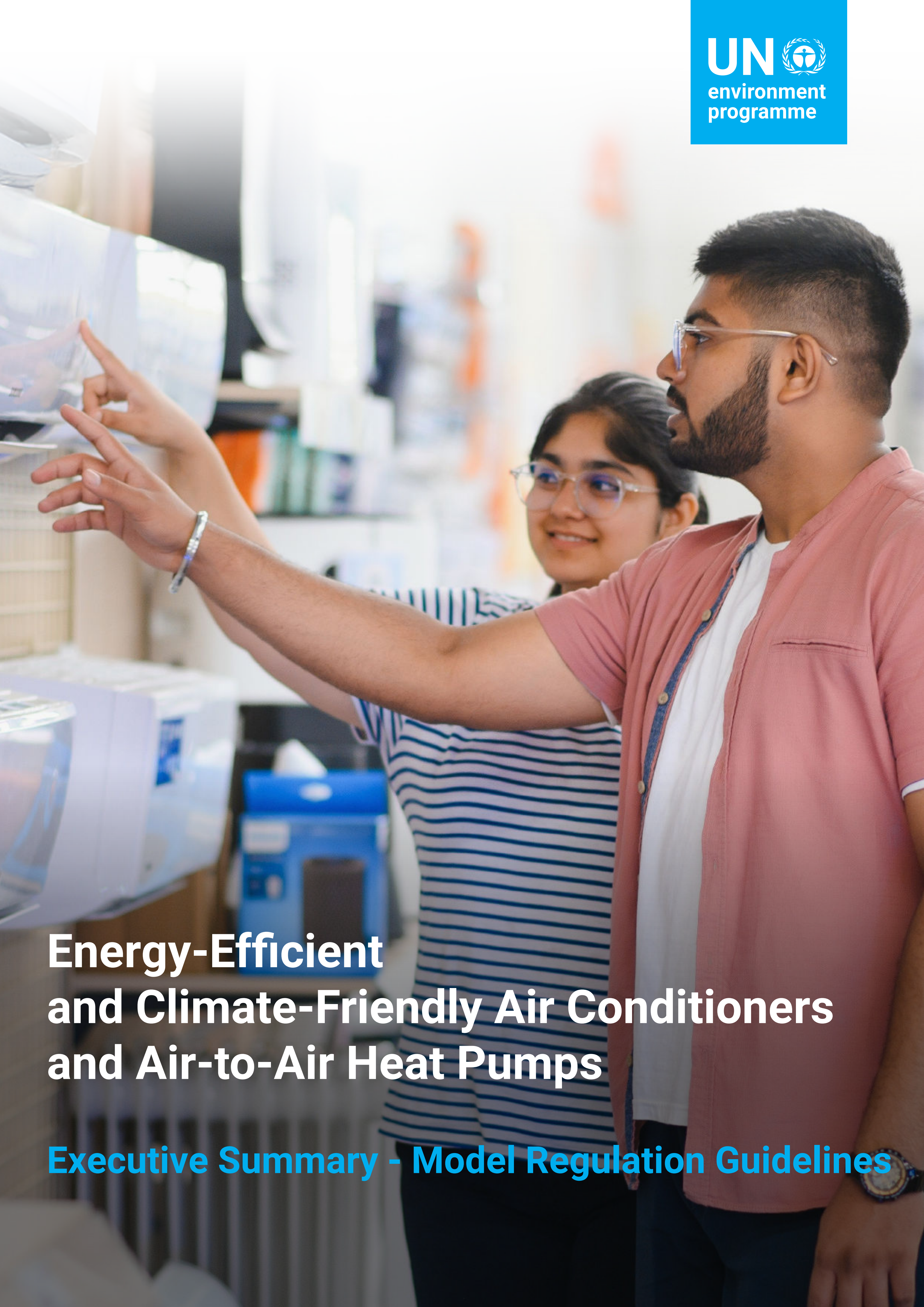


UN environment programme

Energy-Efficient and Climate-Friendly Air Conditioners and Air-to-Air Heat Pumps

Executive Summary - Model Regulation Guidelines

Suggested citation: United Nations Environment Programme (2026). *Energy-Efficient and Climate-Friendly Air Conditioners and Air-to-Air Heat Pumps, Model Regulation Guidelines (March 2026)*. Paris.

Production: United Nations Environment Programme's United for Efficiency (U4E)

URL: https://wedocs.unep.org/items/17c690cc-7e46-4e3f-8d27-393625666a0b

Cover Photo: Hryshchyshen Serhii / Shutterstock

Table of Contents

List of Tables

List of Figures

01 Overview

The Model Regulation Guidelines for Energy-Efficient and Climate Friendly Air Conditioners and Air-to-Air Heat Pumps (the Guidelines) support emerging economies in improving and harmonizing air conditioner (AC) energy-efficiency standards by recommending internationally aligned test methods and performance requirements. Regular updates to national and regional standards are essential to prevent the continued use of outdated technologies and to incorporate the benefits of commercially available and emerging innovations. As international policy practices and testing standards evolve—driven by ongoing research and harmonization efforts—it is important that countries periodically revisit and revise their national standards accordingly.

The 2019 edition of the Guidelines (2019 Guidelines) focuses on non-ducted single-split, window, and portable Air Conditioners and reversible heat pumps with cooling capacities up to 16 kW (UNEP 2019a). It adopted the International Organization for Standardization (ISO)-defined Cooling Seasonal Performance Factor (CSPF) for cooling only Air Conditioners and the Annual Performance Factor (APF) for reversible heat pumps, referencing ISO 16358 and ISO 5151 for testing procedures and seasonal efficiency metrics. The 2019 Guidelines also considered anticipated advancements in major markets, such as China's energy efficiency standards (UNEP 2019b).

Because seasonal efficiency metrics vary by region and climate, direct comparisons across countries are not always effective. Efficiency levels that appear similar may not be equivalent unless converted to account for differences in reference climates, metrics, and standards. To address this, the underlying studies developed regression models to relate various seasonal efficiency metrics, such as China's seasonal energy efficiency ratio (SEER) and ISO's CSPF (UNEP 2019b, Park et al. 2020). The 2019 Guidelines also offer recommended efficiency levels in CSPF and APF, tailored to 17 different climate zones.

The 2025 edition broadens the scope to include ducted split and multi-split systems with cooling capacities up to 70 kW. It introduces the Heating Seasonal Performance Factor (HSPF), to be used alongside CSPF in reversible heat pumps for countries that prefer to regulate heating and cooling separately rather than using the unified APF metric. Additionally, the 2025 update includes the optional Global Cooling Efficiency Accelerator (GCEA) test to identify high-efficiency units during dehumidification—particularly useful for sustainable procurement and endorsement programs in high-humidity regions (GCEA 2025).

This document outlines the updated scope and provides supporting information reflected in the 2025 edition of the Guidelines. Terminology and abbreviations used in this supporting material are consistent with those defined in the U4E Model Regulation for Energy-Efficient and Climate-Friendly Air Conditioners and Air-to-Air Heat Pumps.

02 Scope of Covered Products

The 2019 Guidelines covered Air Conditioners[1], including common types such as single-split (non-ducted), window, and portable Air Conditioners and reversible heat pumps. These were limited to units with cooling capacities up to 16 kW, typical of household and small commercial applications. Given some countries have requirements for larger than 16 kW, although those units have small shares, the 2025 Guidelines expand the scope, both in terms of cooling capacity and system configurations. The 2025 edition now includes systems up to 70 kW, allowing for the inclusion of larger commercial units. Additionally, it covers multi-split systems, ducted single-splits, and single and double duct types, reflecting changes in regional market trends and installation practices. Table 1 and Table 2 summarize the scope and reference standards of the Guidelines in the 2019 and 2025 editions.

Table 1. Summary of the Guidelines' scope

	Guidelines (2019)	Guidelines (2025)
Heat transfer method	Air-to-air	Air-to-air
Functionality / Operating mode	• Cooling only • Reversible heat pumps	• Cooling only • Reversible heat pumps
Configuration / Installation type	• Single-splits (non-ducted) • Window • Portable	• Single-splits (non-ducted) • Window • Portable, wall-mounted (single and double duct) • Single-splits (ducted) • Multi-splits
Cooling capacity	Up to 16 kW	Up to 70 kW
Efficiency metrics	CSPF, APF	CSPF, HSPF, APF
Super-efficient Air Conditioner Performance	-	Optional criteria included as an "informative" Annex.

CSPF: Cooling Seasonal Performance Factor; HSPF: Heating Seasonal Performance Factor; APF: Annual Performance Factor

1 The global Air Conditioner market is dominated by non-ducted split systems, known in the United States as mini-split Air Conditioners. In the United States, Canada, and Mexico, room Air Conditioners are typically understood to be window-type units.

Table 2. **Testing and rating standards referenced in the Guidelines**

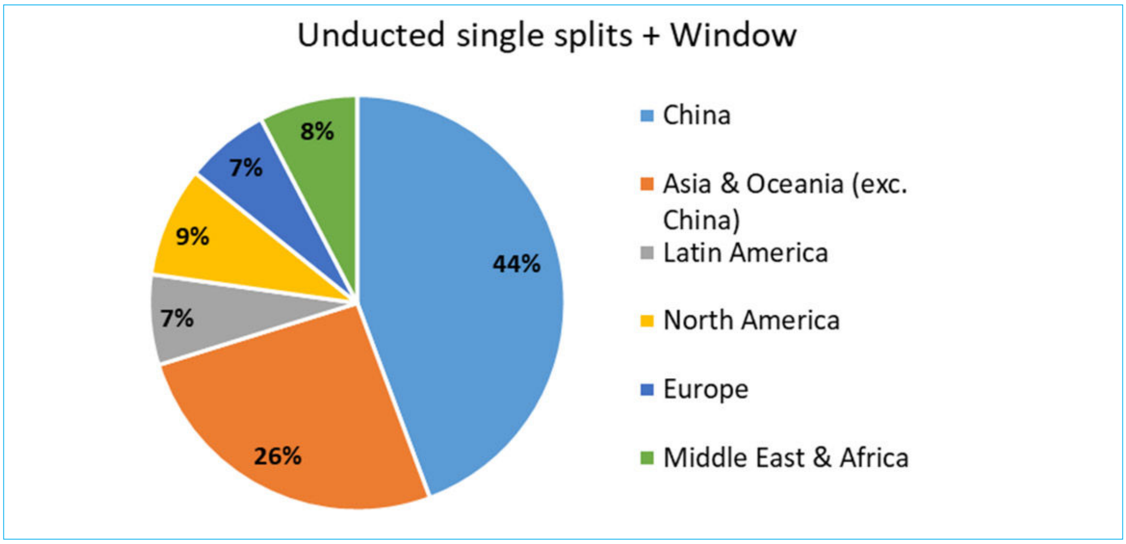
Product type		Reference standards	2019	2025
Non-ducted split and Window		ISO 5151: 2017	V	V
		ISO 5151: 2017/Amd 1: 2020	-	V
		ISO 16358-1: 2013	V	V
		ISO 16358-1: 2013/Amd 1: 2019	V	V
		ISO 16358-1: 2013/Amd 1: 2019/Amd 2: 2024	-	V
Portable and Wall mounted	Double duct	ISO 5151: 2017	V	V
		ISO 5151: 2017/Amd 1: 2020	-	V
	Single duct	ISO 18326:2018	V	V
		ISO 18326:2018/Amd 1: 2021	-	V
Ducted split		ISO 13253-1: 2013	NA	V
		ISO 13253-1: 2013/Amd 1: 2020		V
Multi-split (including VRF*)		ISO 15042: 2017	NA	V
		ISO 15042: 2017/Amd 1: 2020		V
Super-efficient Air Conditioners		Super-efficient Room Air Conditioner Performance Specification Guideline for Indian Market (2025)	NA	V

*VRF: variable refrigerant flow

03 Air Conditioner Market Trends

Market shares by region and type

Asia accounts for approximately 70% of global Air Conditioner (non-ducted split and window type) sales. China is by far the largest market, representing 44% of non-ducted single split and window Air Conditioner unit sales in 2023. The rest of Asia and Oceania (excluding China) forms the second-largest regional market, with a 26% share. North America, the Middle East & Africa, Europe, and Latin America each account for less than 10% of global sales. Non-ducted single split systems are the dominant type in most regions, with the exception of North America, where ducted systems are more common.



(a) market share by region (for non-ducted single splits and window units)

(b) non-ducted single splits (blue) and window units (orange) by region

Source: Authors' work based on JRAIA (2024), BSRIA (2024a, 2024b)

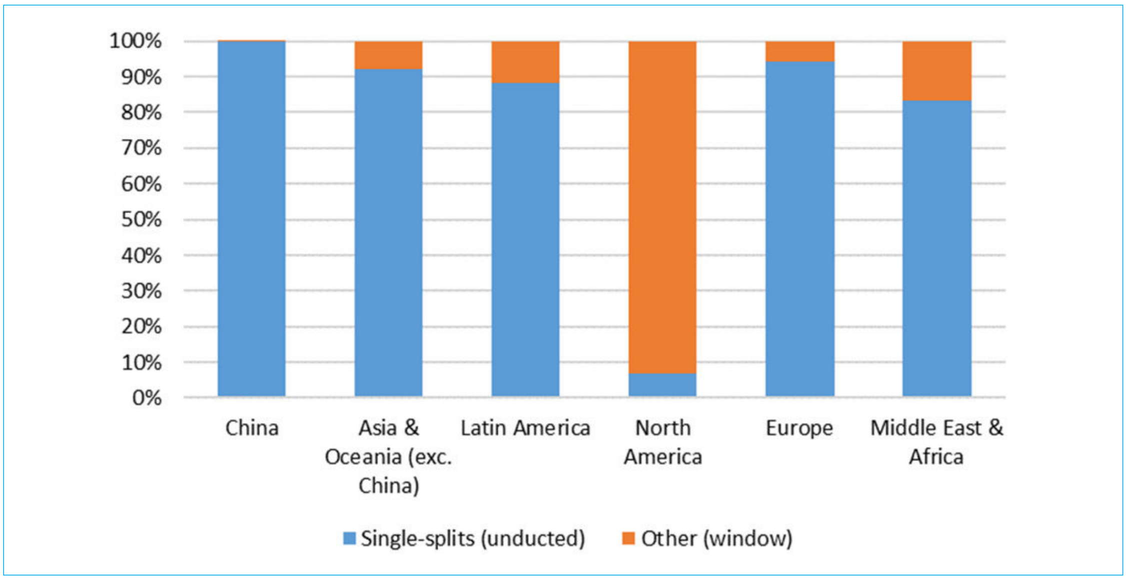


Figure 1. Global Air Conditioner (Non-ducted Split and Window Type) Sales Share in 2023 by Region and Type

Although non-ducted single-split systems dominate the global Air Conditioner market, ducted splits and window units still hold significant shares in certain countries, including the U.S., UAE, Saudi Arabia, and the Philippines:

- In the U.S., the market is led by ducted single-split systems, followed by a substantial share of window units, while non-ducted and portable units play relatively minor roles (BSRIA 2024a, 2024b).

- The UAE and Saudi Arabia are largely served by non-ducted single splits, with the UAE also showing notable use of ducted systems. Saudi Arabia continues to rely on window units as well (BSRIA 2024c, 2024d, 2024e, 2024f).

- In the Philippines, the market is nearly evenly split between non-ducted single splits and window units, with minimal use of other types (BSRIA 2022a).

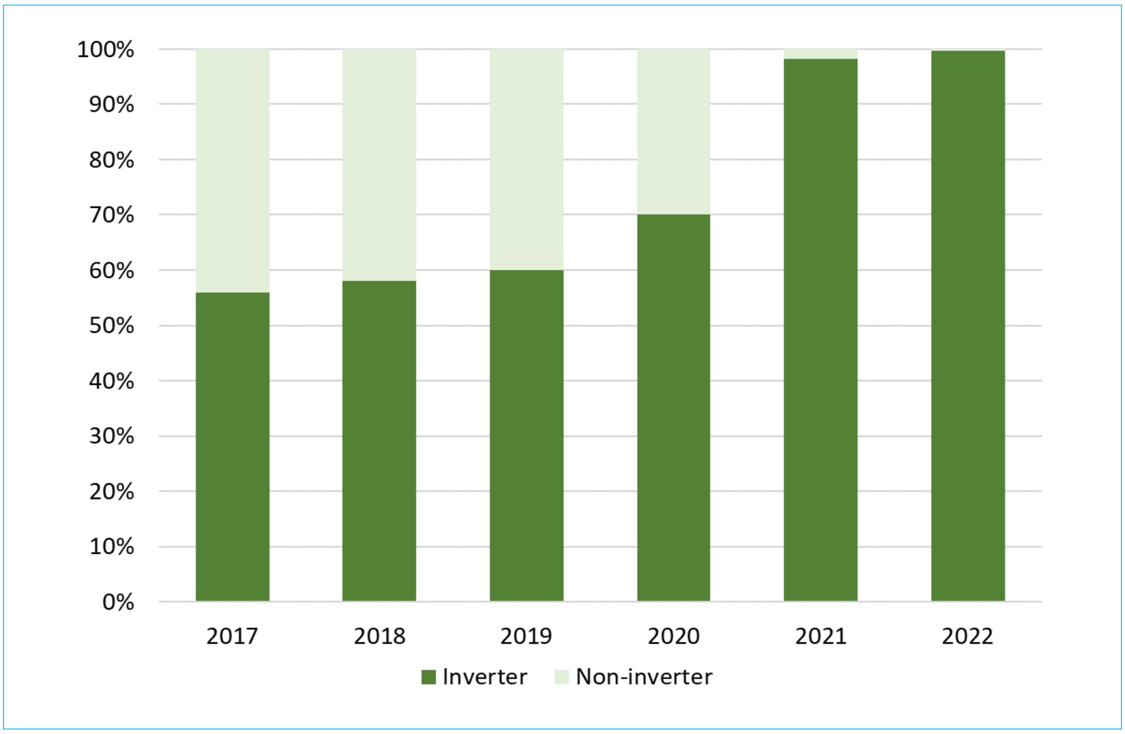
- Singapore presents a more balanced market, with single- and multi-split systems holding similar shares (BSRIA 2022c).

Overall, ducted systems are most prevalent in North America, while non-ducted single splits and window units dominate in the other regions. According to JRAIA (2024, 2022), global demand of multi-split systems, including VRF, is estimated to have increased approximately 6.7 million units in 2019 to 8.1 million units in 2023.[2]

Market penetration of variable-speed (inverter-driven) Air Conditioners

Although fixed-speed units still dominate Air Conditioner markets in many developing countries, the adoption of variable-speed (inverter) Air Conditioner units is increasing, contributing to their share reaching around 80% global single-split Air Conditioner sales. A major driver of this trend is China, which accounts for roughly half of global Air Conditioner sales. Following the implementation of new MEPS in 2020, China experienced a rapid transition to inverter technology, with inverter units rising from 55% of sales in 2017 to nearly 99% by 2021 (Figure 2). (Park and Shah 2025. Note that nearly all inverter units in China are reversible heat pumps.).

2 JRAIA (2024, 2022) do not specify the demand of multi split systems in Japan, although VRF demand in Japan accounts for approximately 5%-8% of the global demand. For this estimate, we applied the same share to multi-split systems.



Source: Park and Shah (2025)

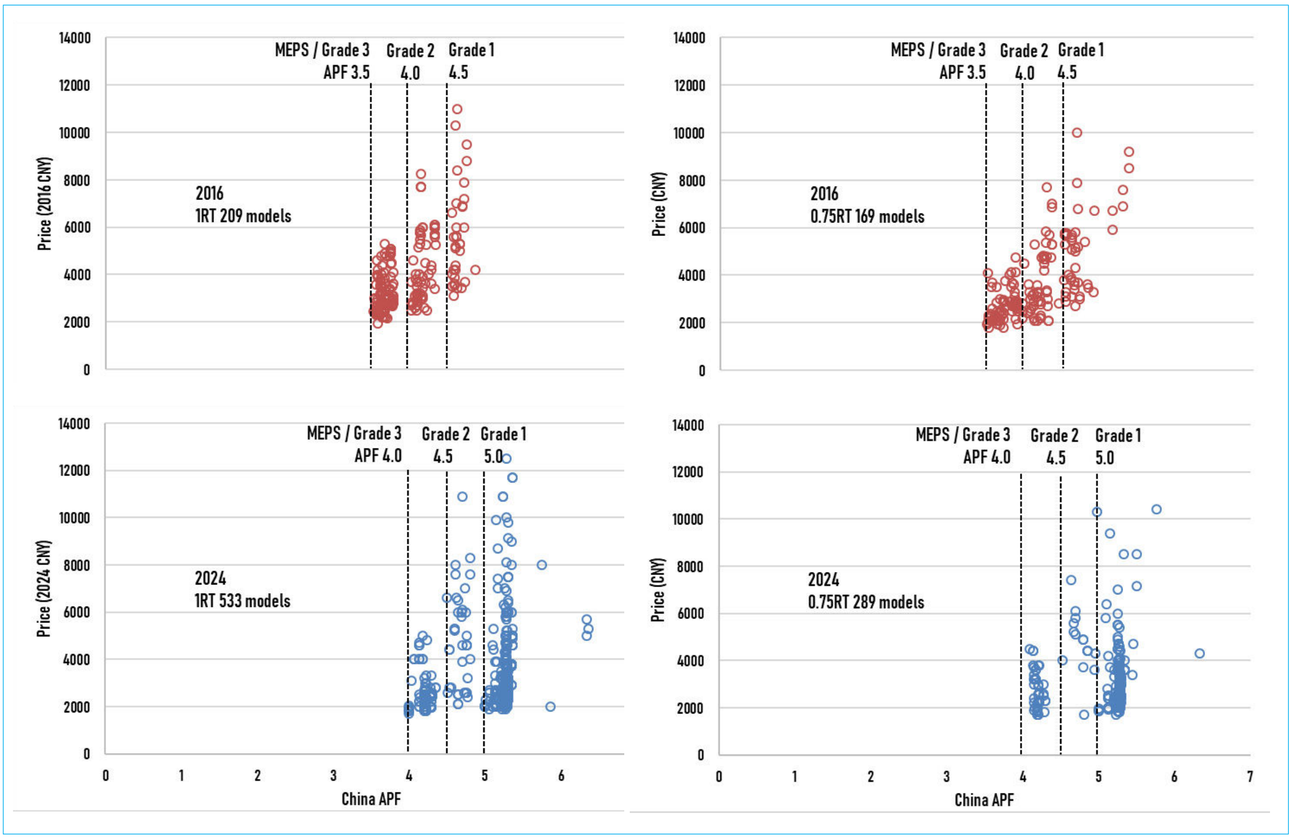
Figure 2. China's Air Conditioner market transition (2017–2022)

In India, the market has also shifted significantly with variable-speed (inverter) units making up approximately 70% of sales by 2022 (BSRIA 2024g). In ASEAN countries, the penetration of variable-speed (inverter) Air Conditioners varies widely, ranging from around 10% to over 90%, depending on country. A survey conducted by the International Institute for Energy Conservation (IIEC) estimates that in Malaysia, inverter models are estimated to make up between 30% and 65% of the market (Park and Shah 2025, Park et al. 2021).

In the Philippines, the market share of inverter units increased from ~70% in 2020 to over 90% in 2023 (BSRIA 2025a, 2022b). In Malaysia, the market share of inverter units is expected to rise significantly from 35% in 2023 to 70% by 2026 (BSRIA 2025b), driven by the MEPS improvement plan announced in 2025 (see Section 3 and Table 3).

Price trends

Park et al. (2017) analyzed the relationship between efficiency and price of Air Conditioners in China. They found that while high efficiency is often a feature of high-end products, highly efficient and cost-competitive models are also available. After that, Air Conditioner price trends in China shifted following the implementation of stricter MEPS in 2020 (Figure 3). The data suggest that manufacturers generally maintain similar price levels across their product lineup, even as performance improves. Moreover, high-efficiency models meeting Grade 1 (China APF ≥ 5) qualified models are not necessarily priced higher than baseline inverter models (Grade 3, China APF 4). In fact, the lowest-priced models in 2024 were below those in 2016, even without adjusting for inflation.



(Cooling Capacity 0.75 RT/1 HP/2.6 kW, left panel; 1 RT/1.5 HP/3.5 kW, right panel)

Source: Park and Shah (2025)

Figure 3. Price trends for variable-speed Air Conditioners in China, 2016 vs. 2024

In Malaysia, Air Conditioner market prices also reflect the bundling of features beyond energy efficiency, as prices at the same efficiency level can vary by more than 200%. CSPF 5–6 inverter units are available within the same price range (USD 200–400) as CSPF 3–4 fixed-speed models (Park and Shah, 2025, UNEP and IIEC, 2024).

04 Energy-Efficiency Performance Requirements

U4E Guidelines assisted policy implementation

The 2019 edition of the U4E Guidelines references ISO 16358 and ISO 5151 for testing protocols and seasonal efficiency metrics, incorporating both current and anticipated developments in major markets, including China's energy efficiency standards.

The Association of Southeast Asian Nations (ASEAN) represents one of the world's fastest-growing markets for cooling technologies. With Air Conditioner penetration at just 15% in 2020, the number of installed units in the region is projected to increase from 50 million in 2020 to 300 million by 2040. In response, the ten ASEAN Member States (AMS) updated their regional policy roadmap in 2021 to harmonize minimum energy performance standards (MEPS) across the region (ACE 2021). The roadmap outlines a phased approach - adopting MEPS equivalent to ISO CSPF 3.7 by 2023, comparable with levels in India, and ISO CSPF 6.09 by 2025, consistent with the 2019 Guidelines. Following the roadmap's release, national implementation efforts began. Singapore led the way by adopting 2019 Guidelines-aligned MEPS in April 2025 (NEA 2025a). Malaysia followed with a scheduled implementation date of January 1, 2030, introducing intermediate CSPF requirements (≥3.1 through 2025, and ≥4.1 in 2026) to provide manufacturers with adequate lead time to adapt while ensuring energy efficiency gains (Energy Commission 2025).

Similarly, the Southern African Development Community (SADC), comprising 16 countries, approved a regional standard in 2023, which follows a phased alignment with the 2019 U4E Guidelines (SADCSTAN 2023). The first phase, implemented in 2024, bans Air Conditioners with CSPF values below 4.5, with the threshold rising to 6.1 by 2027. The East African Community (EAC), composed of 8 member countries, has taken a similar path. In addition to agreeing on a common MEPS, EAC countries adopted a regional energy label to streamline trade and improve compliance. The regional standard was approved in March 2025 (EAC 2025, EACREEE 2024). Rwanda is expected to be the first to enforce the standard, having developed and validated its national regulation in parallel.

Nigeria is another strong example of how the U4E Guidelines can be adapted to local conditions. In 2025, Nigeria released a national energy efficiency standard for Air Conditioners (UNEP 2025). Given the country's generally higher temperatures compared to the SADC and EAC regions, a customized climate table was developed to reflect its local climatic variations. Nigeria's implementation plan consists of three progressive phases, with the final step—aligned with the 2019 Guidelines and covering multi-split and ducted systems—set to take effect in 2031.

Figure 4 shows a comparison of the minimum requirements for Air Conditioners in select economies. Table 3 presents the Energy Commission's MEPS improvement plan for Air Conditioners in Malaysia. Table 4 provides an overview of country- and region-specific policies that align with the 2019 U4E Guidelines.

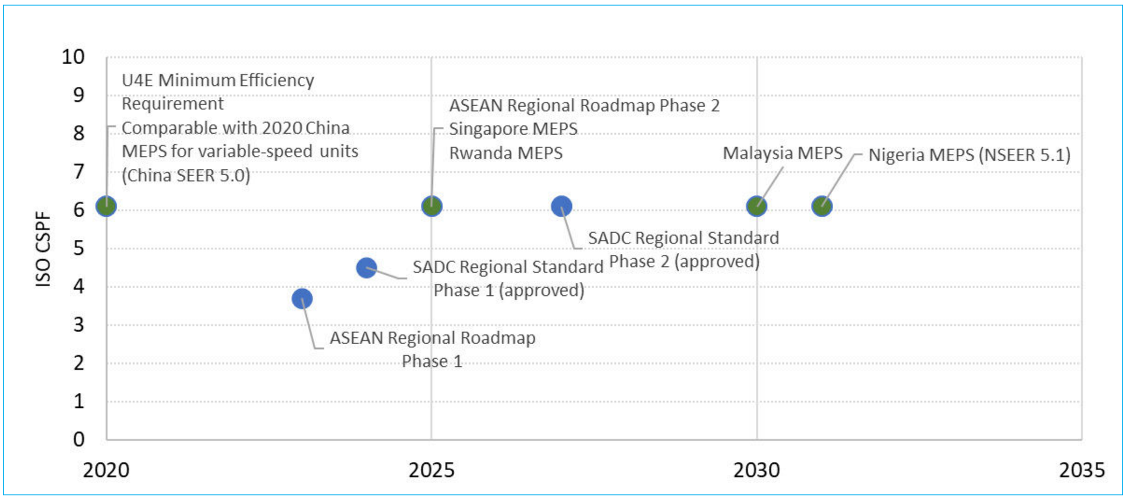


Figure 4. MEPS improvement in support of the Guidelines (as of August 2025)

Table 3. MEPS improvement plan for Air Conditioners in Malaysia

Capacity <4.5 kW (1.0–1.5 HP)

		Phase 1	Phase 2
	Jan 1, 2025 – Dec 31, 2025	Jan 1, 2026 – Dec 31, 2029	Jan 1, 2030
5	≥5.30	≥ 6.09	≥ 7.50
4	4.60 ≤ CSPF < 5.30	5.40 ≤ CSPF < 6.09	7.30 ≤ CSPF < 8.00
3	3.30 ≤ CSPF < 4.60	4.80 ≤ CSPF < 5.40	6.60 ≤ CSPF < 7.30
2	3.10 ≤ CSPF < 3.30	4.10 ≤ CSPF < 4.80	6.09 ≤ CSPF < 6.60

4.5 kW ≤ Capacity <7.1 kW (2.0–2.5 HP)

		Phase 1	Phase 2
	Jan 1, 2025 – Dec 31, 2025	Jan 1, 2026 – Dec 31, 2029	Jan 1, 2030
5	≥ 5.10	≥ 5.60	≥ 7.00
4	4.00 ≤ CSPF < 5.10	5.00 ≤ CSPF < 5.60	6.50 ≤ CSPF < 7.00
3	3.10 ≤ CSPF < 4.00	4.40 ≤ CSPF < 5.00	6.09 ≤ CSPF < 6.50
2	2.90 ≤ CSPF < 3.10	4.00 ≤ CSPF < 4.40	5.60 ≤ CSPF < 6.09

Source: The Energy Commission of Malaysia (Park and Shah, 2025)

Table 4. Summary of MEPS improvements aligned with U4E Guidelines

Region	Implementation	Status
ASEAN (10 countries)	Regional roadmap	Updated in 2021 to adopt ISO CSPF 3.7 by 2023 and ISO CSPF 6.09 by 2025
	National implementation	• Singapore has adopted WCOP 4.86 (equivalent to CSPF 6.09), effective April 2025 • Malaysia has adopted CSPF 3.1 (2025), CSPF 4.1 (2026), and CSPF 6.09 (2030) • Other AMS in discussion or development in Philippines, Vietnam, Lao PDR, and Cambodia
SADC (16 countries)	Regional standard	Approved in 2023 to adopt ISO CSPF 4.5 by 2024 and ISO CSPF 6.09 by 2027
	National implementation	In process in South Africa, Eswatini, Botswana, and Zimbabwe
EAC (8 countries)	Regional standard	Approved in 2025
	National implementation	Rwanda is expected to implement the regional standard in their Technical Regulation in 2025
Other	National implementation	• Nigeria has adopted NSEER 5.1 (equivalent ISO CSPF 6.09) by 2031 • Gambia implementation is in process. • Countries such as El Salvador, Honduras, Cuba, Brazil, and Ghana, among others, may not be fully aligned with the Model Regulations but have drawn significant influence from them during their development processes, resulting in higher efficiency standards.

Source: Pitarch et al. (2025)

In India, the MEPS (corresponding to the 1-star level) have improved at an average rate of 2–3% annually over the past decade. By 2025, the 1-star and 5-star levels are 3.3 and 5.0 ISEER, respectively, with further revisions expected to raise them to 3.8 and 5.8 (see Table 5). The market has experienced a transition toward variable speed (or inverter) technology, accounting for more than 75% of new sales in 2023. According to Abhyankar et al. (2025), the ISEER 5.0 level, today's 5-star threshold which is similar to the U4E Guidelines MEPS recommendations, has already exceeded by more than 600 models, representing about 20% of the market. The identified best available technology (BAT) in India achieves an ISEER of 6.3, which is nearly double the MEPS level of ISEER 3.3. The most efficient commercially available Air Conditioner sold globally is estimated to achieve an ISEER of 7.4 (comparable to a CSPF of 8.6), or even higher (CSPF 9–10), depending on the size. (Abhyankar et al. 2025, Phadke et al. 2020, Park et al 2020).

Table 5. Minimum ISEER levels for star labels for variable speed Air Conditioners in India

	2021-2025		2026-2027		2028-2029	
	ISEER	ISO CSPF equivalent[a]	ISEER	ISO CSPF equivalent[a]	ISEER	ISO CSPF equivalent[a]
1-star	3.3	4.1	3.5	4.4	3.8	4.7
2-star	3.5	4.4	3.8	4.7	4.3	5.2
3-star	3.8	4.7	4.3	5.2	4.7	5.7
4-star	4.4	5.4	5.0	6.0	5.2	6.2
5-star	5.0	6.0	5.6	6.7	5.8	6.9
India BAT	6.3	7.4	-		-	

a Authors' work using a regression equation (ISO CSPF = 1.0957 x ISEER + 0.5315) based on performance data (see Annex A).
Sources for ISEER values: MOP (2025), Abhyankar et al. (2025); Source for BAT: Abhyankar et al. (2025)

Cooling efficiency requirements in the 2025 edition of the Guidelines

For determining the CSPF of fixed-speed units in Group 1 and 3 climates, the Guidelines use only one set of test data at full-capacity operation at 35°C, and use another set of data points at 29°C calculated by the default equations in ISO 16358. The CSPF values of fixed-speed units are calculated in a linear relationship with the EER values: CSPF = α × EER (α = 1.062 with the ISO temperature bin hours).

For variable-speed units in Group 1 and 3 climates, the Guidelines determine CSPF while reducing compliance costs by using two sets of test data at full- and half-capacity operation at 35°C and another set of data points at 29°C calculated by ISO 16358 default equations, without considering minimum-capacity operation.

Table 6 shows the test conditions used in the Guidelines for evaluating cooling efficiency in Air Conditioners. Efficiency results for the same model may vary depending on whether the optional test points of ISO 16358 are used, or the default equations specified in the Guidelines are applied. Countries adopting the U4E recommendations but opting to allow the ISO optional test points should therefore conduct an analysis to adjust the recommended efficiency levels accordingly.

Similarly, countries applying test standards different from those referenced in the Guidelines but seeking to adopt the recommended MEPS should translate the Guidelines levels (based on ISO standards for different climates) into equivalent values under their chosen test method. In some cases, more than one standard is accepted for conformity assessment. In such situations, each standard should include its own minimum performance levels, aligned to ensure comparable stringency and to avoid unintended advantages.

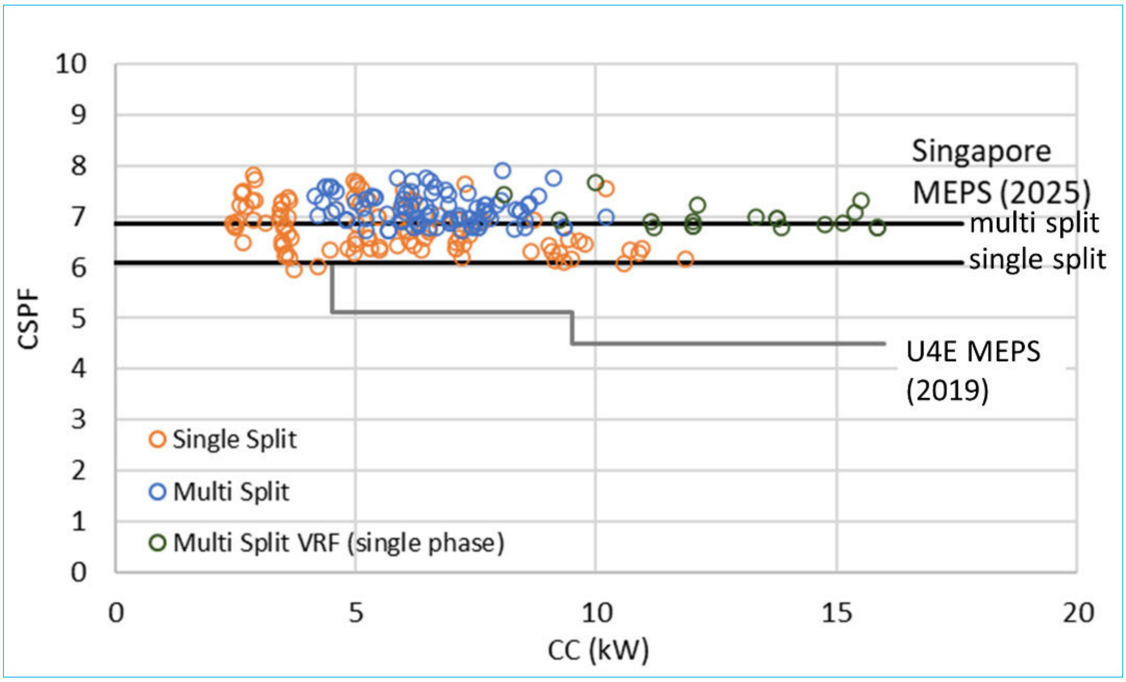
Table 6. Primary test conditions for cooling efficiency in Air Conditioners

	Fixed Speed	Variable Speed
Full capacity (35°C)	Required	Required
Half capacity (35°C)	NA	Required
Min capacity (35°C)	NA	Not Considered
Full capacity (29°C)	Default[a]	Default[a]
Half capacity (29°C)	NA	Default[a]
Min capacity (29°C)	NA	Not Considered

a capacity(29°C) = capacity(35°C) × 1.077; power input(29°C) = power input (35°C) ×0.914.
Reference standard: ISO 16358-1: 2013

Figure 5 presents the CSPF[3] from models in the Singapore database plotted against cooling capacity (CC, in kW) for three types of Air Conditioner systems: single splits (orange), multi splits (blue), and single-phase multi split VRF systems (green), all with capacities up to 17.6 kW. The solid black lines represent Singapore's 2025 MEPS: CSPF 6.09 (converted from WCOP 4.86, see Appendix A) for single splits, CSPF 6.86 (converted from WCOP 5.50) for multi splits, including single-phase VRFs. All registered products are clustered between CSPF 6.1 and 8.0, indicating strong compliance with the stringent MEPS levels. The 2019 U4E MEPS, shown in grey, is less stringent than Singapore's 2025 MEPS across the capacity range, particularly for higher cooling capacities. This indicates that the Singapore MEPS are more stringent than the current U4E MEPS for capacities higher than 4.5 kW and that many multi-splits and VRF products already available in the market have the capability to meet or exceed the U4E MEPS levels if they would be implemented for this type of units.

3 For this analysis, the default ISO 16358-1 climate has been used to calculate energy efficiency.



Source: Authors' work based on the data from NEA (2025b)

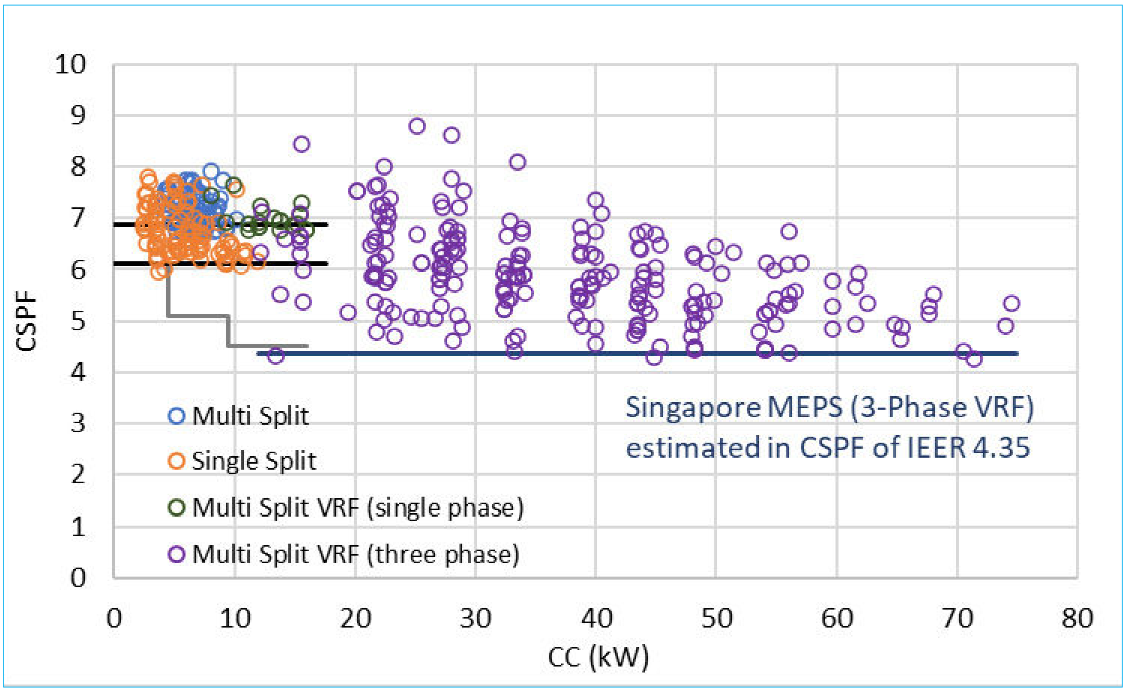
Note: The plotted efficiency data for Singapore products and MEPS have been converted from WCOP to CSPF by LBNL (see Appendix A). As a result, some converted values may appear slightly below the CSPF thresholds of 6.09 or 6.86 due to calculation differences.

Figure 5. CSPF of Air Conditioners (up to 16 kW CC) in Singapore, compared to Singapore 2025 MEPS and 2019 U4E Guidelines

Singapore has established MEPS for three-phase VRF systems—typically large-capacity units—based on AHRI 1230 and the Integrated Energy Efficiency Ratio (IEER) metric. As shown in Figure 6, the estimated CSPF-equivalent efficiency of three-phase VRF units available in Singapore (represented in purple) varies by cooling capacity (CC):

- For units between 20–30 kW, CSPF ranges from 4 to 9,
- For 30–40 kW, CSPF ranges from 4 to 8,
- For 40–60 kW, CSPF ranges from 4 to 7
- For units above 60 kW, CSPF remains in the range of 4 to 6

These values are approximate, based on the conversion of IEER to CSPF, and indicate a wide spread of efficiency performance across available models.

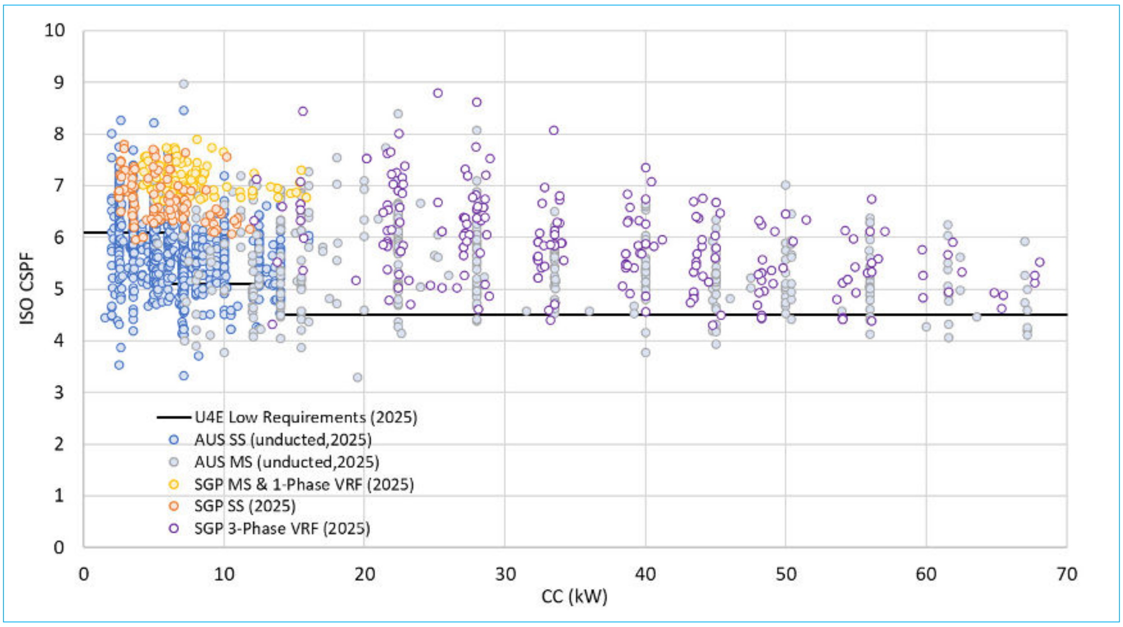


Source: Authors' work based on the data from NEA (2025b)

Note that the plotted efficiency data for Singapore products have been converted from WCOP to CSPF, or estimated from IEER to CSPF by LBNL. While the estimated CSPF corresponding to an IEER of 4.35 falls within an approximate range of 4.1 to 5.5, we have assumed a CSPF of 4.35, aligned with the lowest converted value (see Appendix A).

Figure 6. CSPF of Air Conditioners, including 3-phase multi-split VRF, in Singapore, compared to Singapore 2025 MEPS and 2019 U4E Guidelines

For the 2025 U4E Guidelines edition, the minimum efficiency requirements remain unchanged from the 2019 version, while the capacity ranges have been slightly adjusted. Figure 8 presents the new efficiency requirements, plotted with the models from the Singapore and Australian databases. Table 7 shows the share of models from each database that would comply with the 2025 U4E low efficiency requirements, as well as the distribution of models classified as low, intermediate, and high efficiency by type (single-split and multi-split). Of 1,614 models analyzed (841 single-split and 774 multi-split), 75% (1,212 models - 529 single-split and 683 multi-split) are assessed to meet the new low efficiency requirements. In addition, the CSPF of 671 models (~42% of the total) have CSPF values concentrated between 5 and 6. Although some single-split models with CC≤6kW in Australia do not meet the CSPF requirement of 6.1, the Australian MEPS is not defined by CSPF. It appears that a CSPF of 3.5 or similar might be roughly equivalent to the current MEPS level (for cooling capacities under 6 kW). However, 53% of the 739 single-split models analyzed achieve a CSPF between 5 and 6, and 34% achieve a CSPF of 6 or higher (see Figure 7 and Figure 8).



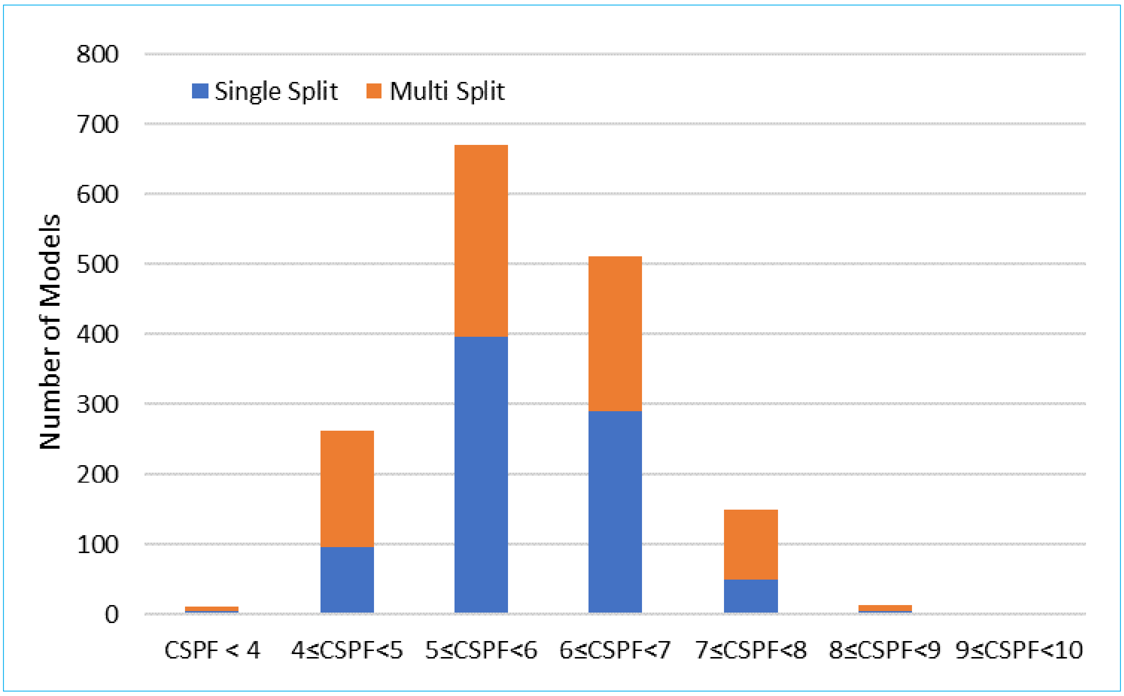
AUS: Australia; SGP: Singapore; SS: single split; MS: multi split

Total 1,614 models (AUS SS: 739, AUS MS: 425, SGP MS&1-Phase VRF: 121, SGP SS: 102, SGP SS: 227)

Non-ducted systems account for approximately 90% of the market in Singapore, although NEA (2025b) does not distinguish between ducted and non-ducted systems.

Source: Authors' work based on the data from NEA (2025b) and Commonwealth of Australia (2025)

Figure 7. CSPF requirements in the U4E Guidelines (2019 and 2025)

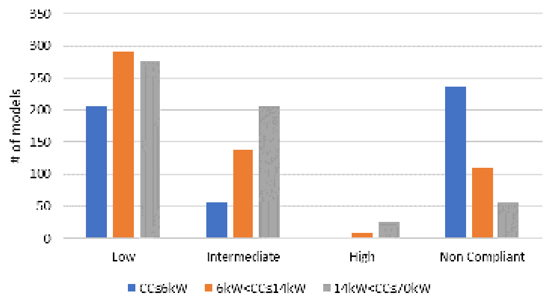
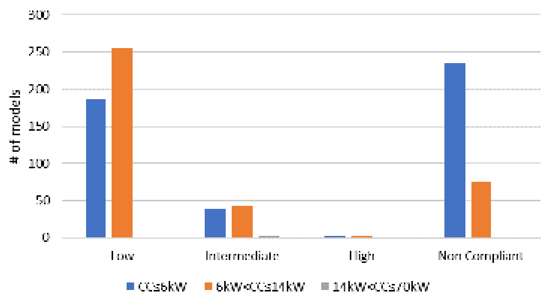
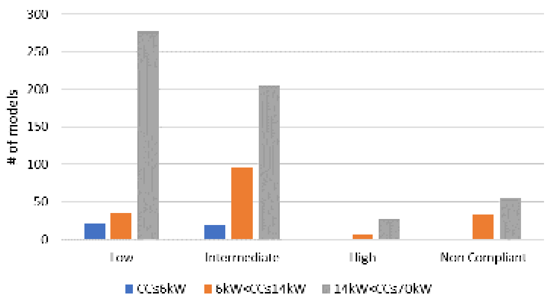


Total 1,614 models (single split: 841, multi split, including VRF: 773)

Source: Authors' work based on the data from NEA (2025b) and Commonwealth of Australia (2025)

Figure 8. CSPF distribution of the 1,614 models in Singapore and Australia in 2025

Table 7. **Distribution of the 1,614 models (Figure 8), by efficiency class and type**

	Efficiency Class	CC≤6kW	6kW<CC≤14kW	14kW<CC≤70kW	Distribution
All	Low	206	291	277	 Compliant 1,212 models (75%) Non compliant 402 models (25%)
	Intermediate	56	138	206	
	High	3	9	26	
	Non compliant	237	109	56	
SS	Low	186	256	0	 Compliant 529 models (63%) Non compliant models 312 (37%)
	Intermediate	38	42	2	
	High	3	2	0	
	Non compliant	236	76	0	
MS	Low	20	35	277	 Compliant 683 (88%) Non compliant 90 (12%)
	Intermediate	18	96	204	
	High	0	7	26	
	Non compliant	1	33	56	

Heating efficiency requirements in the 2025 edition of the Guidelines

For determining the HSPF of fixed-speed units, the Guidelines use only two sets of test data at full-capacity operation at 7°C and frosting range full-capacity operation at 2°C, and use another set of data points at -7°C calculated by predetermined equations.

For variable-speed units, the Guidelines determine HSPF by using three sets of test data at full- and half-capacity operation at 7°C, frosting range full-capacity operation at 2°C, and other sets of data points at -7°C, full- and half-capacity operation at 2°C, frosting range half-capacity operation at 2°C, calculated by ISO 16358-determined equations, without considering minimum-capacity operation.

Table 8 shows the rating conditions the Guidelines are based on for heating efficiency in reversible heat pumps.

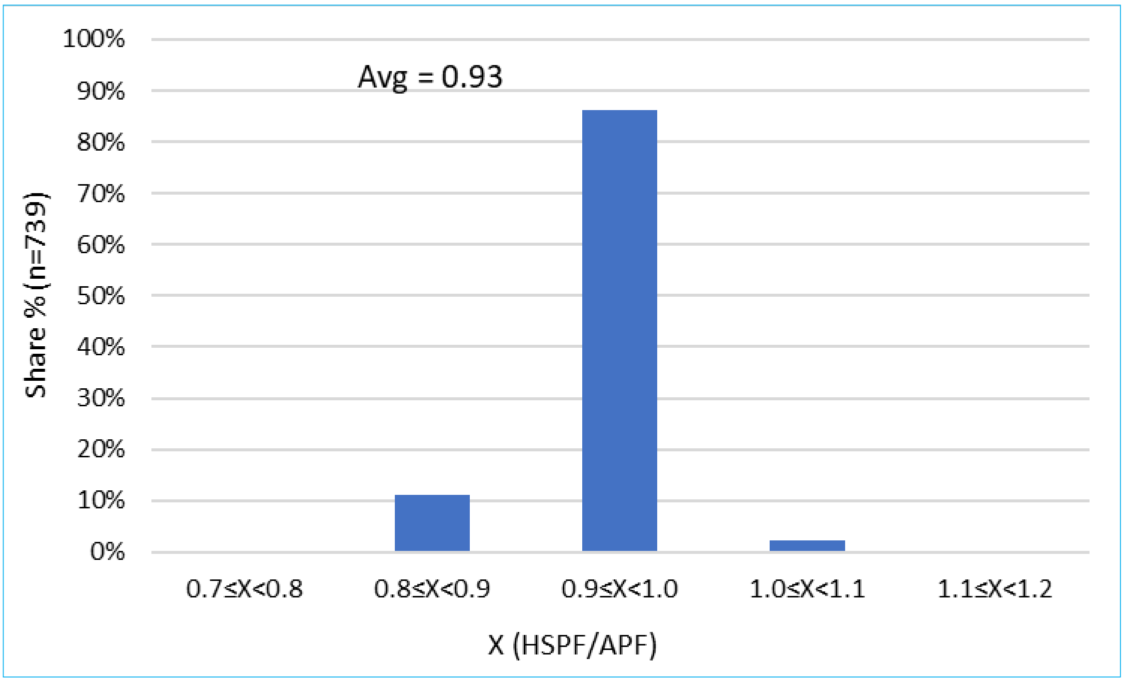
Table 8. Primary test conditions for heating efficiency in Air Conditioners

	Extended Capacity	No Extended Capacity	
	Variable Speed	**Fixed Speed**	**Variable Speed**
Full capacity (7°C)	Required	Required	Required
Half capacity (7°C)	Required	NA	Required
Extended capacity, frosting (2°C)	Required	NA	NA
Full capacity, frosting (2°C)	Default	Required	Required
Half capacity, frosting (2°C)	Default	NA	Default
Extended capacity, frosting (-7°C)	Default	NA	NA
Full capacity (-7°C)	Default	Default	Default
Half capacity (-7°C)	Default	NA	Default
Extended capacity (2°C)	Calculated	NA	NA

a **Heating extended-load operation (ISO 16358-2):** Operation of the equipment at maximum continuous refrigeration capacity at H2 condition. Unless otherwise regulated by the automatic controls of the equipment, all indoor units and compressors shall be functioning.

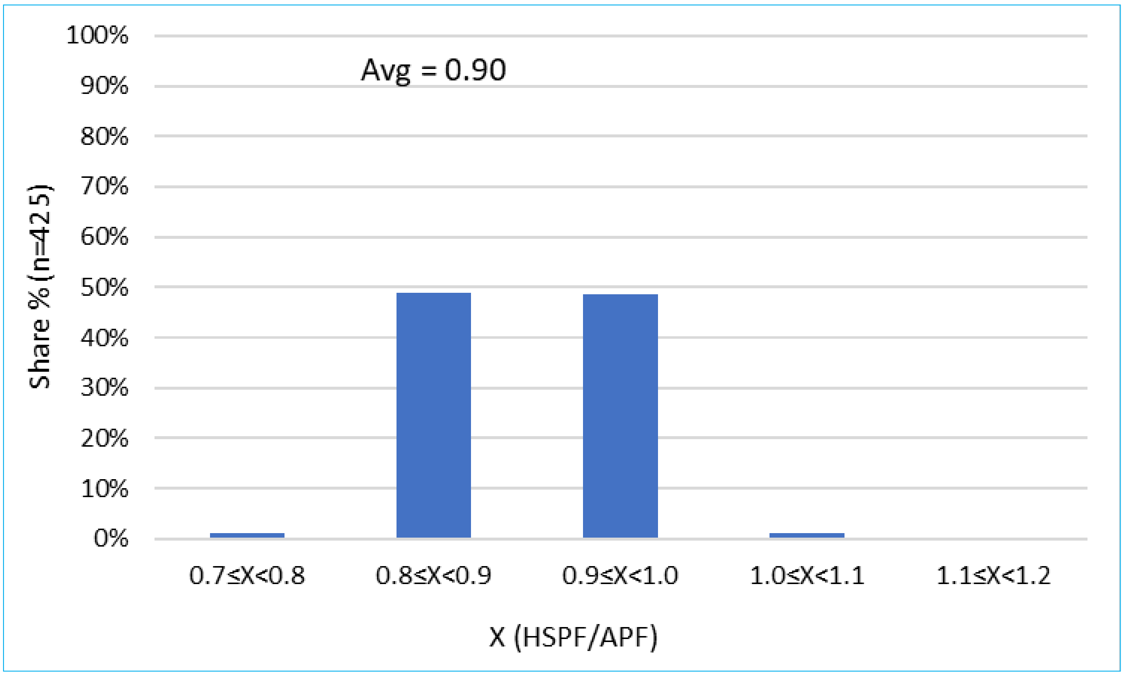
Heating full-load operation (ISO 16358-2): Operation of the equipment at maximum continuous refrigeration capacity at H1 condition. Unless otherwise regulated by the automatic controls of the equipment, all indoor units and compressors shall be functioning.

Based on ISO HSPF results of 739 single-split heat pump models selected from the Australian energy efficiency program database, the average ISO HSPF-to-APF ratio is 0.93 with values ranging from 0.84 to 1.15 (Figure 9). For 425 multi-split heat pump models selected from the same database, the average ratio is 0.90 with a range of 0.79 to 1.15 (Figure 10). Accordingly, the Guidelines' HSPF requirements using the ISO 16358 temperature bin hours have been set at 91% of the corresponding APF requirements for both single and multi-split systems.



Source: Authors' work based on the data from Commonwealth of Australia (2025).

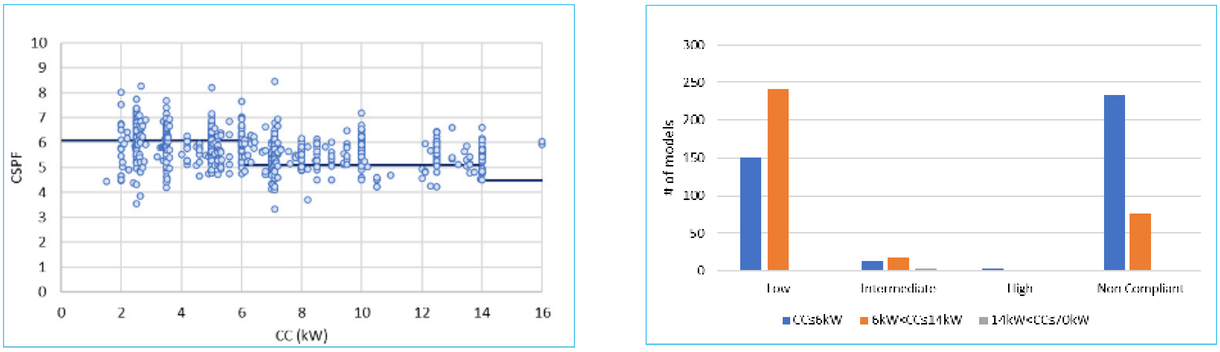
Figure 9. **Distribution of HSPF of 739 single split heat pumps models in Australia**



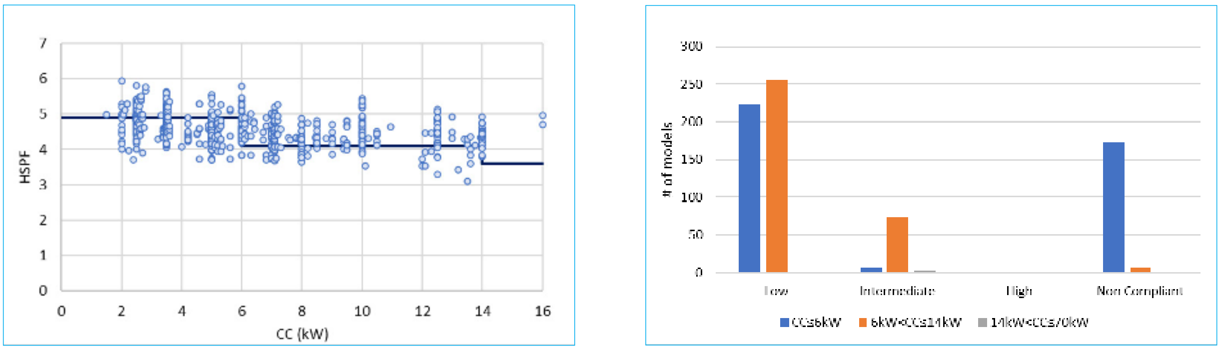
Source: Authors' work based on the data from Commonwealth of Australia (2025).

Figure 10. **Distribution of HSPF of 425 multi split heat pumps models in Australia**

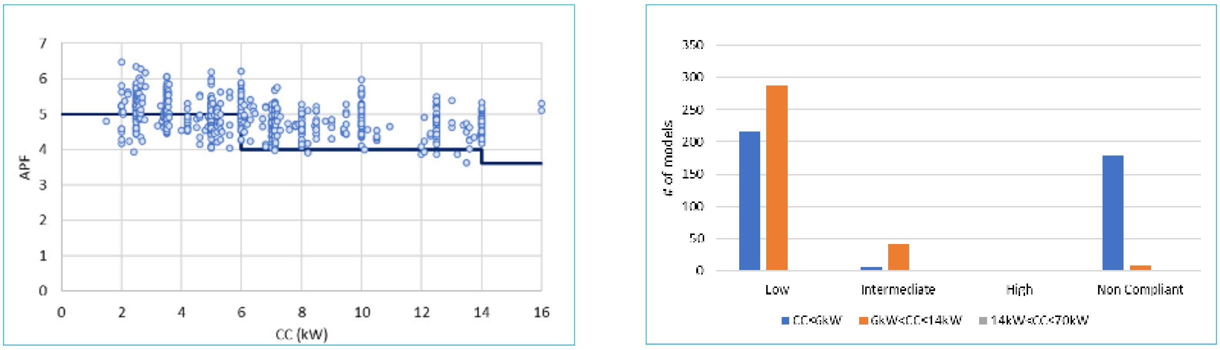
Figure 11 presents the CSPF, HSPF, and APF values plotted against cooling capacity (CC, in kW) for the 739 single-split heat pump systems. Among these, 429 models (58%) meet the Guidelines' minimum requirements for CSPF, 560 models (76%) for HSPF, and 552 models (75%) for APF.



(a) Cooling Efficiency in ISO CSPF



(b) Heating Efficiency in ISO HSPF



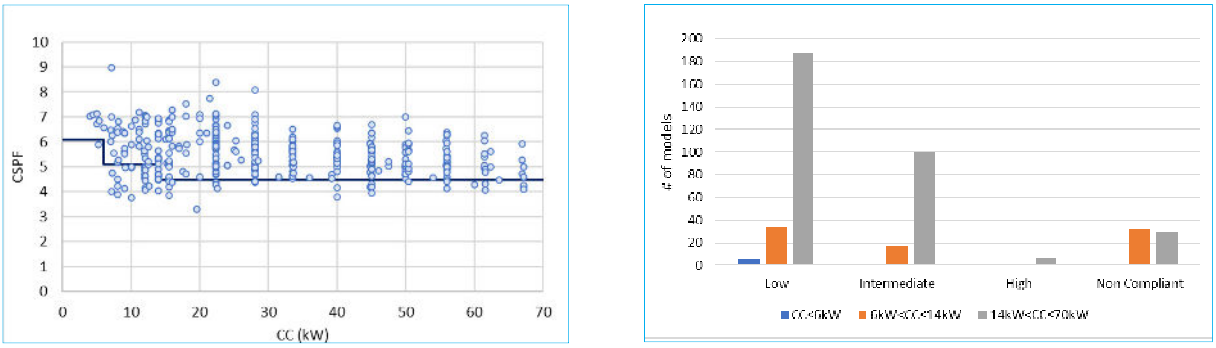
(C) Cooling & Heating Efficiency in ISO APF

Source: Authors' work based on the data from Commonwealth of Australia (2025).

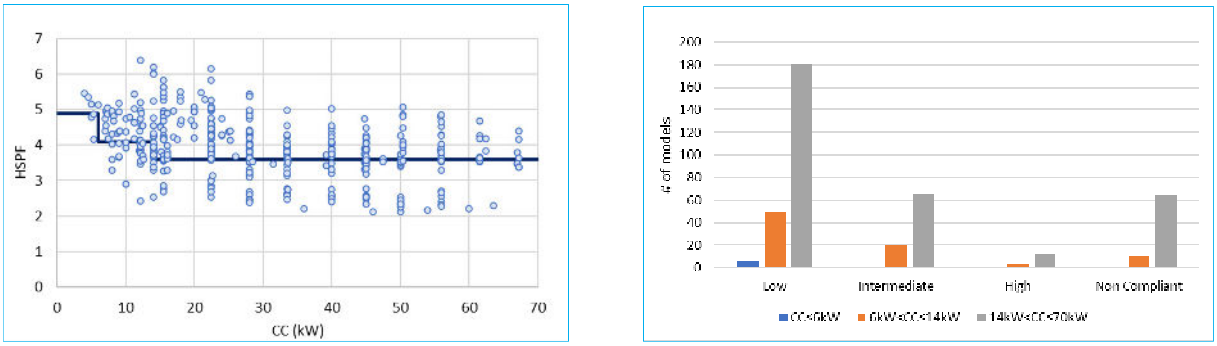
Note: The plotted ISO efficiency data for Australian program data have been calculated by authors.

Figure 11. CSPF, HSPF, and APF of 739 single-split heat pumps in Australia, compared to the U4E Guidelines low requirements

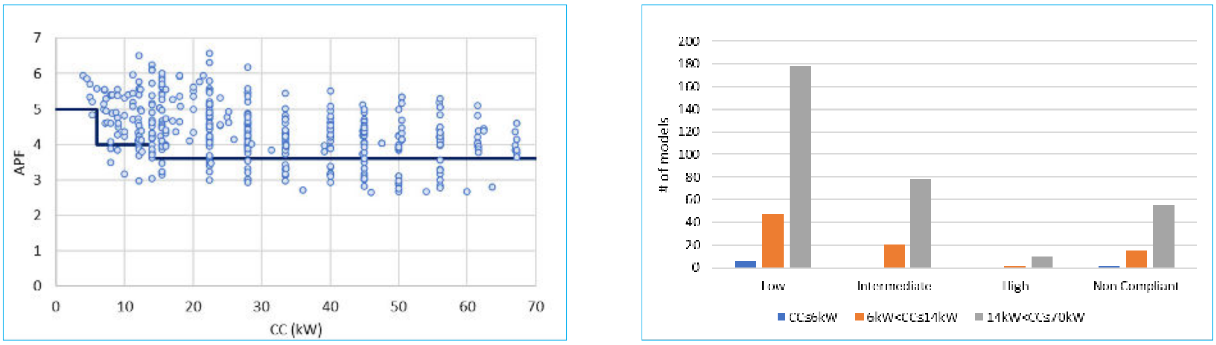
Figure 12 presents the CSPF, HSPF, and APF values plotted against cooling capacity (CC, in kW) for the 425 multi-split heat pump systems. Among these, 351 models (85%) meet the Guidelines' low requirements for CSPF, 337 models (82%) for HSPF, and 341 models (83%) for APF.



(a) Cooling Efficiency in ISO CSPF



(b) Heating Efficiency in ISO HSPF



(C) Cooling & Heating Efficiency in ISO APF

Source: Authors' work based on the data from Commonwealth of Australia (2025).

Note: The plotted ISO efficiency data for Australian program data have been calculated by authors.

Figure 12. CSPF, HSPF, and APF of 425 multi-split heat pumps in Australia, compared to the U4E Guidelines low requirements

In addition, based on ISO HSPF results of 30 single-split and 40 multi-split heat pump models selected from the same database, the average ISO HSPF-to-APF ratios vary by climate profiles in Group 1 and Group 3, ranging from 0.84 to 0.98.4 Separately, based on ISO HSPF and ISO (T3) CSPF results for several models, ISO HSPF-to-APF ratios range approximately from 0.96 to 1.05. For this case, a factor of 0.96 has been adopted to maintain consistency with the expected efficiency order: CSPF > APF > HSPF. The Guidelines' HSPF requirements with other temperature bin hours have been set in this range of the corresponding APF requirements for single and multi-split systems (Table 9).

4 Note that the range refers to the average ISO HSPF-to-APF ratios by climate group. For the 70 models analyzed, individual ISO HSPF-to-APF ratios range from 0.55 to 1.12.

Table 9. Average HSPF-to-APF Ratio by Climate Group

Climate Group by Guidelines			Average HSPF-to-APF Ratio
Group 1	Primary	ISO 16358	0.91
	Secondary	0A	-
		1A	0.89
		2A	0.84
		3A	0.92
		2B	0.92
		3B	0.89
		3C	0.94
Group 2	Primary	ISO 16358 Amd 1	0.96
	Secondary	0B	0.96
		1B	0.96
Group 3	Primary	U4E Group 3	0.94
	Secondary	4A	0.92
		5A	0.94
		6A	0.98
		4B	0.89
		5B	0.94
		6B	0.94
		7	0.96
		8	0.97

05 Cost-Effectiveness of Multi-Split VRF Systems

While many studies have examined trends in price–efficiency relationships, life cycle cost–efficiency, and cost-effectiveness for Air Conditioners (Dale et al., 2002, 2009; Ellis et al., 2007; Van Buskirk et al., 2013; Spurlock, 2013; Phadke et al., 2017; Abhyankar et al., 2017), there is limited literature analyzing the cost-effectiveness of multi-split VRF systems.

VRF systems are advanced multi-split systems that connect multiple indoor units to one outdoor unit, with each indoor unit independently regulated. VRF systems typically use variable-speed compressors, electronic expansion valves, and a network of refrigerant pipes to optimize energy use and reduce losses. The term "variable refrigerant flow" refers to the system's ability to adjust refrigerant delivery to each indoor unit based on real-time demand, allowing for individualized comfort, diverse unit capacities, and heat recovery between zones. Single VRF modules generally have cooling capacities of 10–56 kW, while combined systems can reach up to 150 kW. Indoor units typically range from 2 to 7 kW in capacity (Karali et al. 2020).[5]

Karali et al. (2020) evaluated the costs and benefits of implementing advanced efficiency technologies in VRF systems. The study assessed 144 design combinations across four different VRF configurations commonly used in China, identifying the least-cost combinations capable of achieving specific energy efficiency levels.

The baseline VRF systems analyzed have typical characteristics, including:

- Refrigerant R410A
- Inverter-driven scroll compressor
- Electronic expansion valve

Efficiency improvements were explored through the integration of the following technologies:

- High-efficiency compressors, enhanced via methods such as asymmetric scroll profiles, magnet rotors, torque control, smooth 180° sine wave DC inverters, brushless DC motors, and DC fan motors
- Compressor modules with multiple units, including at least one variable-speed (VSD) inverter-driven compressor
- Advanced heat exchangers, incorporating improvements like microchannel designs, circuit optimization, alternative materials (e.g., aluminum), innovative fin and tube structures, and grooved patterns

To estimate annual unit energy consumption (UEC), the study established a relationship between the APF and UEC using performance data from three VRF models tested in accordance with the Chinese standard GB21455-2013. This relationship was further scaled for higher-capacity commercial systems, accounting for longer operating hours. Table 10 summarizes the key characteristics of the four VRF systems analyzed.

5 While the report assumes indoor unit capacities of 2–7 kW, they can reach up to 28 kW in some configurations.

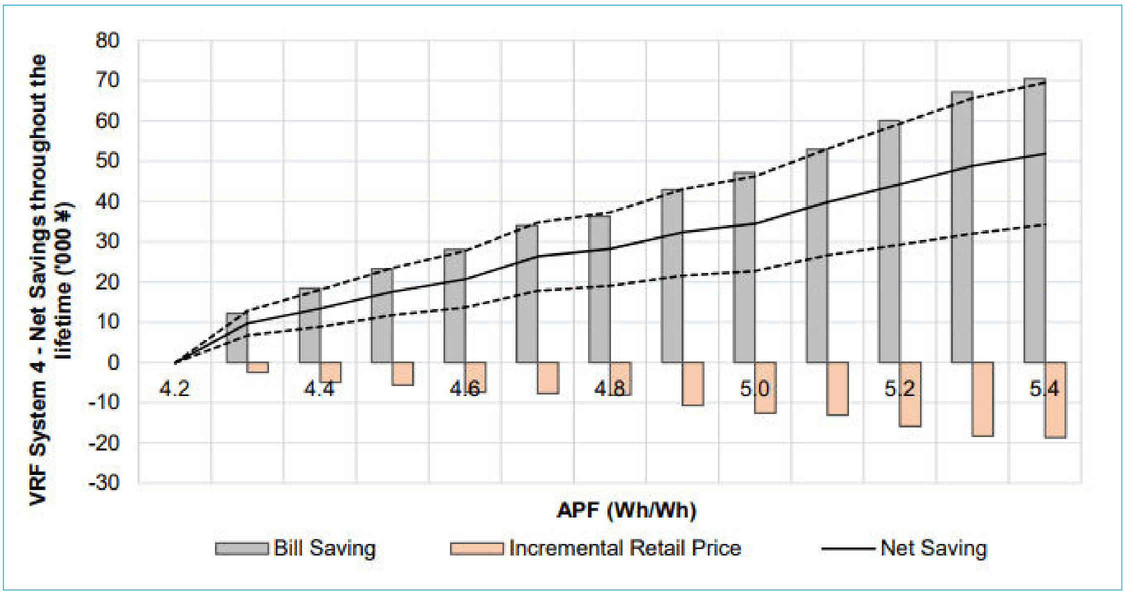
Table 10. Testing Characteristics of Selected VRF Systems

	VRF System 1	VRF System 2	VRF System 3	VRF System 4
Refrigerant (R410A) (kg)	4.0	5.1	13.0	26.0
Number of outdoor units	1	1	2	3
Number of indoor units	4	5	16	30
Capacity (BTU/h)	48,000	60,000	136,500	290,000
Capacity (kW)	14	18	40	85
Number of joints	3	4	15	29
Piping length (m)				
Ø9.52	10.0	13.3	50.0	96.7
Ø6.35	20.0	25	80.0	150.0
Ø12.70	20.0	13.3	50.0	96.7
Ø15.88	10.0	25	80.0	150.0
Additional refrigerant charge (kg)	0.98	1.27	4.46	8.52
Compressor efficiency (EER)	3.3	3.25	3.4	3.0
China APF (Wh/Wh)	4.2	4.2	4.2	4.2
IPLV (W/W)	4.7	4.7	4.7	4.7

Source: Karali et al. (2020)

The study finds that various efficiency improvements in VRF systems—such as higher EER compressors, dual VSD compressor configurations, all-DC inverters, and advanced heat exchangers—can achieve energy savings ranging from 5.3% to 25.8%. Upgrading from a baseline APF of 4.2 to APF 5.5 can improve efficiency by about 30%, with estimated price increases of 10–12%, depending on the system. Retail price analysis shows high variability, suggesting that features beyond efficiency influence market pricing. For larger systems, similar efficiency gains can be achieved with 2.5–10% cost increases, based on scaled estimates. Tables D1 and D2 in Appendix D summarize efficiency improvement options, corresponding incremental costs and savings potential from each baseline design.

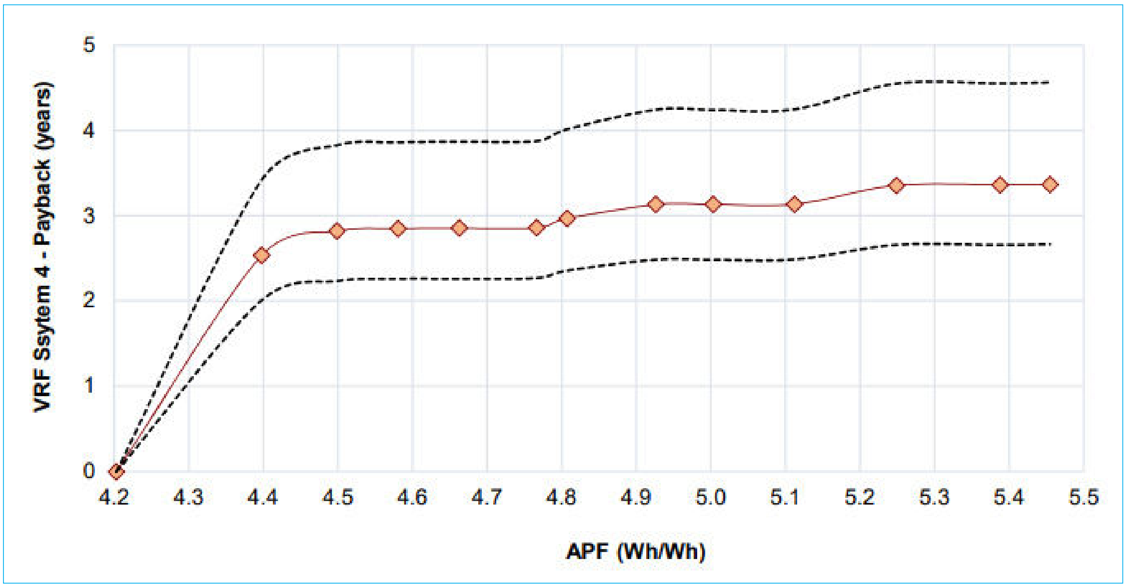
Figure 13 presents the net customer savings over the lifetimes of VRF System 4, the largest commercial system analyzed in that study. These net savings are higher than those observed for small capacity residential VRF systems, and continue to increase with efficiency improvements up to the highest level shown on the x-axis (China APF 5.5). Karali et al. (2020) found that large-capacity commercial systems achieve faster pay back periods than residential systems. Similar to residential systems, a 25% reduction in usage extends the payback period. For additional analysis results, readers are referred to the original study.



Note: Axis scales differ between the two systems. Dotted lines represent the ±25% use sensitivity.

Source: Karali et al. (2020)

Figure 13. Lifetime net savings for each design level of the least-cost curve for VRF system 4 in China



Note: Y-axis scales differ between the two systems. Dotted lines represent the ±25% use sensitivity.

Source: Karali et al. (2020)

Figure 14. Payback periods for each design level of the least-cost curve for VRF system 4 in China

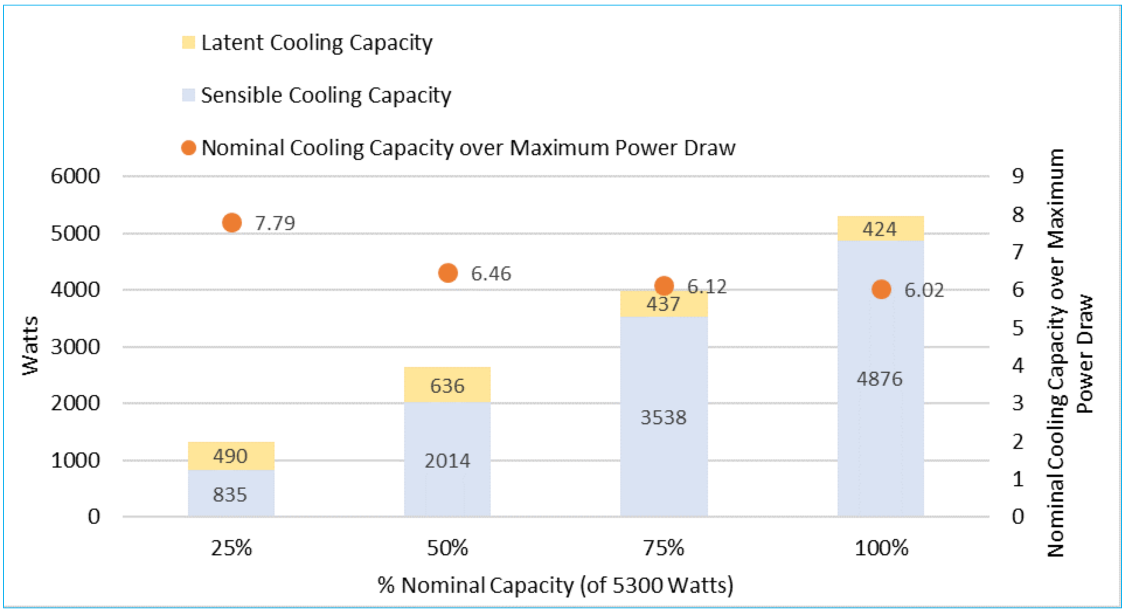
06 Improvement in Testing Methods

AC performance tests are typically conducted under fixed indoor and outdoor conditions, with compressor and fan speeds controlled by manufacturer-specific proprietary settings. These tests measure steady-state performance across various conditions to estimate seasonal energy efficiency, taking into account regional climates and outdoor temperature bin hours. While this standardized approach facilitates consistent measurement and comparison of Air Conditioner performance across facilities, it does not fully reflect real-world energy savings—particularly for advanced technologies or systems designed to manage latent loads and dehumidification more efficiently. Because current testing procedures often assume a constant indoor wet-bulb temperature, they do not fully capture the interactions between temperature and humidity in real life.

Results from the Global Cooling Prize highlighted this issue, showing that existing test standards capture only about 69% of the weighted energy savings achieved by the most efficient technologies under simulated real-world conditions (Kalanki et al. 2021).

Based on the findings from the Global Cooling Prize, the GCEA developed the Super-efficient Room Air Conditioner Performance Specification Guideline for the Indian market (GCEA 2025). The GCEA is also working on improved test procedures and performance metrics that better represent actual energy use, especially in hot and humid climates where overcooling is often used for dehumidification. Figure 15 illustrates the ratio of nominal cooling capacity to maximum power consumption for a super-efficient Air Conditioner with a Cooling Capacity of 5.3 kW under the standard test conditions outlined in the guideline.

The 2025 edition of the U4E Guidelines references this GCEA specification as an optional criterion to identify and promote highly efficient Air Conditioner units, extending its scope to split systems with cooling capacities below 6 kW. For this purpose, the maximum power draw is expressed as a minimum Energy Efficiency Ratio (EER), and the sensible cooling capacity is expressed as a maximum Sensible Heat Ratio (SHR), evaluated at 100%, 75%, 50%, and 25% of nominal cooling capacity under standard rating conditions for outdoor and indoor temperature and humidity.

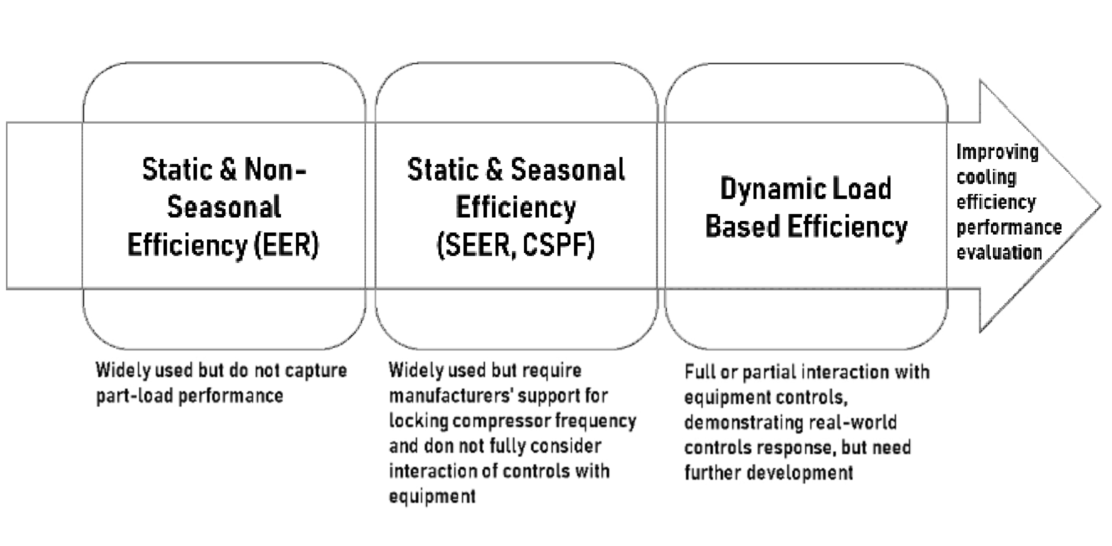


Source: Pitarch et al. (2025)

Figure 15. Nominal cooling capacity over maximum power consumption requirements of super-efficient Air Conditioner at standard test conditions in the Super-efficient Room Air Conditioner Performance Specification Guideline for the Indian Market

There is a growing emphasis on global standardization to ensure that testing and evaluation methods for Air Conditioners accurately reflect real-world performance and are consistent across regions. International organizations and national regulatory agencies are actively working to improve and harmonize test procedures, enabling more accurate and comparable assessments of Air Conditioner and Heat Pump systems worldwide. One such effort is the development of a new standard—ISO 21280, "Testing and rating including seasonal performance of air-to-air air-conditioners and heat pumps considering the effect of native control"—which was in the committee draft stage at the time of writing.

To better represent real-use conditions, dynamic load-based testing is being explored as an alternative approach. By allowing systems to operate under variable conditions that mimic actual usage, this method has the potential to improve the accuracy and relevance of performance evaluations. However, these testing approaches are still under development and require further refinement before widespread adoption (Figure 16) (Park et al. 2022, Carmichael et al. 2020].



Source: Park et al. (2022)

Figure 16. Performance evaluation methods for improving cooling efficiency

Energy performance evaluation methods, including testing and metrics, can evolve to capture the energy consumption associated with new technological features. However, there is currently no systematic effort to advance test procedures and performance metrics in ways that maximize the energy, environmental, and financial benefits of disruptive technologies. It is important for countries to regularly update their energy-efficiency policies—such as standards and labeling programs—by improving test methods and metrics to reflect technological innovation and to avoid the continued deployment of outdated technologies (Park et al. 2022).

References

Abhyankar, Nikit, Nihar Shah, Amol Phadke, and Won Young Park. (2017). Technical and Economic Aspects of Designing an Efficient Room Air-Conditioner Program in India. LBNL 2001048. Berkeley, CA: Lawrence Berkeley National Laboratory http://escholarship.org/uc/item/7401k55r

Abhyankar, Nikit, Jose Dominguez, Nihar Shah, Neelima Jain, and Amol Phadke. 2025. INDIA CAN AVERT POWER SHORTAGES AND CUT CONSUMER BILLS WITH STRONGER Air Conditioner EFFICIENCY STANDARDS. Working Paper. India Energy & Climate Center. UC Berkeley Goldman School of Public Policy. https://iecc.gspp.berkeley.edu/wp-content/uploads/2025/03/IECC-Stronger-AC-efficiency-Standards-Report-2025-Web.pdf

ASEAN Centre for Energy (ACE). 2021. Policy Recommendations to Update the ASEAN Regional Policy Roadmap for Energy Efficient Air Conditioners. https://united4efficiency.org/wp-content/uploads/2022/07/Policy-Recommendations-to-Update-the-Regional-Policy-Roadmap-for-AC.pdf

BSRIA. 2025a. Worldwide Air Conditioning Splits Systems 2025— Philippines

BSRIA. 2025b. Worldwide Air Conditioning Splits Systems 2025— Malaysia

BSRIA. 2024a. Worldwide Air Conditioning Windows and Portables 2024—USA

BSRIA. 2024b. Worldwide Air Conditioning Splits Systems 2024—USA

BSRIA. 2024c. Worldwide Air Conditioning Windows and Portables 2024—UAE

BSRIA. 2024d. Worldwide Air Conditioning Splits Systems 2024—UAE

BSRIA. 2024e. Worldwide Air Conditioning Windows and Portables 2024— Saudi Arabia

BSRIA. 2024f. Worldwide Air Conditioning Splits Systems 2024— Saudi Arabia

BSRIA. 2024g. Worldwide Air Conditioning Splits Systems 2024—India

BSRIA. 2022a. Worldwide Air Conditioning Windows and Portables 2024— Philippines

BSRIA. 2022b. Worldwide Air Conditioning Splits Systems 2024— Philippines

BSRIA. 2022c. Worldwide Air Conditioning Splits Systems 2024— Singapore

Carmichael, Rob, Sarah Widder, Nathan Baker, Jessica DeWitt, Warren Stem, and Michael Brychta. 2020. Domestic Air Conditioner Test Standards and Harmonization. Developed by Cadeo Group. Developed for The IEA Technology Collaboration Programme on Energy Efficient End-Use Equipment. https://www.iea-4e.org/wp-content/uploads/2020/12/AC_Test_Methods_Report_Final_V2_incl_JP_KO.pdf

Commonwealth of Australia. 2025. Energy Rating Registration Database. https://reg.energyrating.gov.au/comparator/product_types/

Dale, Larry, Camille Antinori, Michael McNeil, and Jim McMahon. 2002. Retrospective Evaluation of Declining Price for Energy Efficient Appliances. American Council for an Energy-Efficient Economy (ACEEE) Summer Study on Energy-Efficiency in Buildings. https://www.aceee.org/files/proceedings/2002/data/papers/SS02_Panel9_Paper05.pdf

Dale, Larry, Camille Antinori, Michael McNeil, James McMahon, and K. Sydny Fujita. 2009. Retrospective Evaluation of Appliance Price Trends. Energy Policy 37:597–605. https://doi.org/10.1016/j.enpol.2008.09.087.

East African Centre of Excellence for Renewable Energy and Efficiency (EACREEE). 2024 Regional Validation Workshop for the EAC EE Policy, Regional Compliance Framework, and Energy Label. Sep. 2024. https://www.eacreee.org/article/regional-validation-workshop-eac-ee-policy-regional-compliance-framework-and-energy-label.

East African Community (EAC). 2025. The East African Community Standardization, Quality Assurance, Metrology, and Testing Act, 2006: Notice of Declaration of East African Standards. June 2025.

Ellis, Mark, Nigel Jollands, Lloyd Harrington, and Alan Meier. 2007. Do energy efficient appliances cost more? European Council for an Energy Efficient Economy (ECEEE) Summer Study. https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2007/Panel_6/6.025/.

Energy Commission. 2025. Guidelines on Energy Using Product, Malaysia, 2025. https://www.st.gov.my/contents/2025/EECA/20250505%20GUIDELINES%20ON%20ENERGY%20USING%20PRODUCT.pdf.

Global Cooling Efficiency Accelerator (GCEA). 2025. Super-efficient Room Air Conditioner Performance Specification Guideline for Indian Market. https://www.cleancoolingcollaborative.org/wp-content/uploads/2025/03/Super-efficient-AC-Performance-Specification_Final_March-2025.pdf

The Japan Refrigeration and Air Conditioning Industry Association (JRAIA). 2024. Estimates of World Air Conditioner Demand. July 2024. https://www.jraia.or.jp/english/statistics/file/World_AC_Demand_July2024.pdf

JRAIA. 2022. Estimates of World Air Conditioner Demand. July 2022.

Kalanki, Ankit, Caroline Winslow, and Iain Campbell. 2021. Global Cooling Prize: Solving the Cooling Dilemma. RMI. https://rmi.org/insight/global-cooling-prize-solving-the-cooling-dilemma/

Karali, Nihan, Chao Ding, Won Young Park, Nihar Shah, Jiang Lin. 2020. Energy-Efficiency Improvement Potential of Multi-split Air Conditioning Systems in China. Lawrence Berkeley National Laboratory, Berkeley CA. https://eta.lbl.gov/publications/energy-efficiency-improvement-2

Mocholi, Miquel Pitarch et al. 2025. Energise draft Advancing Performance Evaluation and Policy Implementation for More Sustainable Air Conditioners and Heat Pumps. A draft for the Energise conference 2025.

Ministry of Power (MOP). 2025. Notification S.O.2984 (E). New Delhi. August 28, 2025.

National Environment Agency (NEA). 2025a. Circular: Requirements for Regulated Goods Under the Energy Conservation Act (ECA) with Effect from 1st April 2025, Singapore, 2025. https://www.nea.gov.sg/docs/default-source/cmd-documents/energy-efficiency/circulars/circular-requirements-for-regulated-goods-under-the-energy-conservation-act-%28eca%291-with-effect-from-1st-april-2025.pdf

NEA. 2025b. Database of Registered Products. https://wrms2.nea.gov.sg/els/process/WRMS/GHG_ProductSearch#wrms

Park, Won Young and Nihar Shah. 2025. Enhancing the Energy Efficiency of Room Air Conditioners in Malaysia: Opportunities and Impact Analysis. LBNL-2001640. Lawrence Berkeley National Laboratory, Berkeley CA. https://eta.lbl.gov/publications/enhancing-energy-efficiency-room-air

Park, Won Young, Nihar Shah, Kenji Shiraishi, and Edward Vine. 2022. Improving energy performance metrics to maximize the benefits of disruptive technologies. Energy Research & Social Science, 89, 102678. https://doi.org/10.1016/j.erss.2022.102678

Park, Won Young, Nihar Shah, Virginie Letschert, and Patrick Blake. 2021. Harmonizing Energy-Efficiency Standards for Room Air Conditioners in Southeast Asia. Lawrence Berkeley National Laboratory, Berkeley CA. https://eta-publications.lbl.gov/sites/default/files/asean_ac_ee_harmonization_final_may_2021.pdf

Park, Won Young, Nihar Shah, Jun Young Choi, Hee Jeong Kang, Dae Hoon Kim, Amol A Phadke. 2020. Lost in translation: Overcoming divergent seasonal performance metrics to strengthen air conditioner energy-efficiency policies. Energy for Sustainable Development 55 (2020) 56-68. https://doi.org/10.1016/j.esd.2020.01.003

Park, Won Young, Nihar Shah, and Brian Gerke. 2017. Assessment of commercially available energy-efficient room air conditioners including models with low global warming potential (GWP) refrigerants. Lawrence Berkeley National Laboratory, Berkeley CA. https://eta-publications.lbl.gov/sites/default/files/assessment_of_racs_lbnl-_2001047.pdf.

Phadke, Amol, Won Young Park, Nikit Abhyankar, and Nihar Shah. 2017. Relationship between Appliance Prices and Energy-Efficiency Standards and Labeling Policies: Empirical Evidence from Residential Air Conditioners. The 9th international conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL 2017).

Phadke, Amol A, Nihar Shah, Jiang Lin, Won Young Park, Yongsheng Zhang, Durwood Zaelke, Chao Ding, Nihan Karali. 2020. Chinese policy leadership would cool global air conditioning impacts: Looking East. Energy Research & Social Science 66 (2020) 101570. https://doi.org/10.1016/j.erss.2020.101570

SADC Cooperation in Standardization (SADCSTAN). 2023. Harmonised MEPS on Air Conditioners. Dec. 2023. https://united4efficiency.org/wp-content/uploads/2024/02/SADC-HT-110-SADC-Harmonised-MEPS-on-Air-Conditioners-_v5Dec2023.pdf.

Spurlock, C. Anna. 2013. Appliance Efficiency Standards and Price Discrimination. LBNL-6283. Berkeley, CA: Lawrence Berkeley National Laboratory. https://eta.lbl.gov/publications/appliance-efficiency-standards-and

United Nations Environment Programme (UNEP). 2025. Nigerian Government Approves New MEPS for Air Conditioners to Boost Energy Efficiency. Feb. 2025. https://united4efficiency.org/nigerian-government-approves-new-meps-for-air-conditioners-to-boost-energy-efficiency/.

UNEP and IIEC. 2024. Market Assessment & Cost Benefit Analysis of High-Efficient & Climate-Friendly Room Air Conditioners in Malaysia. Presentation slides. March 27, 2024.

UNEP. 2019a. Model Regulation Guidelines for Energy-Efficient and Climate-Friendly Air Conditioners. Nairobi, 2019. https://united4efficiency.org/wp-content/uploads/2021/11/U4E_AC_Model-Regulation_EN_2021-11-08.pdf

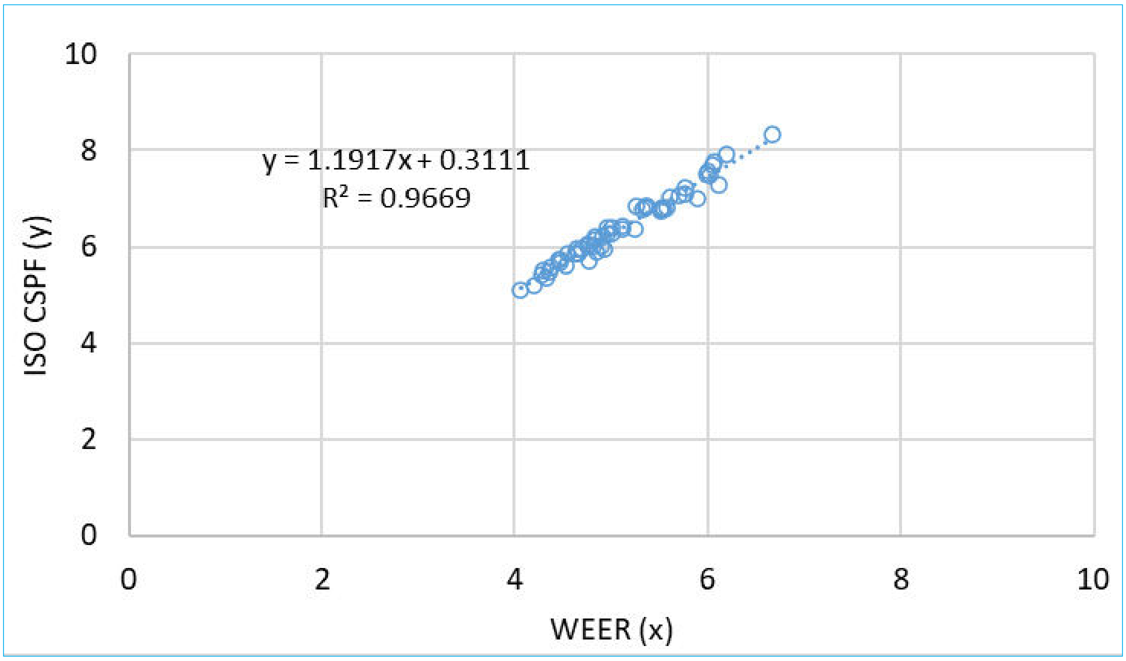
UNEP. 2019b. Supporting Information – Model Regulation Guidelines for Energy-Efficient and Climate-Friendly Air Conditioners. Nairobi, 2019. https://united4efficiency.org/wp-content/uploads/2020/05/U4E_AC_Model-Reg-Supporting-Info_20200227.pdf

Van Buskirk, R.D., C.L.S. Kantner, B.F. Gerke, and S. Chu. 2013. "A retrospective investigation of energy efficiency standards: policies may have accelerated long term declines in appliance costs." Environmental Research Letters 9:114010. https://iopscience.iop.org/article/10.1088/1748-9326/9/11/114010/pdf.

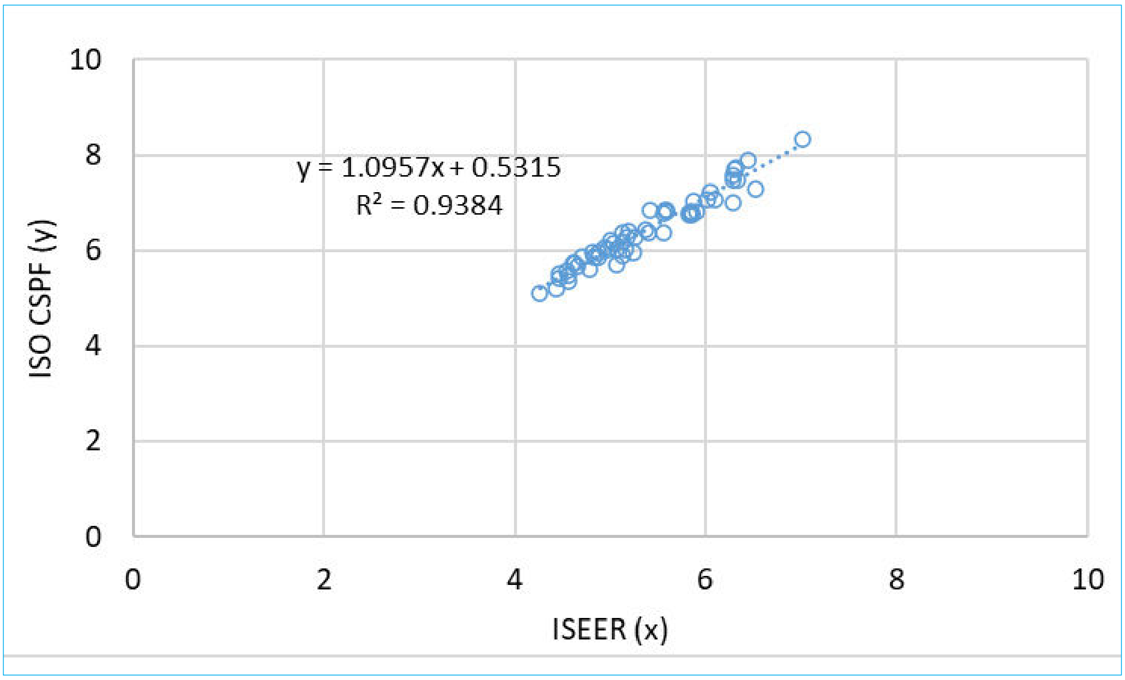
Appendix A. Relationships between WEER (Singapore), ISEER (India) and ISO CSPF

The seasonal efficiency metrics used in many countries, including Australia, Hong Kong, India, Japan, Singapore, and Thailand, are consistent with ISO 16358 defined metrics (i.e., CSPF, HSPF, and APF), using the same test requirements in Table 5, except they use country-specific climatic conditions and some adjustments. Hence, the data on CSPF of Air Conditioners, and CSPF and APF of heat pumps, available in these countries can be largely comparable with efficiency of products in other countries that develop their energy-efficiency standards aligned with the Guidelines.

Park et al. (2020) establish regression equations for identifying relationships between efficiency metrics in China, the EU, India, Japan, South Korea, and the U.S., to compare efficiency of Air Conditioners and heat pumps available in those markets. This analysis is built up on Park et al. (2020) by primarily using performance data of Air Conditioners from the Singapore database. The Singapore database provides full capacity and EER (full capacity over power input) at 35°C and EER_half (half capacity over power input). Given cooling half-capacity at outdoor temperature t to be 50% (±5%) of full capacity at t at full-load operating conditions, we assume half-capacity to be 50% of full capacity at 35°C and calculate power input at half-capacity mode.



(a)



(b)

Data source: National Environment Agency (NEA)'s database of registered products (2020)

Figure A1. Relationships between WEER (Singapore) and ISO CSPF (a) and ISEER (India) and ISO CSPF for 57 Air Conditioner models

Appendix B. Relationships between IEER and ISO CSPF

The correlations between different performance metrics—such as IEER (AHRI 1230) and ISO CSPF—are relatively low under varying conditions. This discrepancy is primarily due to differences in temperature bin distributions or weighting factors, the number of parameters considered, and the methods used to account for part-load performance.

In this analysis, we estimated performance at half-capacity operation at 35°C and calculated performance at 29°C using the default equations from ISO 16358, based on data for 227 VRF models from the Singapore database. A factor of 0.38 was applied to represent the ratio of half-capacity to full-capacity power consumption at 35°C (see Figure B1). Using this approach, we estimated CSPF values for the 227 models and found that a CSPF corresponding to an IEER of 4.35 falls within an approximate range of 4.1 to 5.5.

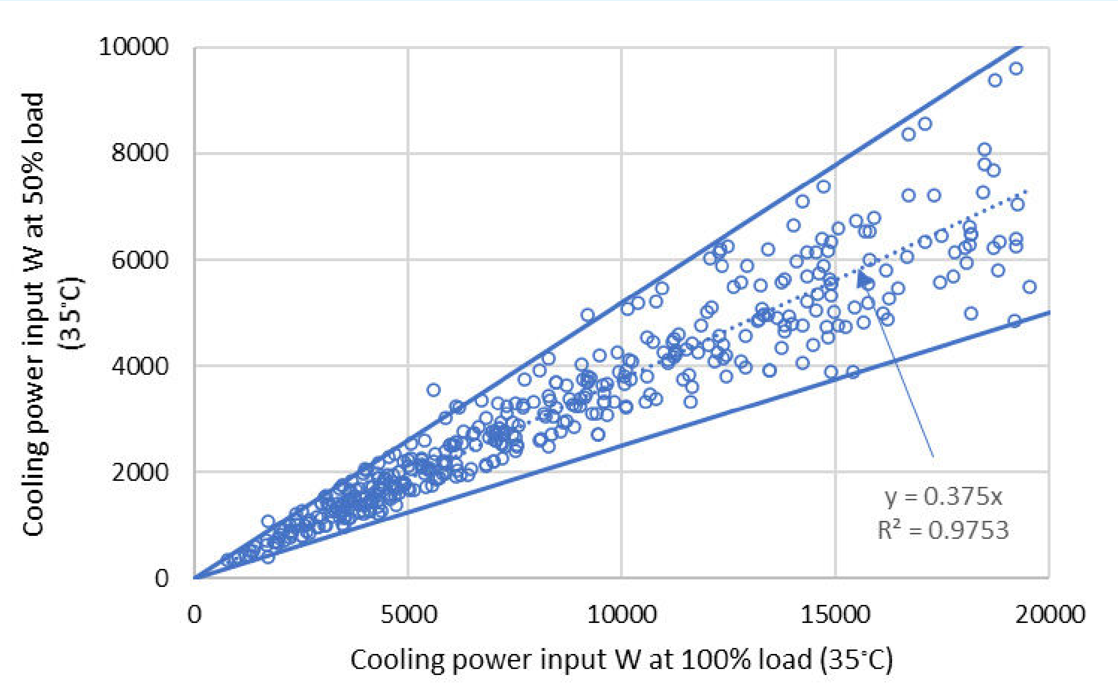
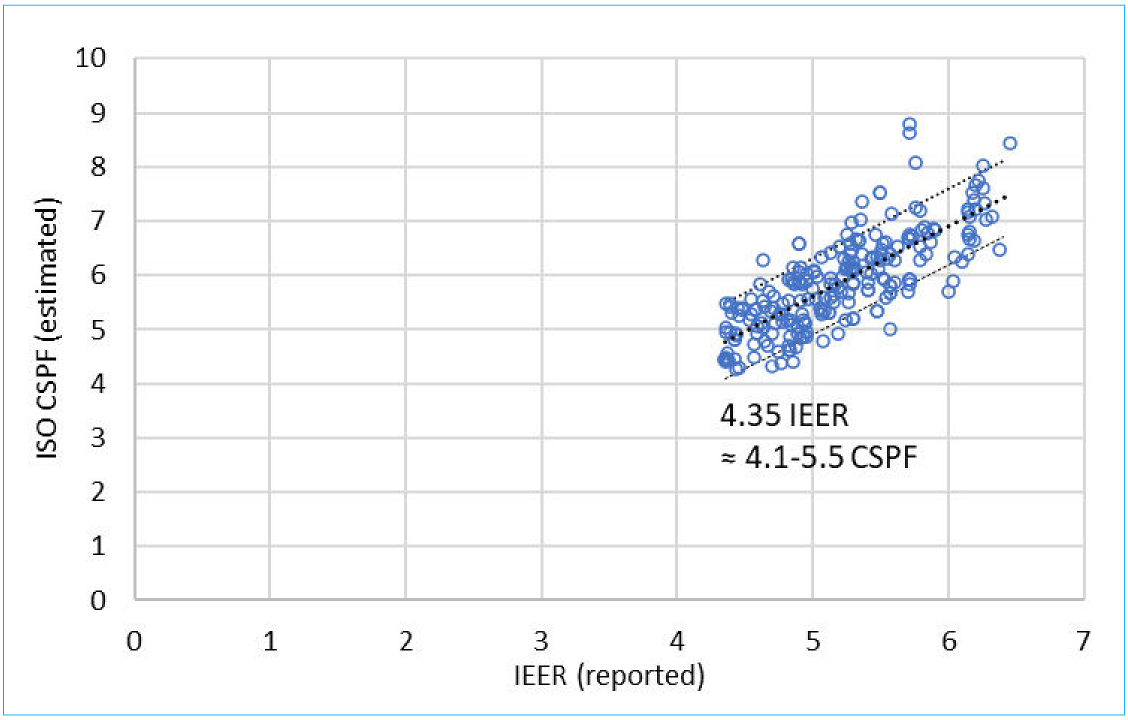


Figure B1. Relationships between cooling power input at 100% load and 50% load for 227 VRF models



Estimated CSPF using one set of reported data at full-capacity operation at 35°C, estimated data at half-capacity operation at 35°C, and another set of data points at 29°C calculated by ISO 16358 default equations, without considering minimum-capacity operation.

Figure B2. Relationships between IEER (reported) and ISO CSPF (estimated) for 227 VRF models

Appendix C. Efficiency of Ducted and Non-Ducted Split Systems

The 2025 U4E Guidelines edition includes ducted split systems. Figure X shows efficiency distribution of 1,036 (non-ducted 713 and ducted 323) models with cooling capacities in a range of 2.5 kW to 14 kW from the Australian database. Of the 1,036 models analyzed, ducted split systems tend to have a larger share in the lower efficiency range, while non-ducted split systems are more prevalent in the higher efficiency range. However, the majority of both types—56% overall (61% of non-ducted and 54% of ducted models)—have CSPF values concentrated between 5 and 6.

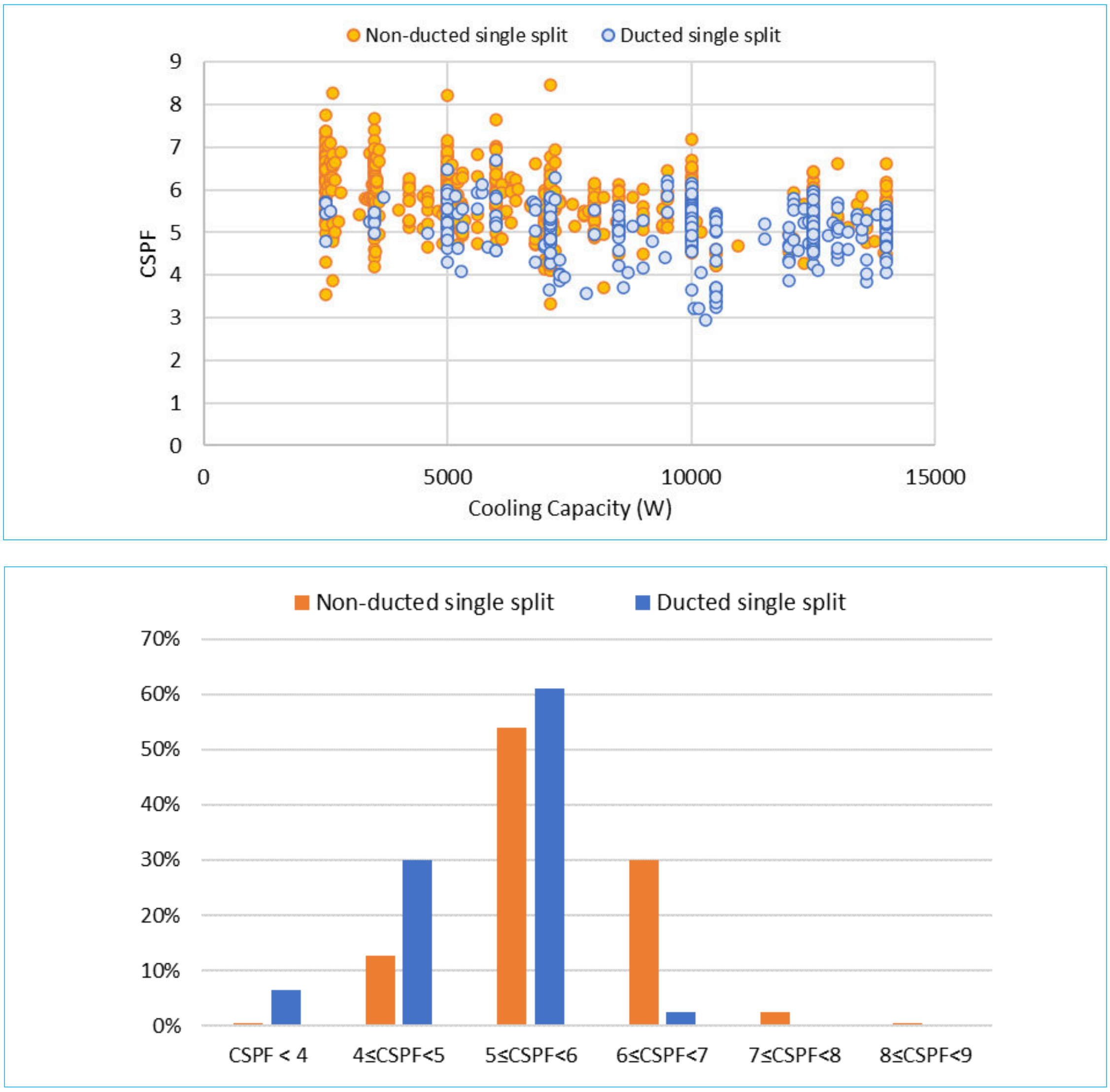


Figure C1. **CSPF Distribution of Non-ducted and Ducted Air Conditioners in Australia**

Appendix D. Incremental Manufacturing Cost and Energy Savings in VRF Systems

Table D1. **Incremental Manufacturing Cost and Energy Savings of Efficient Components for Chinese VRF Systems 1 and 2**

	Component	Manufacturing Cost (USD)	Energy Savings from Baseline	Manufacturing Cost (USD)	Energy Savings from Baseline
Compressor					
Baseline Compressor	with DC inverter (VSD)	$320	-	$459	-
Efficient Compressor 1	with DC inverter (VSD)	$343	5.9%	$495	6.0%
Efficient Compressor 2	with DC inverter (VSD)	$393	11.0%	$573	11.2%
Efficient Compressor 3	with DC inverter (VSD)	$443	15.5%	$651	15.5%
Multiple Compressors 4-7	DC+DC VSD compressors for each design options listed above	2x for each design options listed above	24.0%	2x for each design options listed above	26.0%
Multiple Compressors 8-11	DC VSD + FSD compressors for each design options listed above	1.4x for each design options listed above	19.2%	1.45x for each design options listed above	20.8%
Inverter					
All DC inverter	DC inverter for fans	$64	5.3%	$63	5.5%
Heat Exchanger (HE)					
Baseline HE		$169		$264	
Efficient HE 1	UA of both HEs increased by 20%	$203	8.3%	$317	8.3%
Efficient HE 2	UA of both HEs increased by 40%	$237	14.2%	$370	14.2%
Efficient HE 3	UA of both HEs increased by 60%	$270	19.0%	$423	19.0%
Efficient HE 4	UA of both HEs increased by 80%	$346	22.3%	$541	22.3%

Source: Karali et al. (2020)

Note: Costs are based on inputs from Chinese VRF system manufacturers. Energy savings are adjusted from Riviere et al. (2009) based on reported savings change between capacities. U (W/m2 /K) is the overall heat transfer coefficient, A(m2) is the total heat exchange area. The currency exchange rate applied is 1 Chinese Yuan = 0.139 USD.

Table D2. **Incremental Manufacturing Cost and Energy Savings of Efficient Components for Chinese VRF Systems 3 and 4**

	Component	Manufacturing Cost (USD)	Energy Savings from Baseline	Manufacturing Cost (USD)	Energy Savings from Baseline
Compressor					
Baseline Compressor	VRF3: 1xVSD + 1xFSD VRF4: 1xVSD + 2xFSD	$2,800		$5,599	
Efficient Compressor 1	VRF3: 1xVSD + 1xFSD VRF4: 1xVSD + 2xFSD	$3,118	6.7%	$6,236	7.9%
Efficient Compressor 2	VRF3: 1xVSD + 1xFSD VRF4: 1xVSD + 2xFSD	$3,436	12.7%	$6,872	14.9%
Efficient Compressor 3	VRF3: 1xVSD + 1xFSD VRF4: 1xVSD + 2xFSD	$3,754	15.5%	$7,508	15.6%
Multiple Compressors 4-7	2xVSD compressors for each design options listed above	1.4x for each design options listed above	12.0%	1.4x for each design options listed above	12.0%
Multiple Compressors 8-11	3xVSD compressors for each design options listed above	2.5x for each design options listed above	18.0%	2.5x for each design options listed above	18.0%
Inverter					
All DC inverter	DC inverter for fans	$227	6.5%	$468	7.0%
Heat Exchanger (HE)					
Baseline HE		$480		$1,019	
Efficient HE 1	UA of both HEs increased by 20%	$577	8.3%	$1,224	8.5%
Efficient HE 2	UA of both HEs increased by 40%	$646	14.3%	$1,429	14.5%
Efficient HE 3	UA of both HEs increased by 60%	$803	19.2%	$1,663	19.5%
Efficient HE 4	UA of both HEs increased by 80%	$984	22.5%	$2,092	23.0%

Source: Karali et al. (2020)

Note: Costs are based on inputs from Chinese VRF system manufacturers. Energy savings are adjusted from Riviere et al. (2009) based on reported savings change between capacities. U (W/m2 /K) is the overall heat transfer coefficient, A(m^2) is the total heat exchange area. The currency exchange rate applied is 1 Chinese Yuan = 0.139 USD.

Special thanks to UNEP's funding partners. For more than 50 years, UNEP has served as the leading global authority on the environment, mobilizing action through scientific evidence, raising awareness, building capacity and convening stakeholders. UNEP's core programme of work is made possible by flexible contributions from Member States and other partners to the Environment Fund and UNEP Planetary Funds. These funds enable agile, innovative solutions for climate change, nature and biodiversity loss, and pollution and waste.

Support UNEP. Invest in people and planet.
www.unep.org/funding

UN environment programme

www.unep.org
unep-communication-director@un.org