S. data have been estimated for ISO 22041 (CC4 and M1).

b. ND: normal duty; HD; heavy duty

c. Topten EU lists energy-efficient models

d. VCS.SC.M: vertical closed solid, self-contained condensing, medium temperature.



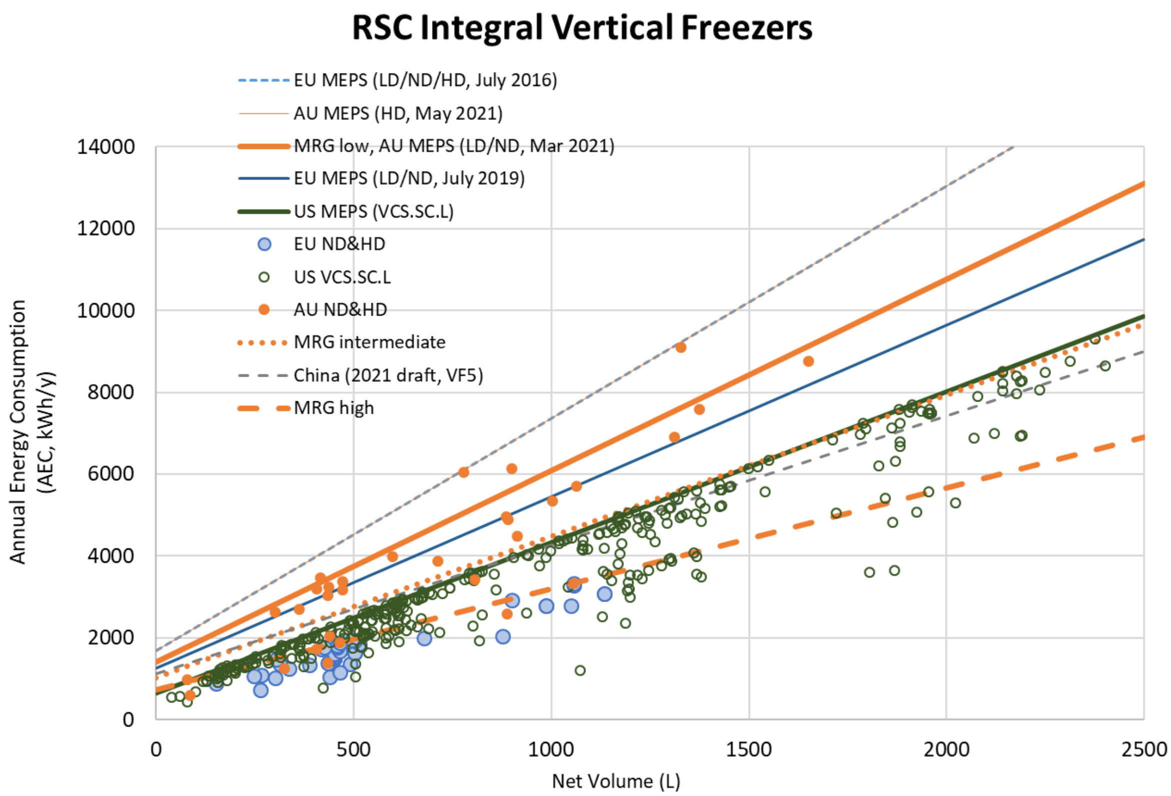
	Number of models	Average Net Volume	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/Net Volume	EEI
		L	kWh/d	kWh/y	kWh/d/m^3	
AU (ND/HD)[b]	37	259	6.65	2428	25.7	EEI_{AU} 12-115
EU (Topten, ND/HD)[c]	7	96	2.18	797	22.8	EEI_{EU} 15-35
U.S. (HCS.SC.L)[d]	32	295	1.67	611	5.7	EEI_{US} 39-99

a. U.S. data have been estimated for ISO 22041 (CC4 and L1).

b. ND: normal duty; HD; heavy duty

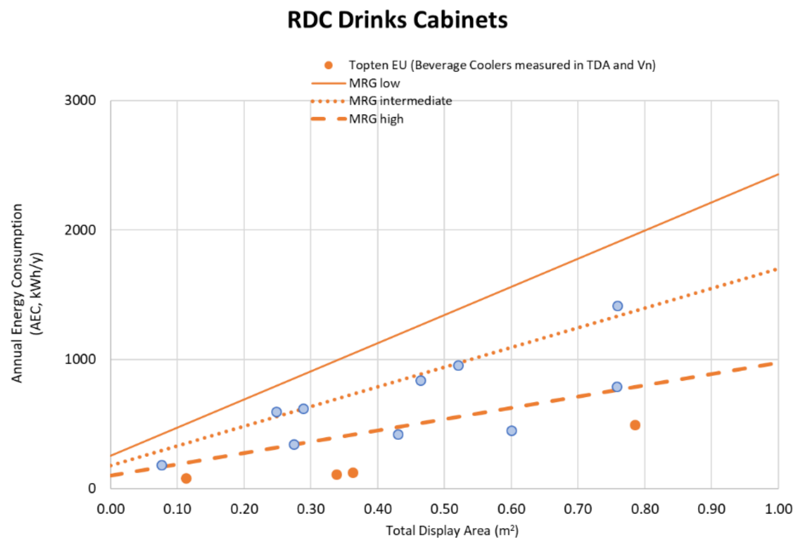
c. Topten EU lists energy-efficient models

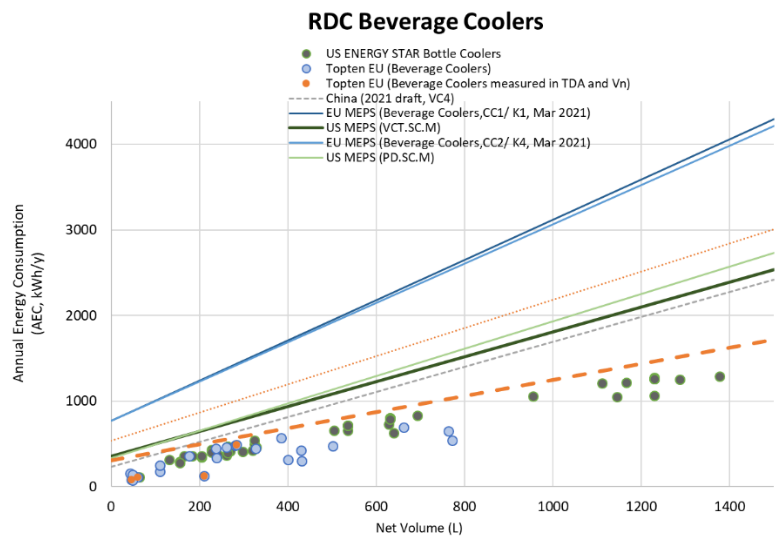
d. HCS.SC.L: horizontal closed solid, self-contained condensing, low temperature.



	Number of models	Average Net Volume	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/Net Volume	EEI
		L	kWh/d	kWh/y	kWh/d/m^3	
AU (ND/HD)[b]	34	693	10.72	3912	15.5	EEI_{AU} 31-114
EU (Topten, ND/HD)[c]	38	573	5.09	1859	8.9	EEI_{EU} 29-50
U.S. (VCS.SC.L)[d]	616	928	9.74	3557	10.5	EEI_{US} 26-100

a. U.S. data have been estimated for ISO 22041 (CC4 and L1).
b. ND: normal duty; HD; heavy duty
c. Topten EU lists energy-efficient models
d. VCS.SC.L: vertical closed solid, self-contained condensing, low temperature.





Note that the Guidelines energy requirements are based on TDA. The requirements on this chart are based on authors' assumptions.

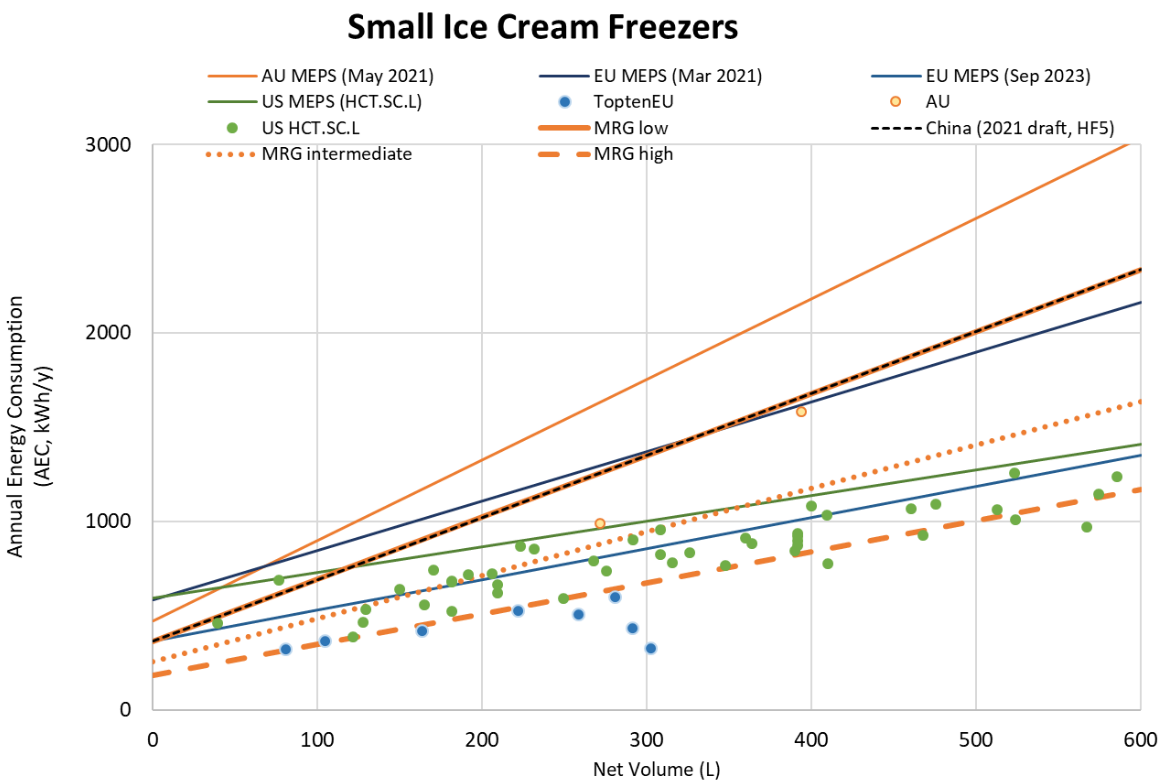
	Number of models	Average TDA	Average Net Volume	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/TDA	Average TEC_{adj}/Net Volume	EEI
		m^2	L	kWh/d	kWh/y	$kWh/d/m^2$	$kWh/d/m^3$	
AU (drinks cabinets)[b]	14	0.48	-	1.88	687	3.94	-	EEI_{AU} 9-78
EU (Topten, beverage coolers)[c]	23	-	297	0.97	353	-	3.26	EEI_{EU} 9-32
U.S. (VCT.SC.M)[d]	49	-	566	2.11	771	-	3.73	EEI_{US} 29-74

a. U.S. data have been estimated for ISO 23953 (CC3 and M2).

b. Energy consumption requirements are based on TDA in accordance with ISO 23953.

c. Topten EU lists energy-efficient models.

d. VCT.SC.M: vertical closed transparent, self-contained condensing, medium temperature.

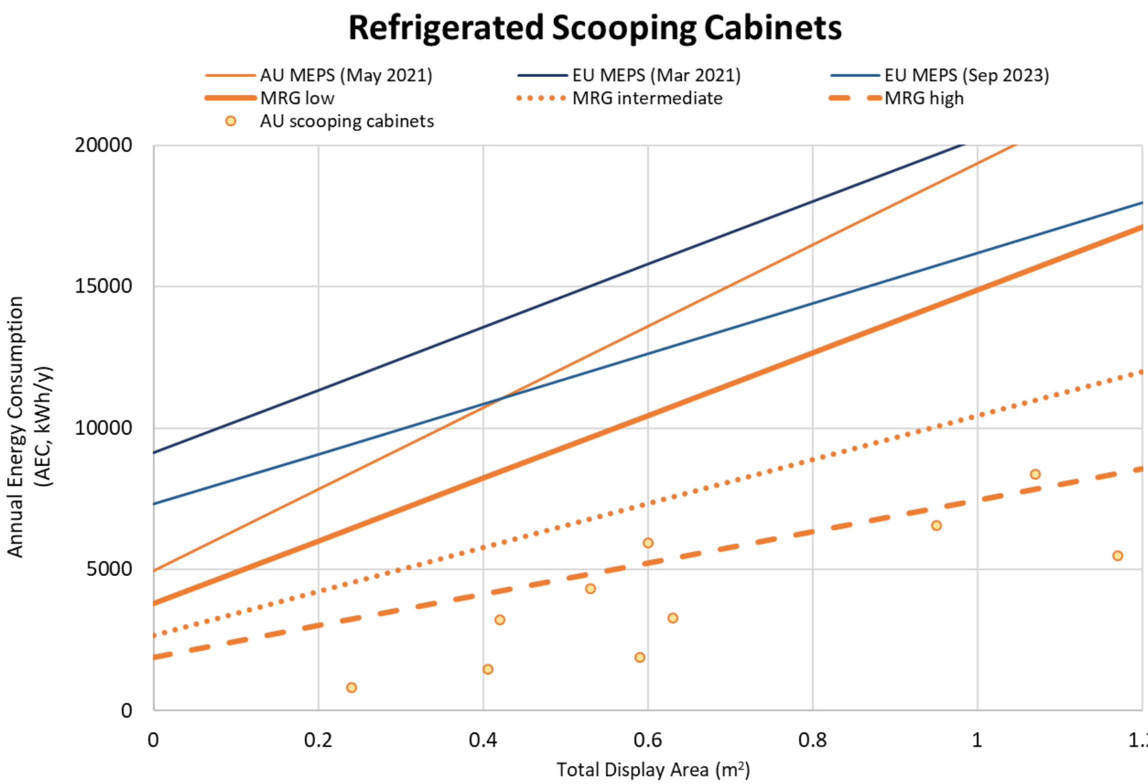


	Number of models	Average Net Volume	Average TEC_{adj}[a]	Average AEC_{adj}	Average TEC_{adj}/Net Volume	EEI
		L	kWh/d	kWh/y	kWh/d/m³	
AU	2	333	3.52	1285	10.6	EEI_{AU} 79-95
EU (Topten)[b]	8	213	1.21	440	5.7	EEI_{EU} 19-35
U.S. (HCT.SC.L)[c]	45	313	2.25	820	7.2	EEI_{US} 51-99

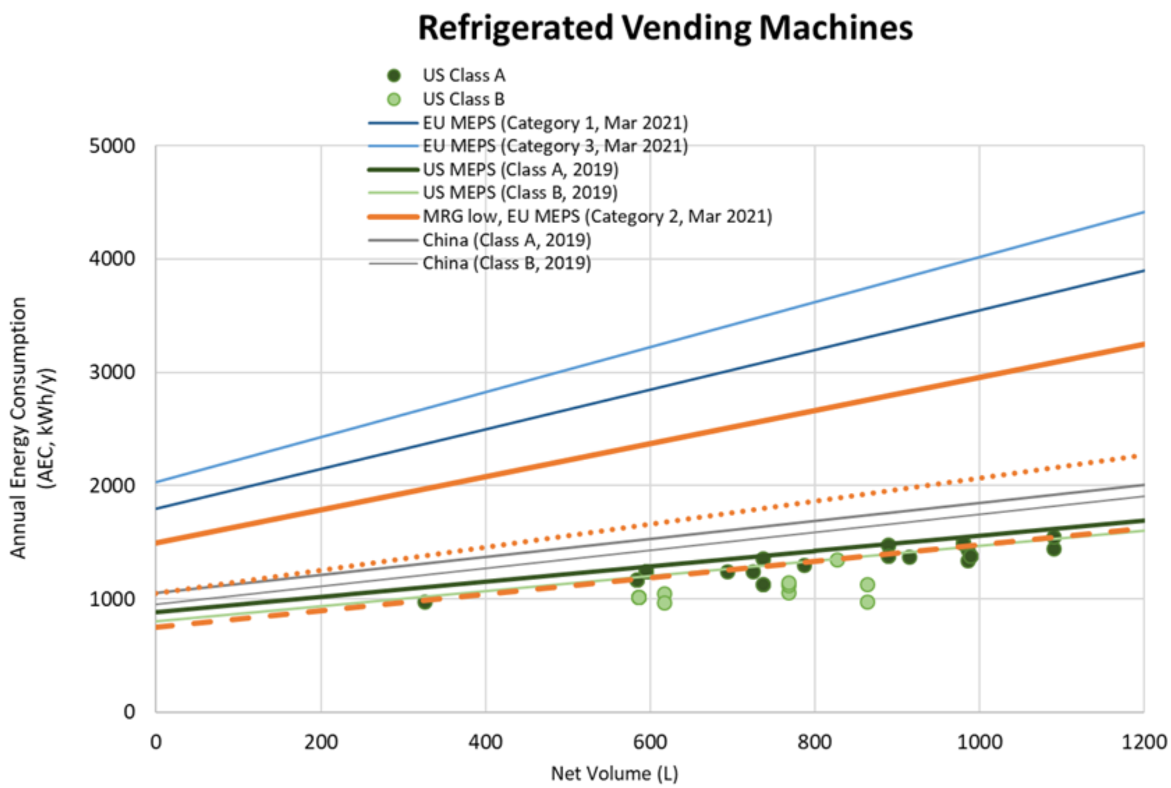
a. U.S. data have been estimated for ISO 22043 CC A (max) and package temperature C1.

b. Topten EU lists energy-efficient models.

c. HCT.SC.L: horizontal closed transparent, self-contained condensing, low temperature.



	Number of models	Average TDA	Average TEC	Average AEC	Average TEC/TDA	EEI
		m^2	kWh/d	kWh/y	$kWh/d/m^2$	
AU	10	0.66	11.33	4134	17.17	EEI_{AU} 13-57



	Number of models	Average Net Volume	Average TEC	Average AEC	Average TEC/Net Volume	EEI
		L	kWh/d	kWh/y	kWh/d/m^3	
U.S. Class A	33	809	3.65	1332	4.5	EEI$_{US}$ 9-75
U.S. Class B	13	694	2.93	1070	4.2	EEI$_{US}$ 68-98