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International review of market trends, technologies and policies for commercial refrigeration equipment and implications for China

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List of Acronyms and Abbreviations

AEC	annual energy consumption
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAT	Best Available Technologies
BC	beverage cooler
CAGR	compound annual growth rate
CRE	commercial refrigeration equipment
ECM	electronically commutated fan motors
EEV	electronic expansion valve
EEI	energy efficiency index
EPA	Environmental Protection Agency
ETA	Emerging Technology Award
EU	European Union
GWP	global warming potential
HC	hydrocarbon
HFC	hydrofluorocarbon
HFO	hydrofluro-olefins
ICF	ice cream freezer
IHC	integral horizontal chiller
IHF	integral horizontal freezer
IVC	integral vertical chiller
IVF	integral vertical freezer
ISO	International Organization for Standardization
LED	light-emitting diode
MEPS	minimum energy performance standard
PSC	permanent split capacity
RAEC	reference annual energy consumption
RDC	refrigerated display cabinets
RHC	remote horizontal chiller
RHF	remote horizontal freezer
RSC	refrigerated storage cabinets
RVC	remote vertical chiller
RVF	remote vertical freezer
SAEC	standard annual energy consumption
SNAP	Significant New Alternatives Policy
TDA	total display area
TEC	total energy consumption
VIP	vacuum insulation panel
YoY	year-on-year

1. Introduction

Globally, commercial refrigeration equipment is a key end-user of electricity and greenhouse gas emitter, responsible for the second highest emissions impact among residential and commercial cooling and refrigeration products after stationary air-conditioning (Shah et al. 2019). The Asia-Pacific region is a key market for commercial refrigeration equipment, and the market for products such as refrigerated display cases is expected to continue growing rapidly in the coming years (Global Newswire, 2022). Within Asia, China is the primary producer and consumer of refrigerated display cases. For example, China's total sales of refrigerated display cases with remote condensing units have increased quickly from 94,000 units in 2015 to 120,000 units in 2020. In 2020, China exported 20,000 units while domestic consumption accounted for 100,000 units (China IOL 2022).

A number of countries have adopted minimum energy performance standards (MEPS) and labeling programs to promote the market adoption of more efficient commercial refrigeration equipment, including refrigerated display cases. While the European Union and Australia and New Zealand recently revised their MEPS for commercial refrigeration equipment in 2019 and 2020, respectively, the U.S. and China last revised their MEPS during the early to mid-2010s. China, in particular, last revised its MEPS for refrigerated display cases in 2011 for equipment with remote condensing units and 2015 for self-contained condensing units. China also has a separate MEPS for refrigerated vending machines that was adopted in 2019.

Previous market surveys have found China's refrigerated display cases consume more energy on a per-unit basis than other countries, and a recent analysis identified refrigerated cabinets with integral[1] condensing units as having the third largest energy savings potential among key cooling products (Waide et al. 2014, EFC 2021). Beyond higher international market efficiency levels, there is significant additional potential to increase the efficiency of self-contained or integral condensing refrigerated display cases and remote condensing refrigerated display cases if today's best available technologies are increasingly adopted. Understanding the global market for commercial refrigeration equipment, including refrigerated display cases as a key product type, and the existing efficiency trends can help inform the revisions of China's MEPS for both integral and remote condensing units.

This report reviews the latest global and China-specific market trends as well as latest technology and policy trends related to commercial refrigeration equipment, with emphasis on refrigerated display cabinets. Section 2 reviews the global and China market trends for commercial refrigeration equipment. Section 3 presents the latest technology options for improving energy performance and compares global Best Available Technologies (BAT) to regional and China-specific baselines, and discusses low-GWP refrigerant options for commercial refrigeration equipment. Section 4 reviews global energy efficiency standards and labeling programs, and compares international efficiency standard requirements with China's proposed and existing standard requirements. Section 5 ends with a review of key findings and conclusions.

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[1] Integral condensing units are also known as self-contained condensing units, and both terms are used interchangeably throughout the report.

2. Market trends assessment

2.1 Global

Commercial refrigeration is assessed to account for about 65% of the global refrigeration market by market value or revenue (JARN, 2021). In 2010, about 120 million commercial refrigeration equipment (CRE)[2] units—including supermarket systems, standalone equipment, condensing units, etc.—were in operation globally (IIR 2019). Among various CRE types, refrigerated display cabinets (RDCs), which store and display chilled or frozen items in a retail environment for easy access by consumers, account for about half of the global CRE market by market value or revenue (Figure 1). North America is the largest market in the world, with a market value of US$ 14 billion, followed by approx. US$ 12 billion of Asia (where China and India lead in growth) and approx. US$ 10 billion of Europe (Figure 2).

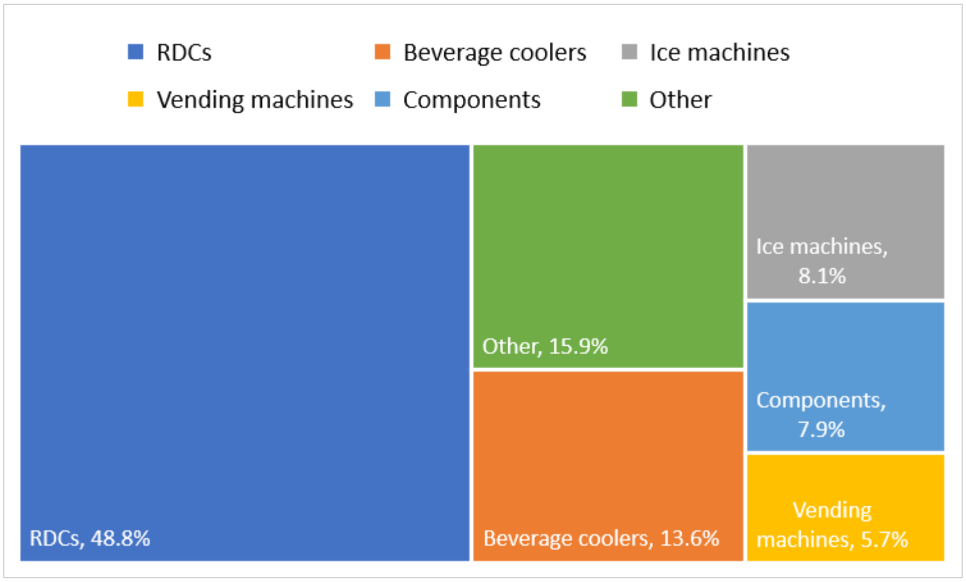


Figure 1. Global CRE market by product type, by market value
Source: JARN (2021), Total USD 43.3 billion

[2] CRE refers generally to non-household refrigeration equipment used in the retail and food service sectors for storage or display of foodstuffs.

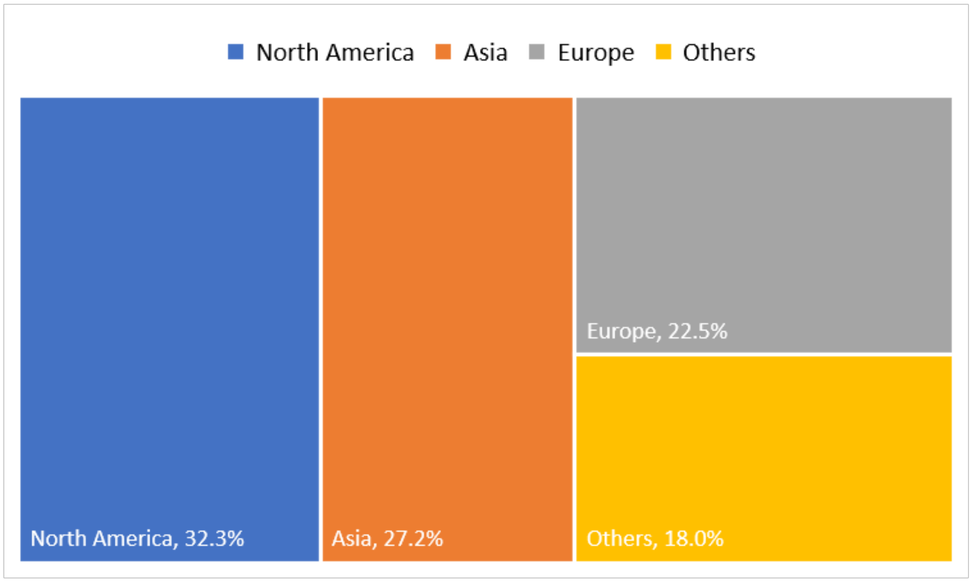


Figure 2. Global CRE market by region, by market value
Source: JARN (2021)

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. CRE products with low GWP[3] refrigerants are commercially available in these markets (Park et al. 2021b).

In Australia and New Zealand, most refrigerated cabinets[4] 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 (DEE 2017). 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 India, sales of deep (or instant) 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 (CLASP and PwC 2020). Estimated annual sales of deep freezers vary by source and definition, from about 390,000 units (2017–2018) to 488,000 units (2019–2020) (AEEE 2021), and from 500,000–600,000 units (2017–2018) to 848,000 units (2019–2020), with chest types accounting for approximately 99% (CLASP and PwC 2020). 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 about 200,000 units (AEEE 2021, JARN 2020).

2.2 China

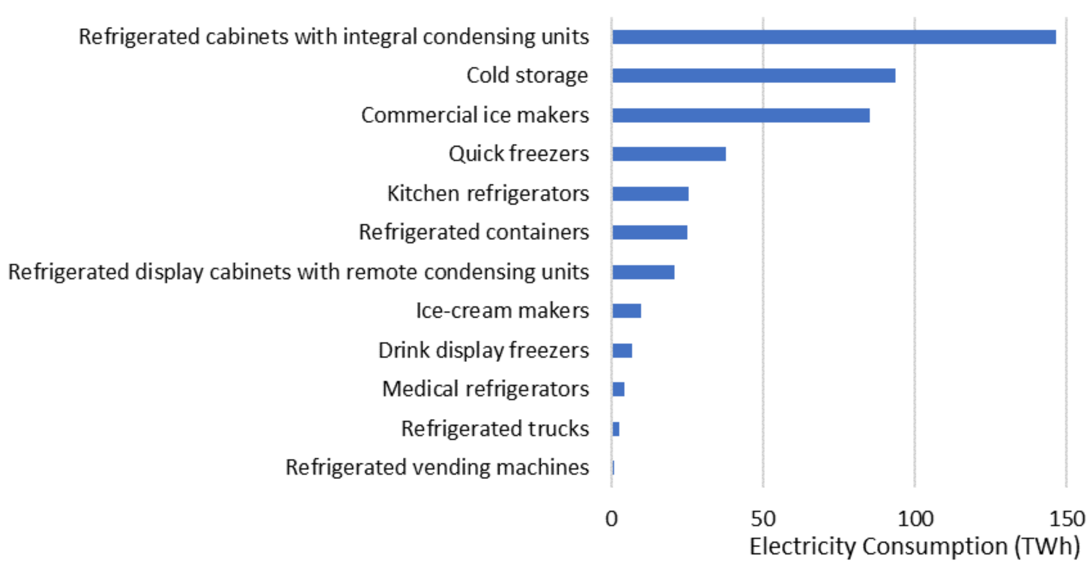
[3] GWP is a measure of how much heat a greenhouse gas traps in the atmosphere up to a specific time horizon, relative to an equal mass of carbon dioxide (CO_2) in the atmosphere.
[4] Refer to a device that consists of an insulated cabinet with an opening (whether or not the opening has a lid or a door), is capable of attaining and maintaining a specified temperature within the insulated cabinet within a range that overlaps the range -18°C to +10°C, and is designed primarily for storage, display, or both storage and display of chilled or frozen foodstuffs (Park et al. 2021a).

In China, the CRE market is growing at an annual rate of 5%–30%, varying by type even during the COVID situation, led by several manufacturers[5], along with the rapid development of supermarkets and convenience stores (JARN 2021, Park et al. 2021b).

In 2020, the total sales of various CRE types were expected to have reached 11.61 million units, a year-on-year (YoY) growth rate of 2.0% (JARN 2021). Estimated annual production or sales of RDCs vary by source and definition, from 460,000 units (2020) (JARN 2021) to about 2 million units, with beverage RDCs making up 1.9 million of the 2 million units (2018) (ICA 2021). The estimated annual production or sales of refrigerated storage cabinets (RSCs) are about 1.87 million units (2018) (ICA 2021). China becomes the fastest-growing market in the world's instant-frozen food industry with an average compound annual growth rate (CAGR) of 20-30% and reached 139.3 billion yuan (about US$ 21.4 billion) in 2020 with a YoY increase of 10.1%. Sale of instant freezers are rapidly increasing deployed and exceeded 2.3 billion yuan (about US$ 353.7 million) in 2020 (JARN 2021).

Leading deep freezer manufacturers in China are divided into three groups; first, foreign brands such as Aero from Canada, Frigoscandia from Sweden, and Marel from Iceland, second, China's leading brands such as Bingshan, BingshanRyosetsu, Moon-Tech, and Square, and third, small and medium companies that usually produce lower-end products (JARN 2021).

In a recent study, industrial and commercial refrigeration products are estimated to consume 459 TWh, or about 5% of China's national electricity consumption (Energy Foundation China, 2021). Of 29 selected cooling products analyzed, commercial refrigerated cabinets with integral condensing units were estimated to account for about 11% of the total cooling energy consumption in 2019. Refrigerated cabinets with integral condensing units were also identified to have the third-largest energy savings potential among key cooling products, after room air conditioners and variable refrigerant flow systems. Other large electricity consumers among industrial and commercial refrigeration products include cold storage, commercial ice makers and quick freezers, as shown in Figure 3.



[5] Aucma, ER Shang-Fukushima, DunAn, Haier, Haier Carrier, Highly Nakano, Hiron, Hisense, Hussmann, Panasonic, and Xingxing (JARN 2021).

Figure 3. Electricity consumption from commercial and industrial refrigeration in China in 2019
Source: authors' work based on (Energy Foundation China 2021)

3. Energy efficient, low-GWP technology options and Best Available Technologies

3.1 Commercial refrigeration equipment product categorization

The product categorization of commercial refrigeration equipment varies by country but generally includes categorization by configuration, by temperature, and by specific applications or end-uses. Table 1 shows a general product categorization adopted by the U4E Guidelines for Commercial Refrigeration Equipment and China's specific product categorization is shown in Appendix 4.

Table 1. General Product Categorization for Commercial Refrigeration Equipment

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

Source: Park et al. 2021b.

3.2 Summary of efficiency improvement options

The majority of commercial refrigeration equipment has cooling systems based on the vapor-compression cycle and its variations. As a result, many of the energy-saving design options are related to various components of the basic vapor-compression cycle. Because design factors such as size and configuration and usage conditions such as operating temperature and ambient conditions may vary significantly, the economic feasibility of energy-saving design options also varies by type of applications (UNEP, 2021b). Nevertheless, there are broad opportunities for incorporating energy-saving designs into various commercial refrigeration equipment systems.

For integral commercial refrigeration systems, significant energy performance improvement can be achieved through high-efficiency variable-speed compressors, improved controls, electronically commutated fan motors (ECM), and thicker insulation (UNEP, 2021b). For larger refrigeration systems, it may be cost-effective to employ techniques such as evaporative condensing and parallel compression for higher energy performance. Because these systems reject heat outdoors, they ease the load on the building heating, cooling, and refrigeration system. Some alternative refrigeration cycles—such as the subcooling cycle, ejector-enhanced refrigeration cycle, and vapor-injection cycle—may provide additional improvements in energy efficiency. The energy-saving opportunities for supermarket refrigeration systems are even greater (Park et al. 2021b). Table 2 summarizes energy-saving design options, estimated incremental costs, and equipment applicability for commercial refrigeration systems.

Table 2. 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
	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*

PSC: permanent split capacity; LED: light-emitting diode; VIP: vacuum insulation panel; EEV: electronic expansion valve
See the cited references for details and the baseline system specifications that correspond to design options in Table 1. For

example, the Technical Support Document of the U.S. Department of Energy (2014) assumes shaded-pole motors, T8 lighting, standard single-speed hermetic compressor, etc. as the baseline (or lowest-efficiency) technologies.
Source: UNEP (2021b) based mainly on US DOE (2014). Gray and italic cells are based on analysis from (Abdelaziz et al. 2020, TEAP 2019, Alan et al. 2018).

3.2 BAT in Australia, EU, and the US market and comparison to China baseline

The BAT in the selected markets of (Australia, Europe, and the U.S. for commercial refrigeration equipment are shown in Tables 3 and 4 in terms of total energy consumption (TEC) per total display area (TDA) or net volume (UNEP 2021b).[6] Corresponding product categories in China and the minimum and maximum range of TECmax are also shown, with detailed values for each product categories shown in Appendix 1 and Appendix 2. Refrigerator or chiller refers to a refrigerating appliance that continuously maintains the temperature of the products stored in the cabinet at chilled operating temperature" (Park et al. 2021a).

Table 3. BAT energy consumption (most efficient in TEC/TDA) in Refrigerated Display Cabinets

	Product Type[a]	TEC/TDA (kWh/d/m^2)	TDA (m^2)	TEC (kWh/d)[b]	AEC (kWh/y)	Market	Product Category in China[c]	$TECmax_{,CN}$[d] (kwh/d)
Chiller (Refrigerator)	RDC-IHC	2.3 2.4	0.54 1.36	1.2 3.3	448 1,212	US EU	HC3, HC5-1, HC5-2	2.3 – 5.8 5.0 – 13.1
	RDC-IVC	2.1 2.1	1.45 3.91	3.0 8.2	1,113 3,006	AU EU	VC1, VC4	8.3 – 20.9 22.3 – 63.9
	RDC-RHC	0.6 1.2	4.58 0.62	2.9 0.7	1,052 271	US US	RS7, RS8, RS9	48.7 – 59.6 6.6 – 8.1
	RDC-RVC	1.9 2.2	2.87 6.72	5.6 14.9	2,036 5,454	US AU	RS3, RS4	37.5 104.2
	RDC-BC	0.9	0.34	0.3	110	EU		
Freezer	RDC-IHF	2.8 2.9	0.71 1.73	2.0 4.9	714 1,799	US EU	HF3 open wall site HF5-1 glass lid	5.1 – 16.8 12.4 – 40.7
	RDC-IVF	5.0 6.2	1.77 1.68	8.9 10.3	3,249 3,796	EU EU	VF4	43.2 41.1
	RDC-RHF	3.6 4.0	2.42 2.84	8.8 11.3	3,216 4,117	US US	RS13, RS14	33.3 – 37.9 39 – 44.5
	RDC-RVF	6.4 6.4	7.24 8.06	46.3 51.4	16,889 18,764	US US	RS12, RS19	209.4 – 384.2 233.1-427.7

a. IHC: integral horizontal chiller; IVC: integral vertical chiller; RHC: remote horizontal chiller; RVC: remote vertical chiller; BC: beverage cooler; IHF: integral horizontal freezer; IVF: integral vertical freezer; RHF: remote horizontal freezer; RVF: remote vertical freezer
b. Measured or estimated to values under ISO 22044 for RDC-BC and ISO 23953 for other RDCs at the conditions of CC3 and package temperature M2 or L1 (see Appendix 3 for temperature classes.)
c. Based on authors' assessment (see Appendix 4 for product categorization.)
d. Estimated EEI based on the China standard

[6] These products do not necessarily have the lowest EEI defined as annual energy consumption (AEC) per SAEC.

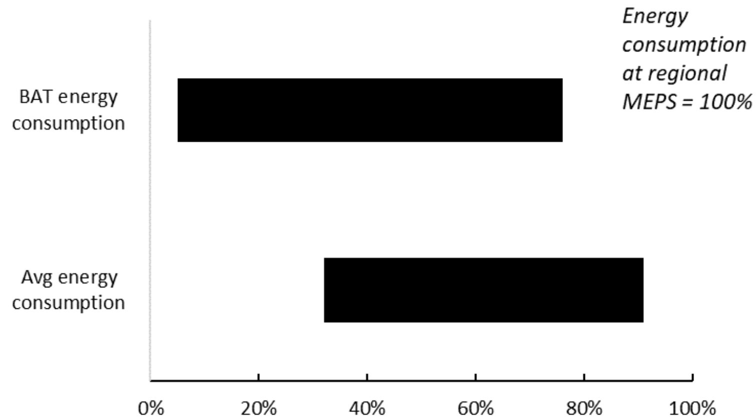
Table 4. BAT energy consumption (most efficient in TEC/100-L) in Refrigerated Storage Cabinets, Refrigerated Display Cabinets – Beverage Coolers and Refrigerated Display Cabinets – Ice Cream Freezer

	Product Type[a]	TEC/100-L (kWh/d/100-L)	Net Volume (L)	TEC (kWh/d)[b]	AEC (kWh/y)	Market	Product Category in China[c]	$TECmax_{CN}$[d] (kWh/d)
Chiller	RSC-IHC	0.16	750	1.2	429	US	HC9	2.1
		0.17	1650	2.8	1,034	US		4.0
	RSC-IVC	0.13	2300	3.0	1,091	US	VC5	6.6 – 9.3
		0.13	2460	3.2	1,179	US		7.0 – 9.9
	RDC-BC	0.16	190	0.3	125	EU		
		0.19	790	1.5	540	EU		
Freezer	RSC-IHF	0.23	910	2.1	756	US	HF9	7.3
		0.24	960	2.3	822	US		7.6
	RSC-IVF	0.24	1380	3.3	1,208	US	VF5	11.9 – 16.6
		0.39	560	2.2	786	US		6.3 – 8.2
	RDC-ICF	0.30	300	0.9	329	EU		
		0.41	300	1.2	438	EU		

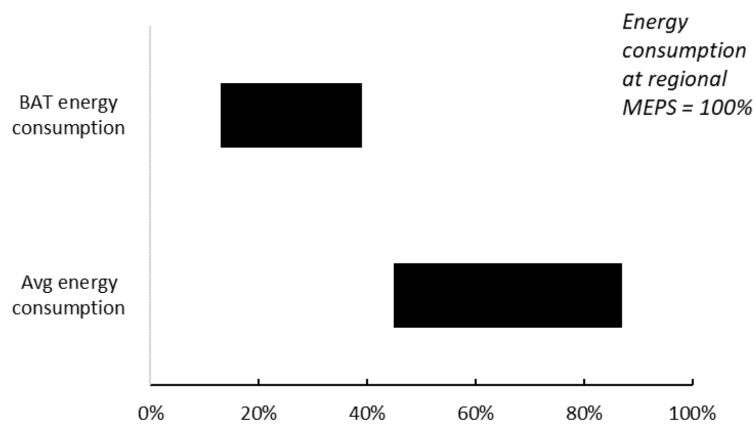
a. ICF: ice-cream freezer
b. For RSCs, estimated to values under ISO 22041 at the conditions of CC4 and package temperature M2 or L1. For RDC-ICF, measured to values under ISO 22043 at the conditions of CC B and package temperature L1.
c. Based on authors' assessment
d. Estimated EEI based on the China standard

Energy-efficient commercial refrigeration equipment systems are commercially available in the global market. Based on product data from Australia, EU and the U.S., the market average energy consumption is 55% to 68% lower, varying by product type, than the specific national or regional MEPS. The most efficient systems consume 61% to 93% less energy, varying by product type, than each specific MEPS (Park et al. 2021b) as shown in Figure 4. More specifically, for refrigerated display cabinets, the average energy consumption is 9%–68% lower than each specific MEPS, while the most efficient BATs consume 23%–95% less energy than each specific MEPS. For refrigerated storage cabinets, the average energy consumption is 13%–55% lower than each specific MEPS and the most efficient BAT systems consume 61%–87% less energy than each specific MEPS.

A. Refrigerated Display Cabinets



B. Refrigerated Storage Cabinets



C. Refrigerated Drink Cabinets and Beverage Coolers

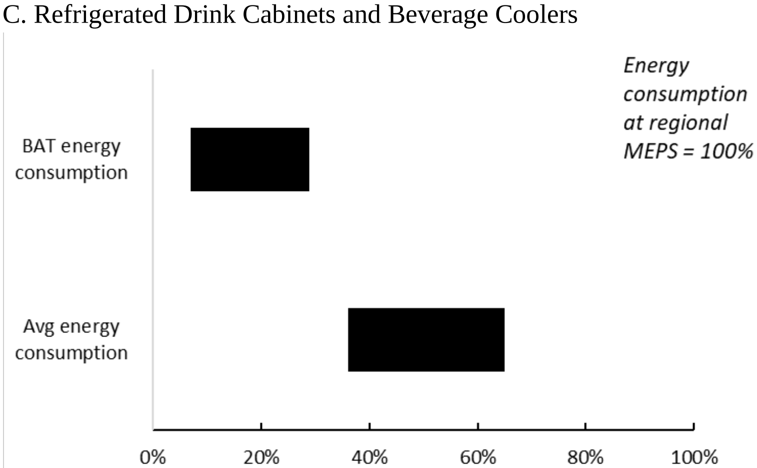


Figure 4. Energy consumption of commercially available CRE systems compared with regional MEPS

Source: Park et al. (2021b)

3.3. Summary of low-GWP refrigerant options

The refrigeration industry is currently in the process of phasing-out hydrofluorocarbon-based refrigerants due to their relatively high global warming potential (GWP). For optimal performance, transitioning new low-GWP refrigerant replacements into refrigeration systems requires re-designing the equipment for these new refrigerants. This transition can also serve as an opportunity to use more energy-efficient designs that can achieve higher system performance (Park et al. 2021b).

Figure 5 shows an overview of the current refrigerants used in commercial refrigeration equipment systems and their proposed replacements. Hydrocarbons (HCs) include natural, non-toxic refrigerants such as R600a (isobutane) and R290 (propane), which have ultra-low GWPs (< 30) (UNEP 2019). Europe has seen early market adoption of R600a and R290 as refrigerants due to their higher energy efficiency compared to other working fluids. However, HC refrigerants are highly flammable and classified by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) as a A3 refrigerant with higher flammability and lower toxicity (ASHRAE 2017), so their use is currently limited to small, self-contained refrigeration systems with a low refrigerant charge. Given this safety classification, reinforced safety regulations and adequate training for technicians and practitioners can help increase the deployment of these refrigerants (Park et al. 2021b).

For larger supermarket refrigeration systems, R744 (CO_2) is being widely deployed across Europe and the U.S. state of California. R744 is an attractive working fluid because of its low GWP of 1, non-toxicity, and widespread availability. In addition, R744 has been researched extensively in the past, so there are very few technical barriers to increasing its market penetration. However, there are higher equipment costs associated with R744-based systems, which require higher-pressure compressors and the use of advanced system configurations such as transcritical booster systems or cascade systems (UNEP 2019).

Alternatively, Hydrofluro-Olefins or HFOs are being considered for application in integral commercial refrigeration systems. HFOs, such as R1234ze and R1234yf, have ultra-low GWPs of < 30 and are generally less flammable, classified by ASHRAE as A2L with lower flammability and lower toxicity. These HFOs 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 to have similar thermodynamic properties as R404A but with a lower GWP than R404A, and with 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 (McLinden et al. 2020). Currently, non-flammable refrigerant blends, classified by ASHRAE as A1, with GWP as low as 1,360 (R448A) are available. Alternatively, to comply with EU F-Gas regulation 517/2014 and for an even greater reduction in GWP, A2L refrigerant blends such as R454C (GWP = 146) and R455A (GWP = 146) can be used in the EU market.

Although these new HFO and HFC/HFO refrigerants can meet the GWP targets set by international mandates, some critics have suggested that policymakers also need to consider the environmental impact of manufacturing and degradation in the atmosphere (ECOS 2021). This suggests that the use of natural refrigerants such as HCs and R744 should be further emphasized, since they have a lower GWP and a lower manufacturing carbon footprint.

Selecting the appropriate refrigerant requires a range of different considerations including the environmental impact, flammability, material compatibility, energy efficiency, size of the system, and cost of the system, among other factors (McLinden et al. 2020). Both natural refrigerants and HFO refrigerants have potential to meet the targets set by international mandates, but concerns over their safe adoption and manufacturing carbon footprint still needs to be addressed along with related safety standards.

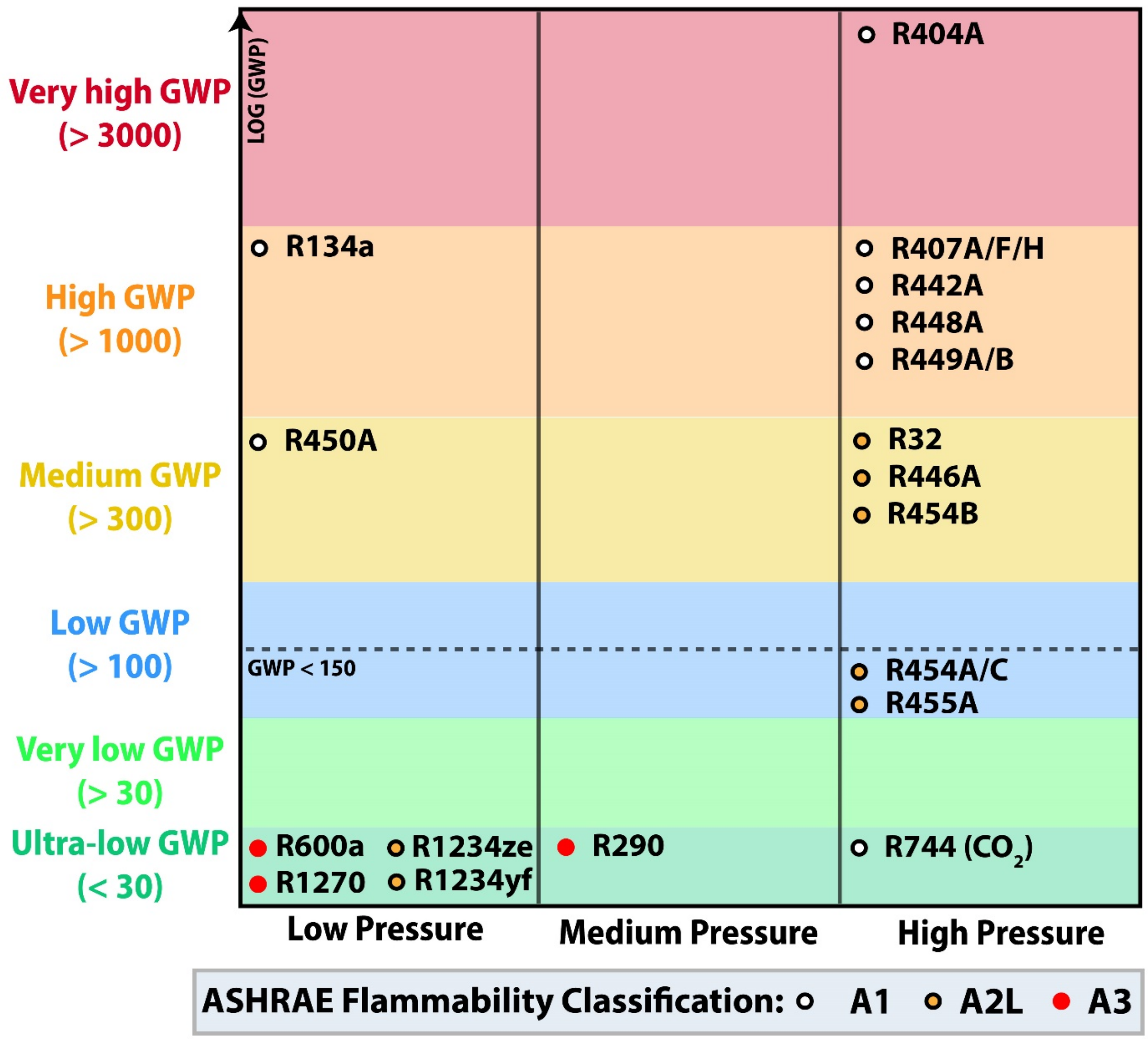


Figure 5. GWP values, flammability classifications, and operating pressures of the refrigerants used in commercial refrigeration and their proposed replacements

Source: UNEP (2021b)

4. International MEPS and Labeling Programs

4.1 Overview of regional MEPS programs

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 5 shows elements that can be considered when classifying the CRE types for energy rating and test standards.

Table 5. Taxonomy of refrigerated cabinet categories

Condensing unit location	Integral, remote direct, remote indirect
Cabinet operating temperature	Chilled, frozen, ice cream, multi-temperature, high-temperature[a]
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

[a] In the recent preliminary technical support document, US Department of Energy (DOE) has considered high-temperature refrigerators, e.g., those designed for displaying chocolate, drying meat, or storing wine, that are distinct from the current definitions of commercial refrigerators, defined as equipment “capable of operating at or above 32 °F (0 °C.” (US DOE 2022)
Source: Ellis et al. (2013), US DOE (2022)

Table 6 shows the product classes defined in the standards in Australia, China, the EU, and the U.S. A notable observation is that China and the U.S. have segmented open and closed cabinets in their MEPS. In Australia and the EU’s recently revised MEPS, current MEPS levels do not consider whether a cabinet is closed or open, with the goal of driving the market toward energy-efficient designs (Park et al. 2021b). 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 (Kemna et al. 2016).

China’s standards for CRE cover RDCs with remote condensing units (Part 1, 2011), refrigerated cabinets with self-contained condensing units (Part 2, 2015; currently under revision), and refrigerated vending machines (Part 3, 2019). Commercial ice makers are likely the next product group to be added to the standard (Park et al. 2021b). The product categories in refrigerated cabinets 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.

Table 6. Product categories defined in regional standards

	Australia	EU	U.S.[a]	China
Category	- 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	- 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
MEPS	- Effective 2021	- Professional Storage Cabinets (Effective 2019) - Refrigerating appliances with a direct sales (Effective 2021)	Effective 2017	- RDCs with remote condensing units (Effective 2011) - Refrigerated cabinets with self-contained condensing units (Effective 2015; currently under revision) - Refrigerated vending machines (Effective 2019)

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). The recent US DOE's Preliminary Technical Support Document has considered potential new equipment classes for chef bases or griddle stands and high-temperature refrigerators.

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]).

An energy efficiency index (EEI) is generally defined as actual energy consumption measured under laboratory conditions, e.g., total energy consumption (TEC) over RAEC (SAEC 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 7 shows an example of EEI calculations in the standards of these three economies.

Table 7. EEI calculations for a hypothetical CRE

	Australia	EU	China
Product type	Integral vertical chiller (RDC-IVC)		
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.
Source: Park et al. (2021b)

4.2 Overview of China MEPS requirements

Table 8 and Table 9 show China's current MEPS requirements in effect for refrigerated display cabinets (RDC) with remote condensing unit (GB 26920.1-2011) and commercial refrigerated cabinets with self-contained condensing unit (GB 26920.2-2015), respectively. Different from other standards, the China MEPS requirements are based on E_{base}, "baseline (base value) of the energy consumption", which is the electricity consumption of a commercial refrigerator with a single compartment and a basic cabinet classification structure running for 24 hours under specified test conditions [kWh/24h]. China's MEPS also define many different product categories, and the corresponding ISO product codes are included in the tables.

The GB 26920.2-2015 MEPS for commercial refrigerated cabinets with self-contained condensing unit is currently under revision. The draft requirements are summarized in Table 10.

Table 8. China MEPS Requirements for Refrigerated Display Cabinets (RDC) with remote condensing unit (GB 26920.1-2011)

Temperature	Cabinet type		ECC_{max} in Climate 3 kWh/(24h•m2)		
			M1[a]	M2[a]	H1, H2[a]
Medium temperature	RS1	Non-illuminated shelf	12.55	11.04	9.72
		Illuminated shelf	15.98	14.06	12.37
	RS2	Non-illuminated shelf	12.73	11.2	9.86
		Illuminated shelf	16.98	14.94	13.15
	RS3	Non-illuminated shelf	14.84	13.06	11.49
		Illuminated shelf	17.63	15.51	13.65
	RS4	Solid door	–	–	–
		Glass door	9.73	8.56	7.53
	RS5	Solid door	–	–	–
		Glass door	–	–	–
	RS6	Direct cooling evaporator (calandria)	14.21	12.5	11
		Fan coil	14.16	12.46	10.97
	RS7	Direct cooling evaporator (calandria)	–	–	–
		Fan coil	14.79	13.02	11.45
	RS8	Direct cooling evaporator (calandria)	12.25	10.78	9.49
		Fan coil	13.19	11.61	10.21
	RS9	Direct cooling evaporator (calandria)	–	–	–
		Fan coil	12.09	10.64	9.36
	RS10	High	–	–	–
		Medium	–	–	–
		Low	18.67	16.43	14.46
Temperature	Cabinet type		ECC_{max} in Climate 3 kWh/(24h•m2)		
			L1	L2	L3
Low temperature	RS11		38.13	30.5	24.4
	RS12		66.33	53.06	42.45
	RS13	Solid envelope	19.48	15.58	12.47
		Glass envelope	19.58	15.66	12.53
	RS14	Solid envelope	17.17	13.74	10.99

		Glass envelope	18.49	14.79	11.83
	RS15	Solid door	–	–	–
		Glass door	37.08	29.66	23.73
	RS16	Solid door	–	–	–
		Glass door	40.56	32.45	25.96
	RS17	Solid door	–	–	–
		Glass door	–	–	–
	RS18		48.58	38.86	31.09
	RS19		36.15	28.92	23.14
	RS20		–	–	–

[a]: See Appendix 3.1 for temperature class definitions.

Table 9. China old MEPS Requirements for Commercial Refrigerated Cabinets with self-contained condensing unit (GB 26920.2-2015)

Temperature Grade	Cabinet type	Baseline Energy Consumption E_{base} (kWh/24h)		
		M1 [a]	M2 [a]	H1, H2 [a]
Horizontal Refrigerator	HC1	11.50TDA	10.45TDA	9.11 TDA
	HC2	Upper: HC1's Ebase; Lower:0.85*VC5's Ebase		
	HC3	16.5TDA	14.85TDA	13.07TDA
	HC4	15.5TDA	13.95TDA	12.28TDA
	HC5-1	5.17TDA	4.65TDA	4.09TDA
	HC5-2	11.51TDA	10.4TDA	9.15TDA
	HC5-3	8.36TDA	7.52TDA	6.62TDA
	HC6-1	5.17TDA	4.65TDA	4.09TDA
	HC6-2	10.85TDA	9.77TDA	8.60TDA
	HC6-3	8.01TDA	7.21TDA	6.34TDA
	HC7	10.35TDA	9.32TDA	8.20TDA
	HC8			
Vertical Refrigerator	VC1	26.79TDA	24.11TDA	21.21TDA
	VC2	20.68TDA	18.61TDA	16.38TDA
	VC3	NA	NA	NA
	VC4	9.40TDA	8.46TDA	7.44TDA
Combined Refrigerator	YC1	Upper: YC1~VC2, YC3~VC4; Lower:1.2*HC4's Ebase		
	YC3			
	YC2	Upper: YC2~VC2, YC4~VC4; Lower:1.2*HC5's Ebase		
	YC4			

Temperature Grade	Cabinet type	Baseline Energy Consumption E_{base} [kWh/24h]		
		L1 [a]	L2 [a]	L3 [a]
Horizontal Freezer	HF1	No value	No value	No value
	HF2	No value	No value	No value
	HF3	29.2TDA	27.5TDA	25.7TDA
	HF4	26.5TDA	25.0TDA	23.32TDA
	HF5-1	10.0TDA	9.1TDA	8.2TDA
	HF5-2	20.44TDA	19.25TDA	17.99TDA
	HF5-3	15.22TDA	14.18TDA	13.1TDA
	HF6-1	8.8TDA	8.0TDA	7.2TDA
	HF6-2	18.55TDA	17.50TDA	16.32TDA
	HF6-3	13.68TDA	12.75TDA	11.76TDA
	HF7	No value	No value	No value
Vertical Freezer	VF1	No value	No value	No value
	VF2	No value	No value	No value
	VF3	No value	No value	No value
	VF4	44.0TDA	39.0TDA	34.32TDA
Combined Freezer	YF1	Upper: VF4' Ebase; Lower:1.2*HF3's Ebase		
	YF2			
	YF3	Upper: VF4 or VF5' Ebase; Lower:1.2*HF5's Ebase		
	YF4			

[a]: See Appendix 3.1 for temperature class definitions.

Table 10. China Proposed Draft MEPS Requirements for Commercial Refrigerated Cabinets with self-contained condensing unit (GB 26920.2-xxxx, under revision)

Temperature Grade	Code	Baseline Energy Consumption E_{base} = a +b xY, [kWh/24h]	
		a	b
Horizontal Refrigerator	HC1	0.29	8.10
	HC2	Upper: HC1's Ebase; Lower:0.85*VC5's Ebase	
	HC3	1.00	8.90
	HC4	1.00	8.70
	HC5-1	0.56	3.24
	HC5-2	0.48	6.25
	HC5-3	0.68	3.91
	HC6-1	0.40	3.10
	HC6-2	0.70	4.03
	HC6-3	0.66	3.79
	HC7	1.23	7.09
	HC8	Upper: HC7's Ebase; Lower:0.85*VC5's Ebase	
Vertical Refrigerator	VC1	4.50	17.50
	VC2	4.00	10.40
	VC3	-	-
	VC4	0.10	5.68
Combined Refrigerator	YC1	Upper: YC1~VC2, YC3~VC4; Lower:1.2*HC4's Ebase	
	YC3		
	YC2	Upper: YC2~VC2, YC4~VC4; Lower:1.2*HC5's Ebase	
	YC4		
Temperature	Cabinet type	Baseline Energy Consumption E_{base} = a +b xY	

		a	b
Horizontal Freezer	HF1	No value	No value
	HF2	No value	No value
	HF3	0.20	23.40
	HF4	0.20	21.20
	HF5-1	0.10	7.10
	HF5-2	0.32	10.38
	HF5-3	0.20	9.00
	HF6-1	0.10	7.70
	HF6-2	0.10	10.40
	HF6-3	0.20	9.50
	HF7	No value	No value
	HF7-1	10.40	30.40
Vertical Freezer	VF1	No value	No value
	VF2	No value	No value
	VF3	No value	No value
	VF4	0.90	23.90
Combined Freezer	YF1	Upper: VF4' Ebase; Lower:1.2*HF3's Ebase	
	YF2		
	YF3	Upper: VF4 or VF5' Ebase; Lower:1.2*HF5's Ebase	
	YF4		

Table 11. China Proposed Draft MEPS Requirements for Solid Door Commercial Refrigerated Cabinets with self-contained condensing unit (GB 26920.2-xxxx, under revision)

Code	Baseline Energy Consumption E_{base} = a +b x V, [kWh/24h]	
	a	b
VC5-1	1.25	2.34
VC5-2	1.25	3.51
HC9	0.54	2.119
VF5-1	2.45	6.84
VF5-2	2.45	10.26
HF9	1.59	6.26
VC5-3	No value	No value
VF5-3	No value	No value

4.3 International comparison with China MEPS: self-contained/integral commercial refrigeration equipment

Figure 6 shows some comparison results of the integral refrigerated display cabinets that have the highest and lowest baseline daily energy consumption requirements defined by the 2015 MEPS and 2021 revisions. The improvement rate varies by size (i.e., TDA). Across all product categories, the baseline energy consumption requirements for RDCs (at TDA of 2–3 m^2) in the 2021 draft[7] are about 12%–45% more stringent compared to the 2015 MEPS.

[7] The China standard is under revision at the time of this analysis. The draft version 6 of the standard revision has been analyzed in this document.

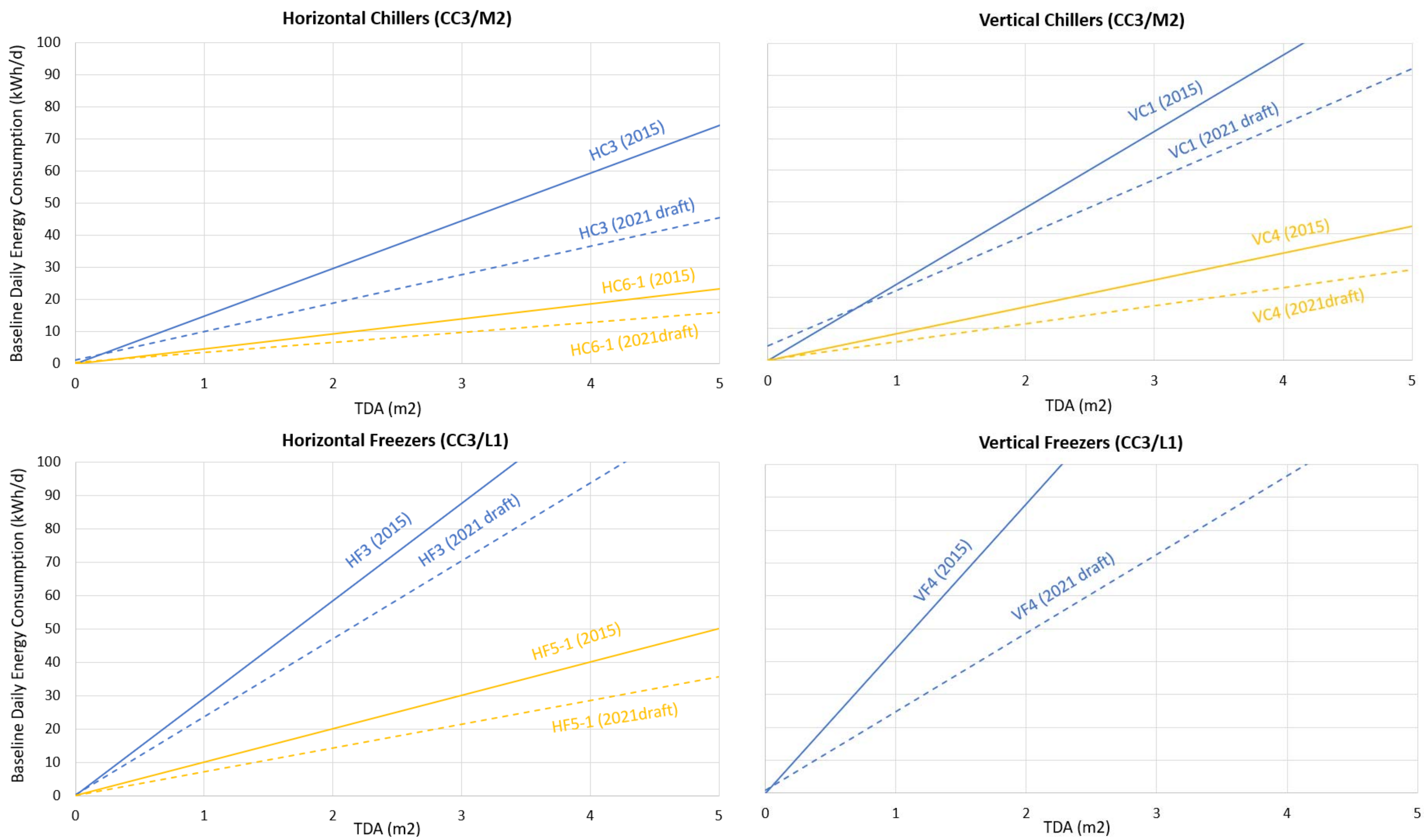


Figure 6. Comparison of the China 2015 MEPS and 2021 Proposed MEPS for Refrigerated Display Cabinets with self-contained condensing units

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 7 compares the 2021 draft Chinese MEPS for integral horizonal chillers and MEPS requirements for corresponding product categories in the U.S., EU, Australia and New Zealand (AU&NZ) standards. China's draft MEPS define 12 product categories following the Chinese standard GB/T 21001.2-2015 (ISO 23953-2.2005) classification for refrigerated display cabinets. The product categories of HC1~HC4 are open, while HC5~HC8 are closed RDC. Since EU and AU&NZ MEPS requirements do not separate close or open RDCs, the China and U.S. MEPS levels are generally less stringent than the Australia and EU MEPS levels for the open cabinets, and more stringent than the Australia and EU MEPS levels for the closed cabinets.

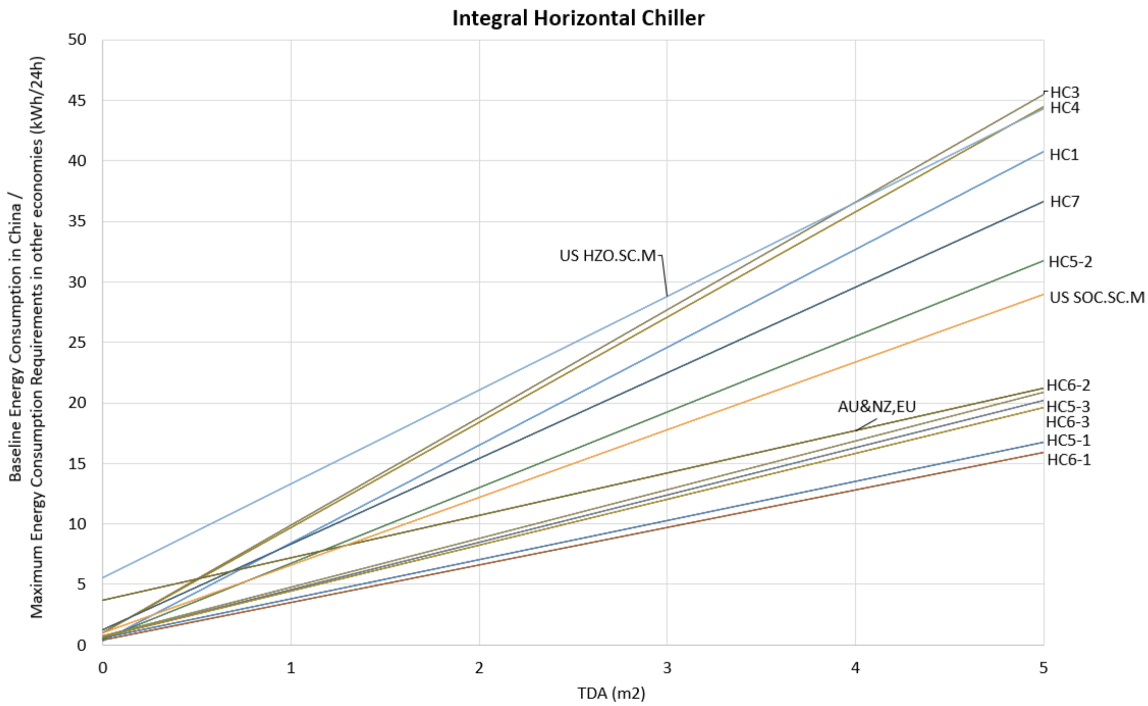


Figure 7. MEPS Comparison between China's Proposed MEPS and other economies for Integral Horizontal Chillers

HC1: chilled, serve-over counter open service access; HC3: chilled, open, wall-site; HC4: chilled, open-island; HC5-1: chilled, glass lid, wall site (4 solid walls); HC5-2: chilled, glass lid, wall site (3 glass walls); HC5-2: chilled, glass lid, wall site (only front glass wall); HC6-1: chilled, glass lid, island (4 solid walls); HC6-2: chilled, glass lid, island (4 glass walls); HC6-3: chilled, glass lid, island (only front glass wall); HC7: Chilled, serve-over counter closed service access; HZO: horizontal open; SOC: service over counter; SC: self-contained condensing unit; M: medium temperature.

Figure 8 shows the MEPS comparison between 2021 Chinese draft MEPS and MEPS requirements in other economies for integral horizonal freezers. Among the 12 product categories in Chinese standards, the categories of HF1~HC4 are open, while HF5~HF7 are closed RDC. Similarly, Chinese MEPS levels are less stringent than the Australia and EU MEPS levels for the open cabinets, and more stringent than the US, Australia and EU MEPS levels for the closed cabinets.

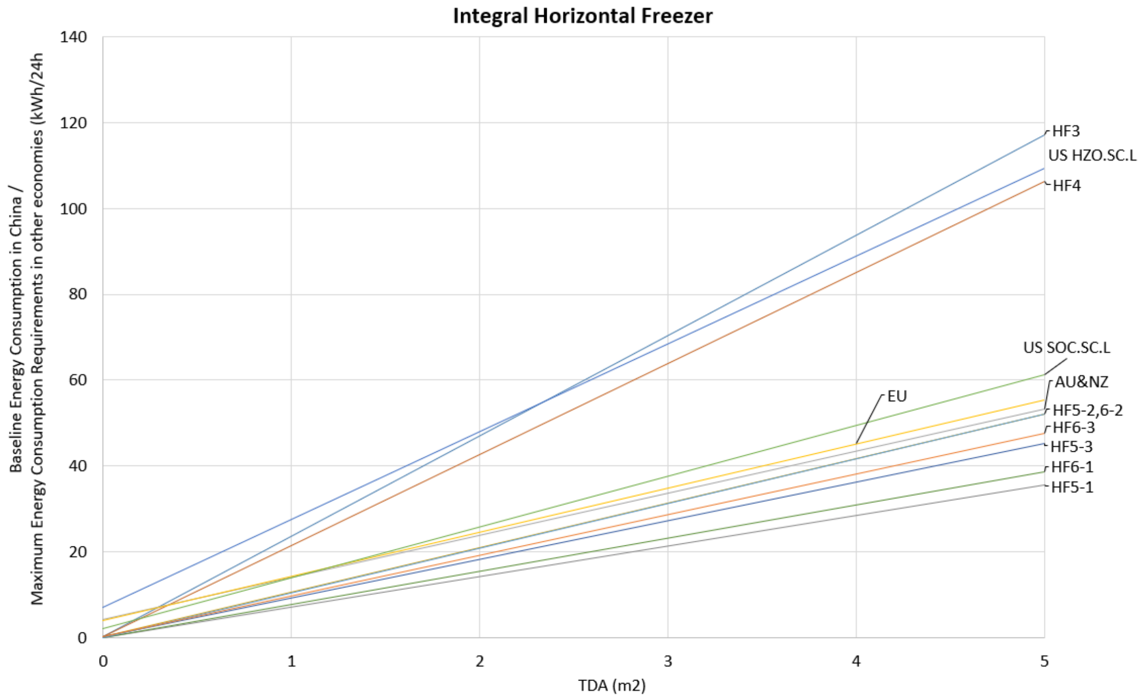


Figure 8. MEPS Comparison between China's Proposed MEPS and other economies for Integral Horizontal Freezers

HF3: frozen, open, wall-site; HF4: frozen, open, island; HF5-1: frozen, glass lid, wall site (4 solid walls); HF5-2: frozen, glass lid, wall site (3 glass walls); HF5-3: frozen, glass lid, wall site (only front glass wall); HF6-1: frozen, glass lid, island (4 solid walls); HF6-2: frozen, glass lid, island (4 glass walls); HF6-3: frozen, glass lid, island (only front glass wall); HZO: horizontal open; SOC: service over counter; SC: self-contained condensing unit; L: low temperature.

Figure 9 and Figure 10 show the proposed Chinese MEPS levels for integral vertical chillers and freezers compared to MEPS requirements from other economies. China's VC1 and VC2 product categories are open cabinets, which have the similar efficiency levels compared to U.S. open cabinets (SVO and VOP) and AU&NZ and EU, respectively. China's VC4 category is closed cabinet with a glass door. VC4 is 52~58% more stringent than AU&NZ and EU at TDA 2~3 m2. For freezers, the baseline energy consumptions are not defined for HF1~HF3 in China 2021 draft MEPS. VF4 is closed cabinet with a glass door, which is 5~11% less stringent than EU, 22~23% less stringent than AU&NZ, and approximately 50% more stringent than US at TDA 2~3 m2.

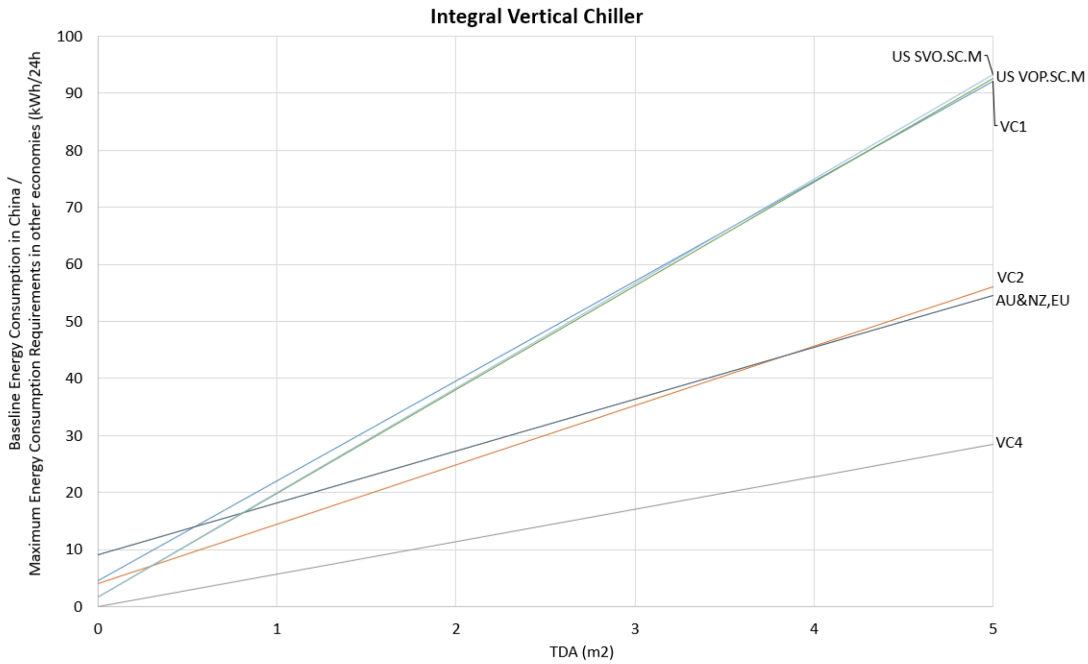


Figure 9. MEPS Comparison between China's Proposed MEPS and other economies for Integral Vertical Chillers

VC1: Chilled, semi-vertical; VC2: Chilled, multi-deck; VC4: Chilled, glass door; VOP: vertical open; SVO: semi-vertical open; SC: self-contained condensing unit; M: medium temperature.

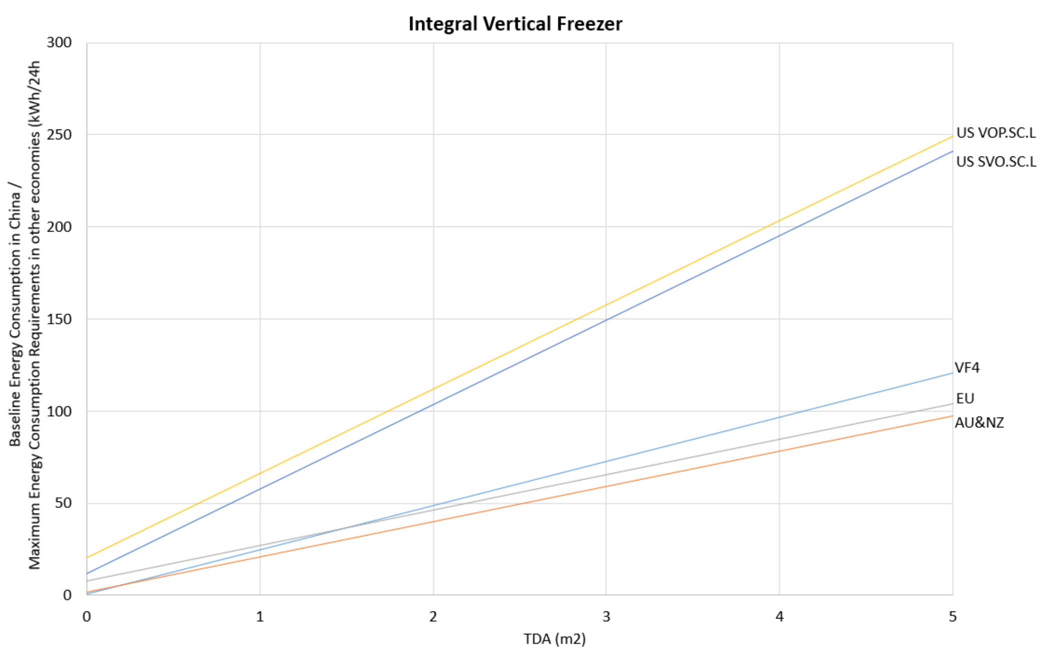


Figure 10. MEPS Comparison between China's Proposed MEPS and other economies for Integral Vertical Freezers

VF4: Frozen, glass door; VOP: vertical open; SVO: semi-vertical open; SC: self-contained condensing unit; L: low temperature.

4.4 International comparison with China MEPS: remote condensing commercial refrigeration equipment

Figure 11 through Figure 14 show the current (2015) Chinese and global MEPS levels for remote condensing units. The Chinese MEPS requirements are based on the existing 2011 MEPS, which have not been revised for 11 years. Regardless of open or closed RDC configurations, the baseline energy consumption are very high compared with the MEPS levels defined in other economies, which indicates large energy saving potential exists across product categories. This suggests that a MEPS revision for RDCs with remote condensing units can have energy savings potential in China.

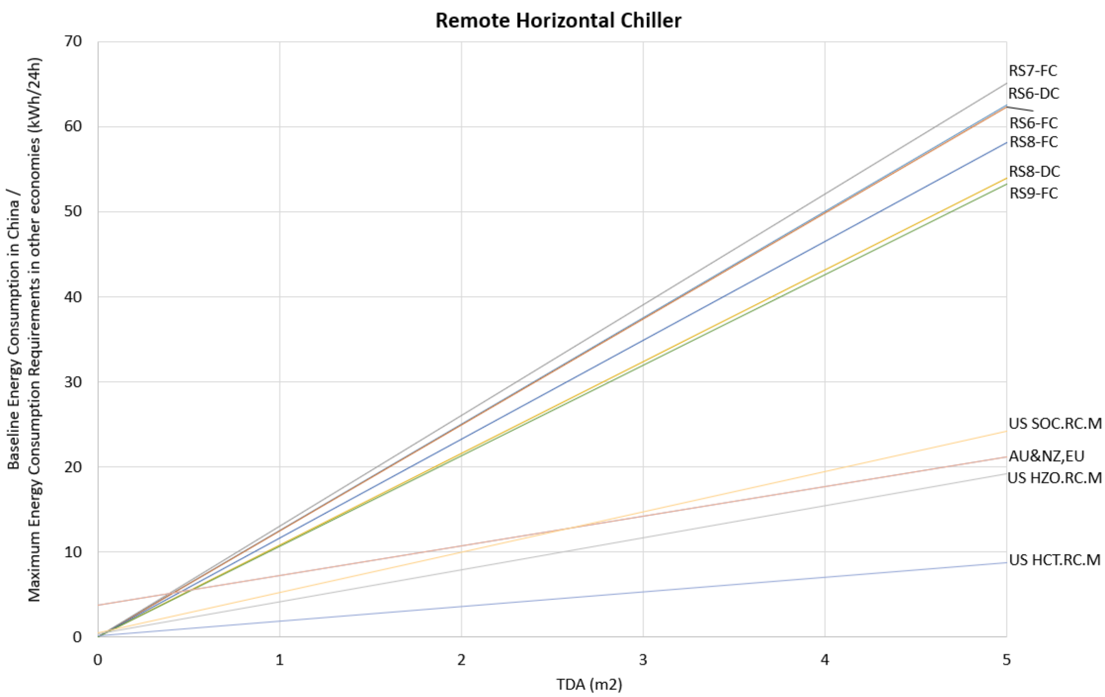


Figure 11. MEPS Comparison between China and other economies for Remote Horizontal Chillers
DC: Direct cooling evaporator (calandria); FC: Fan coil; HZO: horizontal open; SOC: service over counter; HCT: horizontal closed transparent; RC: remote condensing unit; M: medium temperature.

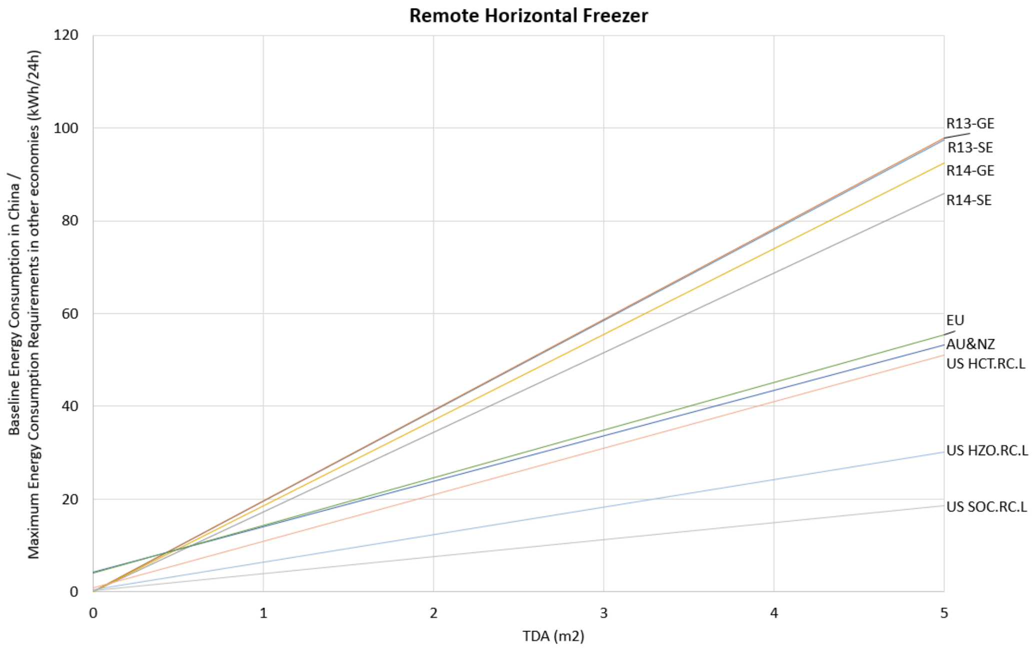


Figure 12. MEPS Comparison between China and other economies for Remote Horizontal Freezers

GE: Glass envelope; SE: Solid envelope; HZO: horizontal open; SOC: service over counter; HCT: horizontal closed transparent; RC: remote condensing unit; L: low temperature

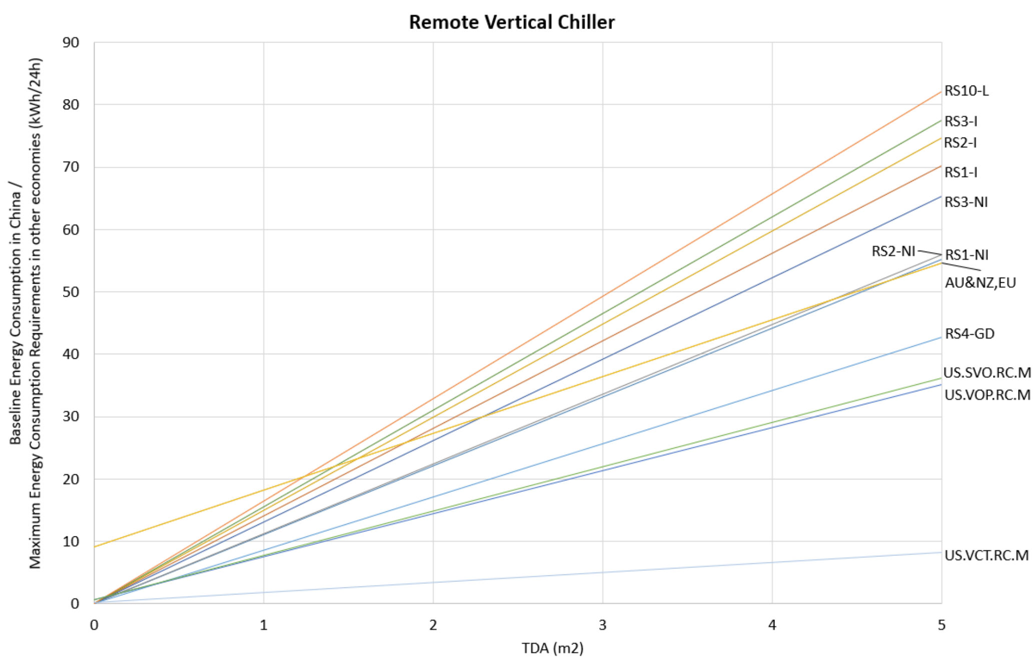


Figure 13. MEPS Comparison between China and other economies for Remote Vertical Chillers

I: Illuminated shelf; NI: Non-Illuminated shelf; VOP: vertical open; SVO: semi-vertical open; RC: remote condensing unit; M: medium temperature

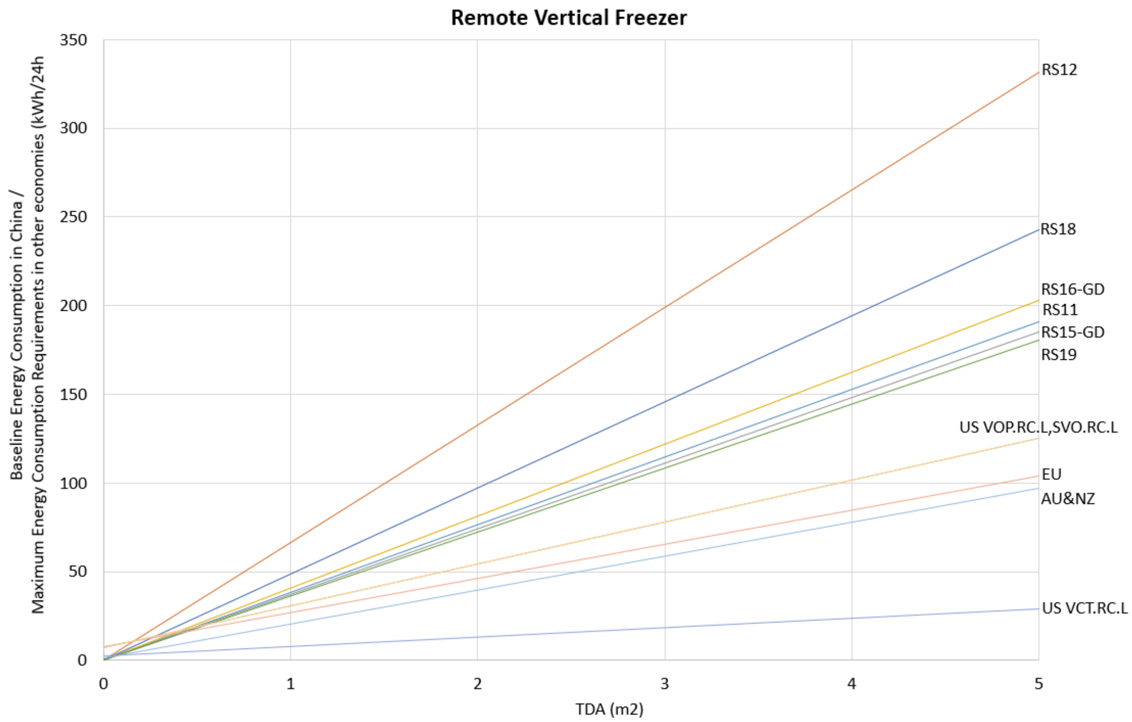


Figure 14. MEPS Comparison between China and other economies for Remote Vertical Freezers
GD: Glass Door; VOP: vertical open; SVO: semi-vertical open; VCT: vertical closed transparent; RC: remote condensing unit; L: low temperature

4.5 International Energy Labeling Programs

4.5.1 U.S. ENERGY STAR

The current voluntary U.S. ENERGY STAR endorsement label version 4.0 specifications for commercial refrigerators and freezers went into effect on March 27, 2017. ENERGY STAR certified commercial refrigeration products are on average 20% more efficient than conventional models and are typically designed with higher efficiency components such as ECM evaporator and condenser fan motors, hot gas anti-sweat heaters, or high-efficiency compressors (U.S. ENERGY STAR 2021). For commercial refrigeration products the U.S. ENERGY STAR labeling specifications cover products that meet industry definition of commercial refrigerator, freezer, refrigerator-freezer or commercial hybrid and is covered by equipment classes that include: low and medium temperature, horizontal and vertical closed, solid and transparent, and self-contained units used for different commercial purposes. It excludes open air and mixed solid/transparent door refrigeration equipment, remote condensing equipment and ice cream freezers. To qualify for the U.S. ENERGY STAR label, thresholds are set for maximum daily energy consumption calculated based on product volume in cubic feet, and distinguished based on equipment family code, operating mode, and rated low or medium temperature. Table 12 shows the current version 4.0 specifications in effect.

Table 12. U.S. ENERGY STAR Program Requirements (v 4.0) for Commercial Refrigerators and Freezers

Table 1: ENERGY STAR Requirements for Commercial Refrigerators, Freezers, and Refrigerator-Freezer[2]		
Product Volume (in cubic feet)	**Refrigerator**	**Freezer**
Vertical Closed		
Solid	*VCS.SC.M**	*VCS.SC.L*
0 < V < 15	0.022V+0.97	0.21V+0.9
15 ≤ V < 30	0.066V+0.31	0.12V+2.248
30 ≤ V < 50	0.04V+1.09	0.285V-2.703
50 ≤ V	0.024V+1.89	0.142V+4.445
Transparent	*VCT.SC.M*	*VCT.SC.L*
0 < V < 15	0.095V+0.445	0.232V+2.36
15 ≤ V < 30	0.05V+1.12	
30 ≤ V < 50	0.076V+0.34	
50 ≤ V	0.105V-1.111	
Horizontal Closed		
Solid or Transparent	*HCT.SC.M, HCS.SC.M*	*HCT.SC.L, HCS.SC.L*
All volumes	0.05V+0.28	0.057V+0.55

* DOE Equipment Class designations relevant to ENERGY STAR eligible product scope
(1) Equipment family code (HCS= horizontal closed solid, HCT=horizontal closed transparent, VCS= vertical closed solid, VCT=vertical closed transparent),
(2) Operating mode (SC=self-contained), and
(3) Rating Temperature (M=medium temperature (38 °F), L=low temperature (0 °F)).

Source: U.S. ENERGY STAR 2017

The U.S. Environmental Protection Agency (EPA) is currently developing revised specifications (version 5.0) for this product category. The version 5.0 development process started in December 2020 and a final draft version of the specification was published for public comment in mid-January 2022. The final version 5.0 specification has been published and is scheduled to take effect on December 21, 2022. Compared to version 4.0, a major change in version 5.0 is expansion of the product category scope to include chef base self-contained low and medium temperature refrigeration units and service over counter self-contained medium temperature refrigeration units. Chef base refrigeration units are defined in the specification as units designed and marketed with the intent of having a griddle or cooking appliance placed on top of it for cooking food, while service over counter units are defined as equipment with sliding or hinged doors in the back for use by sales personnel and with a height not greater than 66 inches. Under version 5.0 specifications, remote condensing, open-air units and ice cream freezers are still excluded from the program.

As seen in Table 13, the new version 5.0 specifications include revised maximum daily energy consumption co-efficient values based on product volume for vertical and horizontal closed refrigeration units. A new set of co-efficient values for calculating maximum daily energy consumption is also provided for chef bases, while the service over counter units uses a different metric of total display area instead of volume to calculate the maximum daily energy consumption limit.

Table 13. U.S. ENERGY STAR Final Version 5.0 Specifications for Commercial Refrigerators and Freezers (effective December 21, 2022)

Table 1: ENERGY STAR Requirements for Commercial Refrigerators, Freezers, and Refrigerator-Freezer[ii]

Product Volume (in cubic feet)	Refrigerator	Freezer
Vertical Closed		
Solid	***VCS.SC.M****	***VCS.SC.L***
0 < V < 15	0.0267V+0.8	0.21V+0.9
15 ≤ V < 30	0.05V+0.45	0.12V+2.248
30 ≤ V < 50		0.2578V-1.8864
50 ≤ V	0.025V+1.6991	0.14V+4.0
Transparent	***VCT.SC.M***	***VCT.SC.L***
0 < V < 15	0.095V+0.445	0.232V+2.36
15 ≤ V < 30	0.05V+1.12	
30 ≤ V < 50	0.076V+0.34	
50 ≤ V	0.105V-1.111	
Horizontal Closed		
Solid or Transparent	***HCT.SC.M, HCS.SC.M***	***HCT.SC.L, HCS.SC.L***
All volumes	0.05V+0.28	0.057V+0.55
Chef Bases**		
	CB.SC.M	***CB.SC.L***
All volumes	0.05V+2.1	0.22V+6.0
Service Over Counter		
Total Display Area (in square feet)	***SOC.SC.M***	N/A
0 < TDA < 20	0.32TDA+0.6	
20 ≤ TDA < 40	0.65TDA-6.0	
40 ≤ TDA	0.4667TDA+1.3333	

* DOE Equipment Class designations relevant to ENERGY STAR eligible product scope

(1) Equipment family code (HCS= horizontal closed solid, HCT=horizontal closed transparent, VCS= vertical closed solid, VCT=vertical closed transparent, SOC= service over counter),

(2) Operating mode (SC=self-contained), and

(3) Rating Temperature (M=medium temperature (38 °F), L=low temperature (0 °F)).

Source: U.S. ENERGY STAR 2022a

4.5.2 U.S. ENERGY STAR Emerging Technology Award

In addition to the ENERGY STAR label, the U.S. ENERGY STAR program also has its Emerging Technology Award (ETA) program that recognizes innovative technologies for reducing energy use and lowering greenhouse gas emissions. The product category for the ETA changes yearly and adaptive commercial refrigeration equipment are chosen as the product category for 2022. More specifically, the 2022 ETA seeks to recognize self-contained, close commercial refrigeration products that uses a variable speed compressor with sensor-driven control systems capable of capacity modulation in response to a varying internal thermal load. The use of such advance adaptive compressors in self-contained commercial refrigeration applications have been shown to increase per unit efficiency by around 25% compared with standard units (U.S. ENERGY STAR 2022b). Table 14 shows the energy efficiency, low-GWP refrigerant and foam requirements and additional product requirements needed to qualify for this award.

Table 14. U.S. ENERGY STAR 2022 Emerging Technology Award Requirements for Adaptive Commercial Refrigeration Equipment

ENERGY STAR® 2022 Emerging Technology Award Requirements: Adaptive Commercial Refrigeration Equipment

Product Type: This award is intended for closed, self-contained commercial refrigeration products using variable speed compressors with sensor-driven control systems capable of capacity modulation.		
Criteria		**Test Method/Required Documentation**
Product Characteristics		
Energy Efficiency	Outperform the measured Annual Energy Consumption for the Federal Minimum Standard by 25%	Perform the 10 CFR Part 431 Subpart C - Commercial Refrigerators, Freezers and Refrigerator-Freezers test method
	Provide documentation of the model information and test results for the product being submitted for consideration	
	Energy measurements must be performed at an EPA-recognized accredited lab[1] or at manufacturer lab certified by an EPA-recognized Certification Body under the Data Acceptance Program	
	All models submitted for consideration must be ENERGY STAR certified and thus listed on the ENERGY STAR Commercial Refrigeration Equipment Qualified Product List to be eligible	
Low-GWP Refrigerant & Foam	Contains refrigerant and foam with a Global Warming Potential (GWP) less than 15 and approved for use in the U.S. market	Listed as Acceptable by the U.S. EPA Significant New Alternatives Policy (SNAP) Program for refrigerants[2] and foams[3]. Product documentation listing the refrigerants and foams contained within the product
Additional Product Requirements		
Warranty Minimum	One year parts and labor	Copy of warranty agreement
Certification	Must meet all applicable U.S. electrical safety requirements	Copy of case files
Commercial Status	This program recognizes only products available for sale in the U.S. at the time of award submission	

Source: U.S. ENERGY STAR 2022c.

4.5.3 EU Energy Label

The EU introduced, for the first time, mandatory EU Energy Label for commercial refrigeration products in March 2019 with the EU Commission Regulation (EU 2019/2018) supplementing EU Regulation 2017/1369 on energy labeling of refrigerating appliances with a direct sales function. The new EU Energy Label requirements cover beverage coolers; ice cream freezers; refrigerated vending machines; gelato-scooping cabinets; horizontal, vertical and combined supermarket refrigerator cabinets; horizontal, vertical and combined supermarket freezer cabinets; and roll-in supermarket cabinets. Unlike the U.S. ENERGY STAR label, the EU Energy Label covers both remote and self-contained or integral units, but with slightly different thresholds for each product type. The EU Energy Label requirements went into effect on March 1, 2021.

As a categorical ranking label, the EU Energy Label defines 7 energy efficiency classes (A-G, with A being the most efficient) based on a unit's calculated energy efficiency index (EEI) value. The EEI represents the ratio of a unit's annual energy consumption relative to a reference annual energy consumption calculated using defined variables and coefficients for specific product category classes. The label layout distinguishes between three major product category types: beverage coolers, ice-cream freezers and all other refrigerating cabinet with a direct sales information. In addition to the energy efficiency class, the label also provides information on the unit's annual energy consumption, temperature class conditions, and total display area or volume for chilled and frozen climate conditions. Figure 15 below shows a sample label layout for refrigerating appliances with direct sales function, with slightly different layouts for beverage coolers and ice cream freezers. Table 15 shows the EEI requirements for each energy efficiency class.

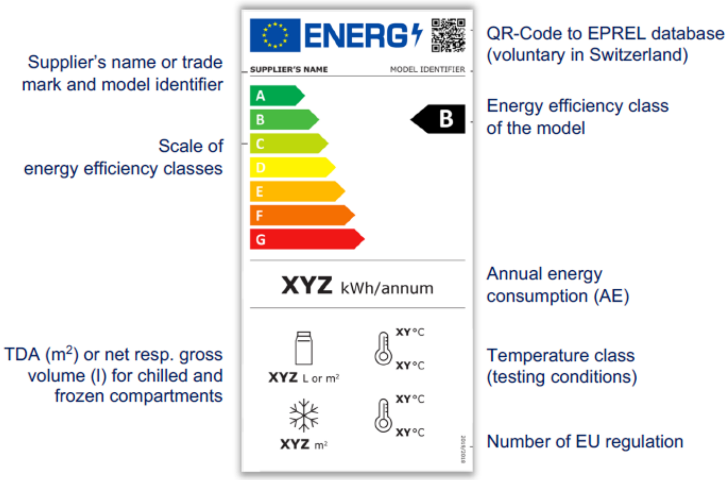


Figure 15. Sample EU Energy Label Design for Refrigerating Appliances with Direct Sales Function

Source: Topten EU 2020.

Table 15. EU Energy Label Energy Efficiency Classes and EEI Requirements

Energy efficiency classes of refrigerating appliances with a direct sales function

Energy Efficiency Class	EEI
A	EEI < 10
B	10 ≤ EEI < 20
C	20 ≤ EEI < 35
D	35 ≤ EEI < 50
E	50 ≤ EEI < 65
F	65 ≤ EEI < 80
G	EEI ≥ 80

Source: EU Commission 2019.

For a given unit, the EEI is calculated by dividing the Annual Energy (AE) consumption (i.e., daily energy consumption multiplied by 365 days, in kWh/year) by the reference or Standard Annual Energy Consumption (SAEC, in kWh/year).

For refrigerating appliances with all compartments having the same temperature class and for refrigerated vending machines, SAEC is calculated as:

$$SAE = 365 \times P \times (M + N \times Y) \times C;$$

For refrigerating appliances that have more than one compartment with different temperature classes, the SAEC is calculated as:

$$SAE = 365 \times P \times \sum_{c=1}^{n} (M + N \times Y_c) \times C_c;$$

,

where c is the index number for a compartment type ranging from 1 to n

M and N are defined co-efficient values for specific product categories, C is temperature conditions and corresponding coefficient values by product classes, and Y is determined by the volume for beverage coolers, net volume for ice cream freezers and vending machines or total display area for other refrigerating appliances, and P is an adjustment factor for differentiating integral supermarket cabinets (P=1.1) from other units (e.g., remote condensing units, P=1). Table 16 shows the M and N values by product category for calculating the SAEC and Table 17 shows the C coefficient values for supermarket cabinets as an example.

Table 16. EU Energy Label M and N Values for Calculating Standard Annual Energy Consumption

M and N values

Category	Value for M	Value for N
Beverage coolers	2,1	0,006
Ice-cream freezers	2,0	0,009
Refrigerated vending machines	4,1	0,004
Gelato-scooping cabinets	25,0	30,400
Vertical and combined supermarket refrigerator cabinets	9,1	9,100
Horizontal supermarket refrigerator cabinets	3,7	3,500
Vertical and combined supermarket freezer cabinets	7,5	19,300
Horizontal supermarket freezer cabinets	4,0	10,300
Roll-in cabinets (from 1 March 2021)	9,2	11,600
Roll-in cabinets (from 1 September 2023)	9,1	9,100

Source: EU Commission 2019.

Table 17. EU Energy Label Coefficient C Values for Calculating Standard Annual Energy Consumption

Temperature conditions and corresponding temperature coefficient values, C

(a) **Supermarket cabinets**

Category	Temperature class	Highest temperature of warmest M-package (°C)	Lowest temperature of coldest M-package (°C)	Highest minimum temperature of all M-package (°C)	Value for C
Vertical, combined supermarket refrigerator cabinets	M2	≤ +7	≥ -1	n.a.	1,00
	H1 and H2	≤ +10	≥ -1	n.a.	0,82
	M1	≤ +5	≥ -1	n.a.	1,15
Horizontal supermarket refrigerator cabinets	M2	≤ +7	≥ -1	n.a.	1,00
	H1 and H2	≤ +10	≥ -1	n.a.	0,92
	M1	≤ +5	≥ -1	n.a.	1,08
Vertical and combined supermarket freezer cabinets	L1	≤ -15	n.a.	≤ -18	1,00
	L2	≤ -12	n.a.	≤ -18	0,90
	L3	≤ -12	n.a.	≤ -15	0,90
Horizontal supermarket freezer cabinets	L1	≤ -15	n.a.	≤ -18	1,00
	L2	≤ -12	n.a.	≤ -18	0,92
	L3	≤ -12	n.a.	≤ -15	0,92

Source: EU Commission 2019.

4.5.4 Topten

The Topten program provides dynamic benchmark for the most energy efficient products based on key selection criteria related to energy efficiency, resource efficiency and health considerations. The Topten EU online search tool includes commercial display refrigerators and freezers based on specific scope and selection criteria. More specifically, Topten EU’s selection include both remote and plug-in/integral cabinets that are very likely to have doors or lids and are available on the European market (Table 18). For these refrigerated display cabinets, the Topten technical criteria include use of natural refrigerant with global warming potential of ≤ 3 and a defined maximum energy efficiency index based on product category using the same calculation method as the EU Energy Label. In March 2022, the Topten database included 55 plug-in horizontal display cabinet, 56 plug-in vertical display cabinet, and 2 vending machines products.

Table 18. Topten EU Technical Specifications for Refrigerated Display Cabinets

Category	Type of Cooling	Energy Efficiency Index	Efficiency Class
Horizontal supermarket freezer cabinets	plug-in / remote	< 35	min. C
Vertical, semi-vertical and combined supermarket freezer cabinets: - small counter top freezers* (TDA < 0.33 m2) - medium-sized cabinets* (0.33 m2 ≤ TDA < 2 m2) - medium-sized cabinets* (0.33 m2 ≤ TDA < 2 m2) - large cabinets* (TDA ≥ 2 m2) * no display area on side walls	plug-in / remote plug-in remote plug-in / remote	< 10 < 30 < 35 < 60	min. A - min. C -
Horizontal supermarket refrigerator cabinets	plug-in / remote	< 50	min. D
Small counter top refrigerators	plug-in / remote	< 20	min. B
Vertical, semi-vertical and combined supermarket refrigerator cabinets	plug-in / remote	< 35	min. C

Source: Topten EU 2022.

4.6 Additional Refrigerant Policy Drivers

In addition to existing international MEPS and labeling programs aimed at improving the overall energy efficiency of commercial refrigeration equipment, some regions have also adopted policies and programs to promote low-GWP refrigerants for commercial refrigeration. To meet the state's target of cutting HFC emissions by 40% under 2013 levels by 2030, the U.S. state of California has adopted policies and programs to phase-out high-GWP HFC refrigerants, including for commercial refrigeration equipment. In 2018, California adopted a Significant New Alternatives Policy (SNAP) to regulate high-GWP HFCs by prohibiting the use of high-GWP refrigerants in new and retrofit stationary refrigeration equipment. Since then, 12 other U.S. states have approved similar SNAP regulations and 4 other states have proposed similar regulations. The California Cooling Act also establishes the Fluorinated Gases Emission Reduction Incentive Program, which authorizes state funding and requires coordination between multiple state agencies to increase adoption of low-GWP refrigerant technologies in the supermarket and industrial sector. For 2019-2020, the state authorized $1 million to fund the incentive program. The funding was allocated in early 2021 to help pay for new, innovative low-GWP refrigerants and refrigeration technologies at 14 grocery stores and 2 retrofits.

In December 2020, California became the first U.S. state to adopt regulations that limits the use of high-GWP refrigerants. Specifically, beginning in 2022, new stationary refrigeration equipment with more than 50 pounds (22.7 kg) of refrigerant will be required to use refrigerant with GWP of less than 150 (CARB, 2020). In addition, food retailers with 20 or more stores will need to maintain a weighted average refrigerant GWP below 2500 by 2026, or reduce GWP by at least 25% by 2026. These food retailers would also need to have an average GWP below 1400 or reduce GWP by 55% by 2030.

5. Conclusions and Key Findings

The global commercial refrigeration equipment market is dominated by refrigerated display cabinets, and Asia is the second largest market after North America. In China, rapid growth of supermarkets and convenience stores continue to drive domestic demand for commercial refrigeration equipment including refrigerated display cabinets and refrigerated storage cabinets. A recent analysis found that commercial refrigerated cabinets with integral condensing units accounted for about 11% of total cooling electricity consumption in 2019, and has the third largest energy savings potential among 29 key cooling products. This report reviews the latest market trends and energy efficient technologies for commercial refrigeration equipment, and energy efficiency standards and labeling policies and programs for this product type. It also analyzed the global best available technologies and compares it to China's proposed standards for integral refrigerated display cabinets to highlight additional areas for technical potential in energy efficiency.

The key findings from our analysis include:

- Key energy efficiency measures for integral commercial refrigeration equipment include technologies such as high-efficiency variable-speed compressors, improved controls, innovative heat exchangers, electronically commutated motor (ECM) fans and thicker insulation.

- Based on available market product data from Australia, EU and the U.S., the average energy consumption of best available technologies (BATs) in these markets are lower by up to 55%-68%, varying by product type, than each regional MEPS. The most efficient BAT systems consume 61%-93% less energy, varying by product type, than each regional MEPS.
- While China and the U.S. have segmented open and closed refrigerated display cabinets (RDCs) in energy-efficiency standards, the Australia and 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. This indicates that, for open RDCs, the China and U.S. MEPS levels are generally less stringent than the Australia and EU MEPS levels, while for selected closed cabinets, the China and U.S. MEPS levels are assessed to be more stringent than the Australia and EU MEPS levels.
- For example, China's proposed MESP for integral vertical chillers with open cabinets have similar efficiency levels compared to U.S., Australia, New Zealand and EU, while China's proposed MEPS for closed cabinet with glass door is over 50% more stringent than U.S., Australia, New Zealand and EU MEPS at total display area of 2-3 m2
- U.S. and EU recently revised their voluntary ENERGY STAR and mandatory energy labels in 2022 and 2019, respectively, to highlight more efficient commercial refrigeration products. U.S. ENERGY STAR program only includes closed and integral refrigerated display cabinets while the EU Energy Label includes both integral and remote condensing units and does not exclude open air units.
- Highly efficient commercial refrigeration units on the market are also recognized through the EU Topten program and U.S. ENERGY STAR's 2022 Emerging Technology Award.
- The refrigeration industry is also undergoing a transition towards low-GWP refrigerants, which presents an opportunity for more energy efficient designs to support new refrigerants. R744 (CO_2) is a widely used low-GWP refrigerant in Europe and California with low flammability and non-toxicity, but requires higher equipment costs. Hydrofluoro-Olefins (HFO) and HFC/HFO blends are other alternatives with relatively low flammability, but may have other environmental impacts from manufacturing and degradation in the atmosphere.

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Appendices

Appendix 1. BAT energy consumption (most efficient in TEC/TDA) in Refrigerated Display Cabinets and Detailed Comparison with Chinese Product Categories

	Product Type[a]	TEC/TDA (kWh/d/m^2)	TDA (m^2)	TEC (kWh/d)[b]	AEC (kWh/y)	Market	Product Category in China[c]	TECmax (kWh/d)	EEI_{CN}[d]
Chiller (Refrigerator)	RDC-IHC	2.3 2.4	0.54 1.36	1.2 3.3	448 1,212	US EU	HC3, HC5-1, HC5-2	5.8(HC3),2.3(HC5-1), 3.9(HC5-2) 13.1(HC3),5.0(HC5-1),9.0(HC5-2)	21%(HC3),52%(HC5-1), 31% (HC5-2) 25%(HC3),66%(HC5-1),37%(HC5-2)
	RDC-IVC	2.1 2.1	1.45 3.91	3.0 8.2	1,113 3,006	AU EU	VC1, VC4	20.9(VC1),8.3(VC4) 63.9(VC1),22.3(VC4)	14%(VC1),36%(VC4) 13%(VC1),37%(VC4)
	RDC-RHC	0.6 1.2	4.58 0.62	2.9 0.7	1,052 271	US US	RS7, RS8, RS9	59.6(RS7),49.4(RS8.1),53.2(RS8.2),48.7(RS9) 8.1(RS7),6.7(RS8.1),7.2(RS8.2),6.6(RS9)	5%(RS7),6%(RS8.1),5%(RS8.2),6%(RS9) 9%(RS7),10%(RS8.1),10%(RS8.2),11%(RS9
	RDC-RVC	1.9 2.2	2.87 6.72	5.6 14.9	2,036 5,454	US AU	RS3, RS4	37.5(RS3) 104.2(RS3)	15%(RS3) 14%(RS3)
	RDC-BC	0.9	0.34	0.3	110	EU			
Freezer	RDC-IHF	2.8 2.9	0.71 1.73	2.0 4.9	714 1,799	US EU	HF3 open wall site HF5-1 glass lid	16.8(HF3),5.1(HF5-1) 40.7(HF3),12.4(HF5-1)	12%(HF3),39%(HF5-1) 12%(HF3),40%(HF5-1)
	RDC-IVF	5.0 6.2	1.77 1.68	8.9 10.3	3,249 3,796	EU EU	VF4	43.2 41.1	21% 25%
	RDC-RHF	3.6 4.0	2.42 2.84	8.8 11.3	3,216 4,117	US US	RS13, RS14	37.7(RS13.1),37.9(RS13.2),33.3(RS14.1),35.8(RS14.2) 44.2(RS13.1),44.5(RS13.2),39(RS14.1),42.0(RS14.2)	23%(RS13.1),23%(RS13.2),26%(RS14.1),25%(RS14.2) 26%(RS13.1),25%(RS13.2),29%(RS14.1),27%(RS14.2)

	RDC- RVF	6.4 6.4	7.24 8.06	46.3 51.4	16,889 18,764	US US	RS12, RS19	384.2(RS12),209.4(RS19) 427.7(RS12),233.1(RS19)	12%(RS12),22%(RS19) 12%(RS12),22%(RS19)

e. IHC: integral horizontal chiller; IVC: integral vertical chiller; RHC: remote horizontal chiller; RVC: remote vertical chiller; BC: beverage cooler; IHF: integral horizontal freezer; IVF: integral vertical freezer; RHF: remote horizontal freezer; RVF: remote vertical freezer

f. Measured or estimated to values under ISO 22044 for RDC-BC and ISO 23953 for other RDCs at the conditions of CC3 and package temperature M2 or L1

g. Based on authors' assessment

h. Estimated EEI based on the China standard

Appendix 2. BAT energy consumption (most efficient in TEC/100-L) in Refrigerated Storage Cabinets, Refrigerated Display Cabinets – Beverage Coolers and Refrigerated Display Cabinets – Ice Cream Freezer

	Product Type[a]	TEC/100-L (kWh/d/ 100-L)	Net Volume (L)	TEC (kWh/d)[b]	AEC (kWh/y)	Market	Product Category in China[c]	TECmax (kWh/d)	EEI_{CN}[d]
Chiller	RSC-IHC	0.16 0.17	750 1650	1.2 2.8	429 1,034	US US	HC9	2.1 4.0	56% 69%
	RSC-IVC	0.13 0.13	2300 2460	3.0 3.2	1,091 1,179	US US	VC5	6.6(VC5-1),9.3(VC5-2) 7.0(VC5-1),9.9(VC5-2)	45%(VC5-1),32%(VC5-2) 46%(VC5-1),32%(VC5-2)
	RDC-BC	0.16 0.19	190 790	0.3 1.5	125 540	EU EU			
Freezer	RSC-IHF	0.23 0.24	910 960	2.1 2.3	756 822	US US	HF9	7.3 7.6	29% 30%
	RSC-IVF	0.24 0.39	1380 560	3.3 2.2	1,208 786	US US	VF5	11.9(VF5-1),16.6(VF5-2) 6.3(VF5-1),8.2(VF5-2)	28%(VF5-1),20%(VF5-2) 35%(VF5-1),27%(VF5-2)
	RDC-ICF	0.30 0.41	300 300	0.9 1.2	329 438	EU EU			

e. ICF: ice-cream freezer

f. 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.

g. Based on authors' assessment

h. Estimated EEI based on the China standard

Appendix 3. Temperature classes

Table A3.1. M-package temperature classes

M-package temperature class	Highest temperature, θah, of warmest M-package colder than or equal to: [°C]	Lowest temperature, θb, of coldest M-package warmer than or equal to: [°C]	Highest minimum temperature, θal, of all M-packages colder than or equal to: [°C]
H1	+10	+1	-
H2	+10	-1	-
L1	-15	-	-18
L2	-12	-	-18
L3	-12	-	-15
M	+6	-1	-
M1	+5	-1	-
M2	+7	-1	-

Table A3.2. Test room climate class

Climate class	Dry bulb temperature [°C]	Relative humidity [%]	Dew point [°C]	Water vapor mass in dry air [g/kg]
1	16	80	12.6	9.1
3	25	60	16.7	12.0
4	30	55	20.0	14.8

Appendix 4. Product categorization in China

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

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 in Park et al 2021b for details.