Harmonizing of Energy-Efficiency Standards for Room Air Conditioners in Southeast Asia

ASEAN Cooperation Project

Promotion of higher efficient air conditioners in ASEAN through harmonisation of standards (ISO 16358) and strengthening of market verification and enforcement capabilities (Phase I)

FINAL REPORT

Prepared in consultation with the CSPF Project Technical Working Group

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Executive Summary

Increasing incomes and urbanization—as well as a warming climate—are driving up the global stock of air conditioners (ACs), particularly in emerging economies with hot climates. Because AC energy consumption is expected to increase substantially as the stock of room ACs[1] rises, improving AC energy efficiency will be critical to reducing AC energy, life cycle cost, peak load, and emissions impacts. Regardless whether the AC is variable-speed or non-inverter technology, a seasonal energy-efficiency metric—such as seasonal energy-efficiency ratio (SEER) or cooling seasonal performance factor (CSPF)—must be adopted to accurately reflect the technology's energy savings potential and communicate the savings to consumers.

This study supports the effort of the Association of Southeast Asian Nations (ASEAN) to improve and harmonize AC energy-efficiency standards by adopting CSPF in accordance with International Organization for Standardization (ISO) Standard 16358. This report provides an overview of seasonal AC energy-efficiency metrics, assesses the regional climatic conditions in ASEAN countries, and make recommendations for adopting ISO standard 16358 in a harmonized way across the region. It explores ASEAN-specific temperature profiles, the United for Efficiency (U4E) Model Regulation Guidelines' temperature bin hours, as well as ISO 16358 temperature bin hours to evaluate the efficiency of ACs. The results show the superiority of CSPF over the traditional energy-efficiency ratio (EER) metric for capturing the higher seasonal efficiency of variable-speed ACs. The results also quantify the potential energy savings from the variable-speed ACs, which range from 25%–60% compared with the lowest-efficiency fixed-speed unit.

This report also provides an overview of selected energy-efficiency standards and labeling policies for ACs internationally, including the U4E Model Regulation Guidelines for ACs and other countries in the Asia Pacific region such as China (expected revision in 2022), India, Japan, and Republic of Korea (South Korea). Based on this analysis, several recommendations are made for discussion amongst the ASEAN member states:

1. Consider adopting the ISO CSPF metric. Many ASEAN countries have already moved to, or are planning to, adopt the ISO 16358. Adopting this widely used metric would improve ASEAN's room AC standards and labeling while facilitating harmonization with international AC-efficiency efforts. Countries such as Singapore who use WCOP (WEER) can consider transition from WCOP (WEER) to ISO 16358 based CSPF in accordance with their policy framework.
2. Combine fixed-speed and variable-speed AC product categories under the same metric so that consumers clearly differentiate between the two and benefit from the energy savings from variable-speed ACs. An AC system that meets the U4E Model Regulation Guidelines low-efficiency requirement (CSPF 6.10, largely aligned with the expected Chinese 2022

[1] This study focuses on ductless split ACs, because the global room AC market is dominated by this type of unit, known in the United States as mini-split ACs. In the United States, Canada, and Mexico, room ACs are typically understood to be window-type units.

MEPS), compared to an EER 2.90 (or CSPF 3.08) fixed-speed AC system, offers annual savings potential in energy consumption of ~420 kWh per unit and emissions reduction of ~295 gCO_2 per unit for 1 refrigeration ton (3.5-3.6 kW cooling capacity) ACs.

3. For determining the CSPF of fixed-speed units, 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 predetermined equations. 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)*
4. For variable-speed units, 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-determined equations, without considering minimum-capacity operation. The equations are:

   Capacity(29 ℃)=Capacity(35 ℃)×1.077;

   Power input(29 ℃)=Power input(35 ℃)×0.914
5. Consider using ISO 16358 temperature bin hours as the single set of temperature bin hours for all ASEAN countries. Using a single set of bin hours would reduce additional costs for manufacturers, regulatory complexity for government agencies, and confusion for consumers, compared with using multiple sets of bin hours for different climate zones.
6. Consider additionally using the ISO CSPF metric based on U4E Model Regulation 0A climate, or temperature bin hours of AC use further tailored for ASEAN for assessing and informing absolute impacts (energy use, electricity cost, emissions, etc.). The ISO 16358 temperature bin hours could be used for efficiency standard purposes without much impact on the relative order of efficiency ratings, given that several ASEAN countries have already implemented the CSPF metric based on ISO 16358 temperature bin hours. However, hours of AC use and total energy use in ACs may need to be adjusted to more accurately reflect the ASEAN context.
7. Develop a regional policy roadmap to harmonize national/regional energy-efficiency standards and labeling and test standards aligned with international standards and U4E Model Regulation Guidelines to capture cost and energy savings while minimizing environmental impacts and encouraging innovation in the industry. Aligning with the U4E Model Regulation Guidelines for AC standards in ASEAN is estimated to roughly offer savings potential of 144 TWh of electricity consumption by 2040, which is equivalent to 66 500-MW power stations, 101 million tonnes of CO_2, and 16 Billion USD on electricity bills.
8. Update standards periodically to mitigate risk of obsolete technology being deployed in markets without updated standards, as well as reflect benefits of commercially available and emerging technology. Since international testing and rating standards will continue to evolve to account for ongoing research and harmonization efforts, it is important for the ASEAN countries to revisit these standards and update them periodically as necessary.

The analyses demonstrated in this report for ASEAN can also be applied to considering adoption of seasonal AC energy-efficiency metrics for standards and labeling in other countries and regions.

ACRONYMS

AC	air conditioner
APF	annual performance factor
ASEAN	Association of Southeast Asian Nations
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CC	cooling capacity
CD	degradation coefficient
CDD	cooling degree-day
COP	coefficient of performance
CSPF	cooling seasonal performance factor
DOE	Department of Energy
EER	energy-efficiency ratio
GB	“Guobiao” (Guóbiāo), which means “national standard”
HCFC	hydrochlorofluorocarbon
HDD	heating degree-day
HFC	hydrofluorocarbon
HSPF	heating seasonal performance factor
IS	Indian Standard
ISEER	India seasonal energy-efficiency ratio
ISO	International Organization for Standardization
JIS	Japanese Industrial Standard
KS	Korean Standard
MEMR	Ministry of Energy and Mineral Resources
MEPS	minimum energy performance standards
MOTIE	Ministry of Trade, Industry, and Energy
MS	Malaysia Standard
PNS	Philippine National Standard
RA	Republic Act
SEER	seasonal energy-efficiency ratio
SHINE	Standards Harmonization Initiative for Energy Efficiency
SNI	Indonesian National Standard
TCVN	Vietnam Standard
TIS	Thai Industrial Standard
U4E	United for Efficiency
WCOP	weighted coefficient of performance
WEER	weighted energy-efficiency ratio

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PART A: COMPARATIVE ANALYSIS

1. Introduction

Energy-efficiency market-transformation programs for room air conditioners (ACs) were initially implemented in the 1990s and early 2000s in many countries. At that time, most countries adopted the energy-efficiency ratio (EER) metric[2]—defined as the ratio of the total cooling capacity (CC) to the effective power input to the device at any given set of rating conditions—for rating AC performance based on International Organization for Standardization (ISO) Standard 5151. Using EER facilitated comparison of performance across different markets and regions (IEA 2011).

Over time, AC manufacturers have improved the energy performance and reduced the costs of AC systems, including efficiency improvements such as the development of inverter-driven or variable-speed ACs. Variable-speed compressors enable an AC unit to respond to changes in cooling requirements by operating at full or partial loads. This flexibility improves efficiency performance and reduces power consumption compared to the efficiency performance and power consumption of conventional ACs with fixed-speed compressors that cycle on and off (Park et al. 2020).

Variable-speed ACs already dominate mature AC markets such as Australia, Europe, Japan, and North America[3] (Figure 1). Although fixed-speed units still dominate the room AC markets in developing countries, the market share of variable-speed room AC units is increasing even in these markets. The market share in sales of variable-speed room ACs in China, the world's largest room AC market, increased from 8% in 2007 to >55% in 2016 (Karali et al. 2020a, Park et al. 2017). In India, Brazil, and South Africa, variable-speed ACs are achieving sales market shares of about 30%, 50%, and 60%, respectively (TCM 2019, UNDP 2019). The share of variable-speed ACs in Association of Southeast Asian Nations (ASEAN) countries is increasing, and it varies by country from about 10% to more than 90% in annual sales. According to a survey that the ASEAN Center for Energy is conducting at the time of this study, the market shares of variable-speed ACs in Malaysia and Thailand are 24% and 48%, respectively. In Singapore, it is over 95%, partly because the MEPS for fixed-speed ACs is more stringent than that for variable-speed ACs in terms of EER (see Table 10).

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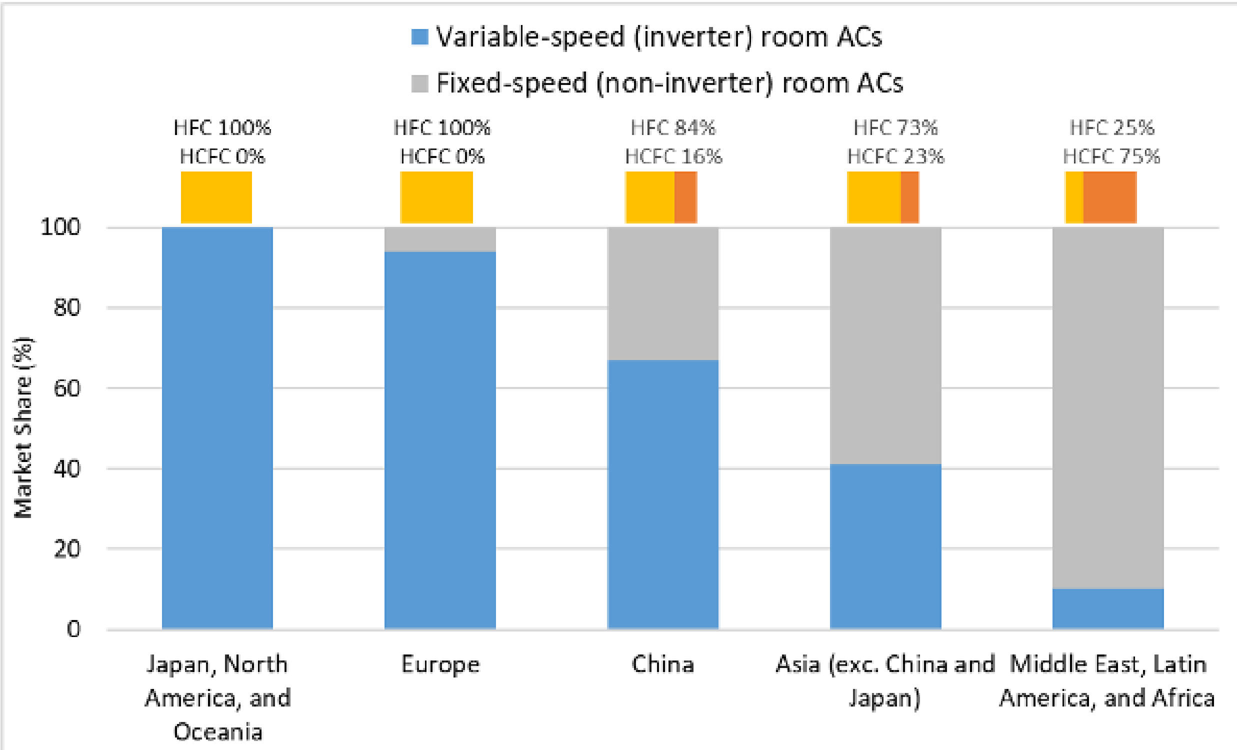
[2] Specifically, EER is defined at the ISO T1 standard CC rating conditions for moderate climates at outdoor and indoor dry bulb temperatures of 35°C (95°F) and 27°C (80.6°F). EER is also defined as the ratio of net CC or the rate of net heat removal (in Btu per hour) to the total rate of electrical energy input (in watts) of a cooling system under designated operating conditions. Although coefficient of performance (COP) is often used for cooling efficiency instead of EER, ISO 5151 defines COP as the ratio of the heating capacity to the effective power input to the device at any given set of rating conditions.

[3] Residential ACs in North America are dominated by window-type room ACs and split system (ducted) central ACs. In the U.S., window-type room ACs are rated with the Combined Energy Efficiency Ratio (CEER), which is a combination of the EER and standby/off mode power consumption. Split system central ACs (both ducted units and ductless mini-split units) are rated with SEER.



HCFC = hydrochlorofluorocarbon, HFC = hydrofluorocarbon
Source: JRAIA (2018) and authors' estimate

Figure 1. Inverter (variable-speed) AC share of AC sales in 2017 by refrigerant type and location

Along with this trend toward variable-speed ACs, seasonal energy-efficiency ratio (SEER) metrics have been designed to more accurately reflect AC performance based on part- and full-load operation at multiple temperature conditions, depending on climate. Local climatic conditions affect the amount of time an AC operates at part or full load, so climate-specific weighting is used in calculating SEER to provide a more representative measure of performance than the traditional EER. Adopting SEER metrics helps capture opportunities for reducing future energy consumption, particularly in countries where large seasonal variations in climate result in ACs running at part load for a larger amount of time (Park et al. 2017).

The SEERs used in the EU and U.S. require more data points for outside temperature and part-load conditions than do those used in the Asian countries which align with the ISO standard. Table 1 shows a comparison of primary test conditions for variable-speed ACs.

Table 1. Comparison of primary test conditions for variable-speed ACs

ISO

<table>
<tr><th>Capacity</th><th>Outdoor DB/WB Temp. (°C)</th><th>Indoor DB/WB Temp. (°C)</th></tr>
<tr><td>Full (required)</td><td rowspan="3">35/24</td><td rowspan="3">27/19</td></tr>
<tr><td>Half (required)</td></tr>
<tr><td>Minimum[b] (optional)</td></tr>
<tr><td>Full (calculated)</td><td rowspan="3">29/19</td><td rowspan="3">27/19</td></tr>
<tr><td>Half (optional)</td></tr>
<tr><td>Minimum[b] (optional)</td></tr>
</table>

U.S.

<table>
<tr><th>Required Test - Compressor Speed/ Cooling Air Volume</th><th>Outdoor DB/WB Temp. (°C) [°F]</th><th>Indoor DB/WB Temp. (°C) [°F]</th></tr>
<tr><td>A_2 – Max/Full</td><td>35.0/23.9 [95/75]</td><td rowspan="5">26.7/19.4 [80/67]</td></tr>
<tr><td>B_2 – Max/Full</td><td>27.8/18.3 [82/65]</td></tr>
<tr><td>E_v – Intermediate/ Intermediate</td><td>30.6/20.6 [87/69]</td></tr>
<tr><td>B_1 – Min/Min</td><td>27.8/18.3 [82/65]</td></tr>
<tr><td>F_1 – Min/Min</td><td>19.4/11.9 [67/53.5]</td></tr>
</table>

EU[a]

<table>
<tr><th></th><th>Part load Ratio (%)</th><th>Outdoor DB Temp. (°C)</th><th>Indoor DB/ WB Temp. (°C)</th></tr>
<tr><td>A</td><td>100</td><td>35</td><td rowspan="4">27/19</td></tr>
<tr><td>B</td><td>74</td><td>30</td></tr>
<tr><td>C</td><td>47</td><td>25</td></tr>
<tr><td>D</td><td>21</td><td>20</td></tr>
</table>

DB = dry bulb, WB = wet bulb

Part load capacities under these conditions are achieved by fixing the compressor speed of the variable-speed unit.

[a] In the EU, the four test points (A, B, C, and D) are points that manufacturers are supposed to "declare." Hence, each point does not need to be tested; the points could also be calculated based on other tested points or based on the performance of similar units.

[b] According to ISO 16358-1:2013, minimum-capacity operation is defined as operation of the equipment and controls at minimum continuous capacity. 25% of minimum capacity is used under the Chinese standard.

Source: Park et al. (2020)

In Southeast Asia, various types of electrical equipment and appliances, including ACs, have minimum energy performance standards (MEPS). The AC MEPS and labeling requirements have been set based on either EER, weighted EER (WEER), or cooling seasonal performance factor (CSPF) in accordance with ISO 16358 which refers to ISO 5151 for test methods (see Section 2 for details on seasonal efficiency metrics). The ASEAN countries in the ASEAN Standards Harmonization Initiative for Energy Efficiency (SHINE) program agreed to set a minimum EER (or WEER) of 2.9 (or a minimum CSPF of 3.08) by 2020 as a mandatory MEPS for all fixed- and variable-speed ACs below 3.52 kW in CC, and to use a test method based on ISO 5151 and CSPF defined in ISO 16358 (ASEAN SHINE 2017). The ASEAN SHINE program focuses on progressively phasing out inefficient ACs and increasing the share of high-efficiency ACs through harmonizing test methods and energy-efficiency standards, including adopting common MEPS requirements, and influencing consumer purchasing decisions (ASEAN SHINE 2017, Shah et al. 2017). However, although the market penetration of energy-efficient variable-speed ACs varies among ASEAN member countries, the ASEAN SHINE MEPS requirements—which are similar to the 2010 MEPS in China—do not fully reflect current market and technology trends. Some

ASEAN countries have already implemented MEPS that are more stringent than the ASEAN SHINE MEPS requirements.

ASEAN is in the process of adopting a seasonal energy-efficiency metric as this report is being written. This study supports ASEAN's effort to improve AC energy-efficiency standards by recommending adoption of the CSPF metric in accordance with ISO 16358. Section 2 provides an overview of seasonal efficiency metrics for room ACs. Section 3 provides outdoor temperature bin hours for room AC use that can be considered in ASEAN countries given local climate conditions. Section 4 evaluates the efficiency performance of room ACs using seasonal versus traditional metrics. Section 5 offers policy insights on energy-efficiency standards and labeling programs based on the findings. Finally, Section 6 summarizes recommendations in support of ASEAN's energy-efficiency standards improvement along with adoption of CSPF.

2. Overview of Seasonal Efficiency Metrics for Room ACs

In general, countries develop and amend energy-efficiency (or energy-conservation) standards to achieve the maximum energy, cost, and greenhouse gas savings that are technologically feasible and economically justified. They also typically collaborate with other countries for international alignment of standards and test procedures. Before or along with the energy-efficiency standards development or amendment, there is typically another process to develop and amend test procedures that are repeatable, reproducible, representative, and enforceable, thus reliably rating the efficiency of all covered products through a formal rulemaking process (Cymbalsky 2016).

The ISO 5151 standard has been adopted by most countries as a reference test standard for measuring the CC and efficiency of non-ducted ACs and heat pumps. ISO 16358 provides a calculation method for cooling/heating seasonal performance factors and refers to ISO 5151 as a testing method (Park et al. 2019, UNEP 2017). International and regional standards offer test parameters to be required and optionally selected. Although measuring more test parameters provides more reliable performance results, including more measurements must be balanced against other factors, such as additional compliance costs, regulatory complexity, and consumer awareness. Adopting the ISO 16358 CSPF metric would improve AC standards and labeling while facilitating harmonization with international AC-efficiency efforts, and it would make the CSPF values comparable with those from other countries whose standards are based on or consistent with ISO 16358 (UNEP 2019, Park et al. 2019).

Climate-specific weighting in a CSPF or SEER metric is used to calculate an AC seasonal energy efficiency that represents performance better than the traditional EER does. In the United States, a seasonal energy-efficiency metric for ACs was developed in 1979 (Didion and Kelly 1979). Since the mid-2000s, as variable-speed ACs have proliferated, region-specific seasonal energy-efficiency metrics have been designed or adopted to estimate AC performance under regional climatic conditions, and they are increasingly used as alternatives to EER or COP to set standards and labeling requirements for ACs and heat pumps. In addition, an intermediate metric—weighted COP (WCOP) or WEER—has been used in ASEAN countries, defined as 0.4 × EER (or COP, 100% load at 35°C) + 0.6 × EER (or COP, 50% load at 35°C). The WEER metric does not consider part-load performance at temperatures lower than 35°C where ACs are estimated to be in operation in hot and humid climates such as Southeast Asia (see Figure 3), hence likely resulting in underestimated energy efficiency (overestimated energy consumption) for variable-speed units (see Table 7).

Seasonal efficiency metrics consider the impact of variations in outdoor temperature on cooling load and energy consumption, requiring (or optionally allowing) multiple test points to compute a seasonally weighted average efficiency. These metrics are intended to represent how the AC would perform over a typical cooling season in a representative building type with typical operating characteristics (Econoler et al. 2011). The seasonal efficiency metrics used in Japan, India, and countries in Southeast Asia are equivalent to ISO 16358:2013-defined metrics.[4] Japan and India use country-specific climatic conditions. Most of Southeast Asian countries use the ISO reference temperature bin hours. The seasonal efficiency metrics used in China and South Korea are largely consistent with ISO 16358:2013-defined metrics, except they use their region-specific climatic conditions and different ways of evaluating performance at part-load operation, along with minor adjustments. The SEERs used in the United States and European Union require more data points for outside temperature and part-load conditions than are required by the ISO standard. The European SEER (EU SEER) also includes the impact of standby and other low-power modes.

Table 2 summarizes seasonal efficiency-related standards and labels, calculation and test methods, and metrics for select economies.

[4] Test procedures for ACs in these countries are based on the ISO 5151 standard. The ISO 16358:2013 standards specify the calculations for evaluating the seasonal performance factor—defined as CSPF (ISO 16358-1:2013), heating seasonal performance factor (HSPF, ISO 16358-2:2013), and annual performance factor (APF, ISO 16358-3:2013, which considers both cooling and heating efficiency for heat pumps)—of equipment with testing covered by ISO 5151, ISO 13253, and ISO 15042.

Table 2. Standards and Labels, Calculation and Test Methods, and Metrics for Seasonal AC Energy-Efficiency Evaluation

	Efficiency Standards and Labels	Seasonal Efficiency Calculation Methods	Efficiency Test Methods	Seasonal Efficiency Metrics
ISO	N/A	ISO 16358-1:2013 (CSPF) ISO 16358-2:2013 (HSPF) ISO 16358-3:2013 (APF)	ISO 5151-2010	CSPF, HSPF, APF
		ASEAN		
Brunei Darussalam	Under development			
Cambodia	Under development	ISO 16358-1:2013	ISO 5151:2010	CSPF
Indonesia	MEMR Regulation No. 57/2017	SNI 8560-1:2018 ISO 16358-1:2013	SNI 8560-1:2018 ISO 16358-1:2013	CSPF
Lao PDR	MEM Regulation on Energy Label and Standard of Air Conditioner in Lao PDR (Draft)	ISO 16358-1:2013	ISO 5151:2010	CSPF
Malaysia	Regulation 101A (3)	ISO 16358-1:2013	MS ISO 5151:2012	CSPF
Myanmar	Under development	ISO 16358-1:2013 (to be adopted by 2022)	ISO 5151-2010 (to be adopted by 2021)	EER, CSPF
Philippines	PNS 396-1:1998 (current) RA 11285 (Effective May 2019) DOE DC2020-06-0015 (Label) DOE DC2020-06-0016 (MEPS)	PNS ISO 16358-1:2014	PNS ISO 5151:2014	CSPF
Singapore	Energy Conservation (Regulated Goods and Registered Suppliers) Regulations 2017 Energy Conservation (Prescribed Regulated Goods) Order 2017	N/A	ISO 5151 for casement, window and single-split air conditioners	WCOP (WEER)
Thailand	TIS-2134-2553 Room Air Conditioners: Energy Efficiency (Draft 2134-25XX under development)	TIS. 2714 Vol. 1-2558; 2-2558; 3-2558 (ISO 16358-1, -2, -3:2013)	TIS. 2710-2558 (ISO 5151:2010)	CSPF
Vietnam	TCVN 7830:2015	TCVN 10273-1:2013	TCVN 6576:2013	CSPF
		Other Asia		
China	GB 12021.3-2010 GB 21455-2013	GB/T 7725-2004 GB/T 17758-2010	GB/T 7725-2004 GB/T 17758-2010	SEER, HSPF, APF
India	Schedule - 19 Variable Capacity Air Conditioners	ISO 16358-1:2013	IS 1391 (Part 1 & Part 2)	SEER
Japan	Top Runner Program	JIS C 9612-2013	JIS B 8615-1:2013	CSPF, HSPF, APF
South Korea	MOTIE Notification No. 2017-206	KS C 9306:2017	KS C 9306:2017	CSPF, HSPF

DOE = Department of Energy; GB = “Guobiao” (Guóbiāo), which means “national standard”; IS = Indian Standard; JIS = Japanese Industrial Standard; KS = Korean Standard; MEMR = Ministry of Energy and Mineral Resources; MOTIE = Ministry of Trade, Industry, and Energy; MS = Malaysia Standard; PNS = Philippine National Standard; RA = Republic Act; SNI = Indonesian National Standard; TCVN = Vietnam Standard; TIS = Thai Industrial Standard.
Source: ACE (2020), Park et al. (2019), and information from International Institute for Energy Conservation (IIEC) and UNEP

The differences in seasonal efficiency metrics are primarily due to the outside temperature profiles used to aggregate steady-state and cyclic ratings into a seasonal efficiency value, as well as the ways of evaluating performance at part-load operation in the metric. Specific parameters to account for AC performance at part-load and/or lower-temperature operation in the efficiency metric also vary by country. Table 2 shows options that can be used for seasonal energy-efficiency evaluation by the selected regional standards and ISO 16358.

The ISO CSPF calculation for fixed-speed units requires two sets of test data: measurement of performance (capacity and power input) at full-capacity operation at 35°C and 29°C. However, in practice, countries require 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 predetermined equations (Table 3), resulting in no additional or different requirement for testing fixed-speed units compared to using the EER metric.

The CSPF calculation, including the India SEER (ISEER) calculation and the SEER calculation for variable-speed units (units with CC ≤ 7.1 kW) in China, requires 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-determined equations.

The China SEER calculation for variable-speed units with CC > 7.1 kW and the Korea CSPF calculation require three sets of test data at full-, half-, and minimum-capacity operation at 35°C, and another set of data points at 29°C calculated by their standard predetermined equations. Minimum-capacity tests are typically conducted at the lowest-capacity control settings of units that allow steady-state operation at the given test conditions. In China, the minimum-capacity test is conducted at 25% of full capacity. ISO 16358 suggests the minimum-capacity test at 29°C be conducted first and allows the minimum-capacity test at 35°C to be measured or calculated using default values.

Table 4 and Table 5 summarize the test requirements for fixed- and variable-speed units in the ASEAN member states and selected countries.

Table 3. Test Requirements and Options for AC Seasonal Energy-Efficiency Evaluation

Operating Condition/Type	Fixed Speed	Variable Speed
Full capacity (35°C)	Required	Required
Half or intermediate capacity (35°C)[a]	Not applicable	Required
Minimum capacity (35°C)	Not applicable	Required/optional/not considered[c]
Full capacity (29°C)	Required/optional[b]	Optional[c]
Half or intermediate capacity (29°C)	Not applicable	Optional[c]
Minimum capacity (29°C)	Not applicable	Optional/not considered[c]

[a] The ISO 16358-1:2013, JIS C 9612-2013 (Japan), and GB/T 7725-2004 (China) standards specify cooling half-capacity at outdoor temperature t to be 50% (± 5% or ± 0.1 kW) of full capacity at t at full-load operating conditions. In South Korea, the KS C 9306:2017 standard is based on full- and minimum-capacity tests. The intermediate-capacity test can be done at a level between the full and minimum capacities, if the minimum capacity is less than 50% of the full capacity.

[b] Although ISO 16358 requires full-load performance at the lower temperature to be measured, this is calculated in regional standards by using predetermined equations as below:

$Capacity(29℃) = Capacity(35℃) \times 1.077$; $Power\ input(29℃) = Power\ input(35℃) \times 0.914$

[c] Performance at the lower temperature can be calculated by using predetermined equations as below:

ISO, China, India, Japan: $Capacity(29℃) = Capacity(35℃) \times 1.077$; $Power\ input\ (29℃) = Power\ input(35℃) \times 0.914$

South Korea: $Capacity(29℃) = Capacity(35℃) \times 1.077$; $Power\ input(29℃) = Power\ input(35℃) \times 0.864$

The ISEER calculation in India does not consider minimum capacity tests.

ISO 16358 suggests the minimum capacity test at 29°C be conducted first and allows the minimum capacity test at 35°C to be measured or calculated by using default values. China (for units with CC > 7.1 kW) and South Korea standards require the minimum capacity test at 35°C and allow the minimum capacity test at 29°C to be calculated by using default values.

Half and minimum capacities are achieved by fixing the compressor speed during the test.

Source: Authors' work based on ISO 16358:2013, China's GB/T 7725-2004 and GB 21455-2013, India's Schedule 19, Japan's JIS C 9612:2013, and South Korea's KS C 9306:2017

Table 4. Comparison of test requirements for fixed-speed ACs

Operating condition	Outdoor dry / wet bulb temperature	EER (Singapore)	ASEAN[a], China (SEER), South Korea (CSPF), Model Regulation	ISO 16358
Full capacity	35/24°C	Required	Required	Required
Half (or intermediate) capacity		Not applicable	Not applicable	Not applicable
Minimum capacity		Not applicable	Not applicable	Not applicable
Full capacity	29/19°C	Not applicable	Calculated[b]	Required
Half (or intermediate) capacity		Not applicable	Not applicable	Not applicable
Minimum capacity		Not applicable	Not applicable	Not applicable

a. Except for Singapore. Not identified for Brunei Darussalam.

b. Capacity(29℃)=Capacity(35℃)×1.077; Power input(29℃)=Power input(35℃)×0.914

Table 5. Comparison of test requirements for variable-speed ACs

Operating condition	Outdoor dry / wet bulb temperature	WCOP (WEER)[a] (Singapore)	ASEAN[b], Japan, India, China (CC ≤ 7.1 kW) Model Regulation	South Korea China (CC > 7.1 kW)	ISO 16358
Full capacity	35/24°C	Required	Required	Required	Required
Half (or intermediate) capacity		Required	Required	Required	Required
Minimum capacity		Not considered	Not considered	Required	Optional
Full capacity	29/19°C	Not considered	Calculated[b]	Calculated[b]	Calculated
Half (or intermediate) capacity		Not considered	Calculated[b]	Calculated[b]	Optional
Minimum capacity		Not considered	Not considered	Calculated[b]	Optional

a. Weighted COP (WCOP) or WEER used in Singapore, defined as 0.4 × EER (or COP, 100% load at 35°C) + 0.6 × EER (or COP, 50% load at 35°C).
b. Except for Singapore. Not identified for Brunei Darussalam.
c. Capacity(29°C)=Capacity(35°C)×1.077; Power input(29°C)=Power input(35°C)×0.914

Degradation coefficient (CD) is a factor of efficiency loss due to the cyclic operation of an AC, which is an important parameter for on-off cycling performance evaluation. Although the actual value of CD can be derived from experiments, CD = 0.25 is typically used for all regional metrics (APEC 2010, Econoler et al. 2011).

Outdoor temperature bin hours for AC use are defined as a set of hours at each outdoor temperature that requires cooling. Outdoor temperature bin hours used for calculating seasonal efficiency vary by regional standard. Table 6 summarizes outdoor temperature bin hours used for seasonal energy-efficiency calculations in select regions and ASEAN member states, respectively. Table 7 shows example results of efficiency and energy consumption estimated by the WEER and CSPF metrics, respectively, for a variable-speed AC. The energy consumption estimated by WEER is greater by ~25% than the result by CSPF.

Table 6. Summary of Outdoor Temperature Bin Hours Used in Calculations of Seasonal Energy Efficiency by Region

	Standard	Temperature range	Number of temperature bins	Total hours of outdoor temperature bin[a]	Average daily hours of AC use (total hours/365)
ISO & ASEAN[b]	ISO 16358: 2013	21–35°C	15 bins (1°C per bin)	1,817	5.0
China	GB 21455-2013	24–38°C	15 bins (1°C per bin)	1,136	3.1
India	Schedule 19	24–43°C	20 bins (1°C per bin)	1,600	4.4
Japan	JIS C 9612: 2013	24–38°C[c]	15 bins (1°C per bin)	1,569	4.3
South Korea	KS C 9306: 2017	24–38°C[c]	15 bins (1°C per bin)	941	2.6

a. While the Malaysian MEPS and labeling requirements are based on the ISO temperature bin hours, the standard calculates annual energy consumption of an AC system for annual 4,380 hours (12 hours per day × 365 days).
b. Except for Singapore. Not identified for Brunei Darussalam
c. Although JIS C 9612:2013 and KS C 9306:2017 define outdoor temperature bin hours in the range of 24–38°C, zero hours are actually assigned to 35–38°C in JIS C 9612:2013 and 38°C in KS C 9306:2017.

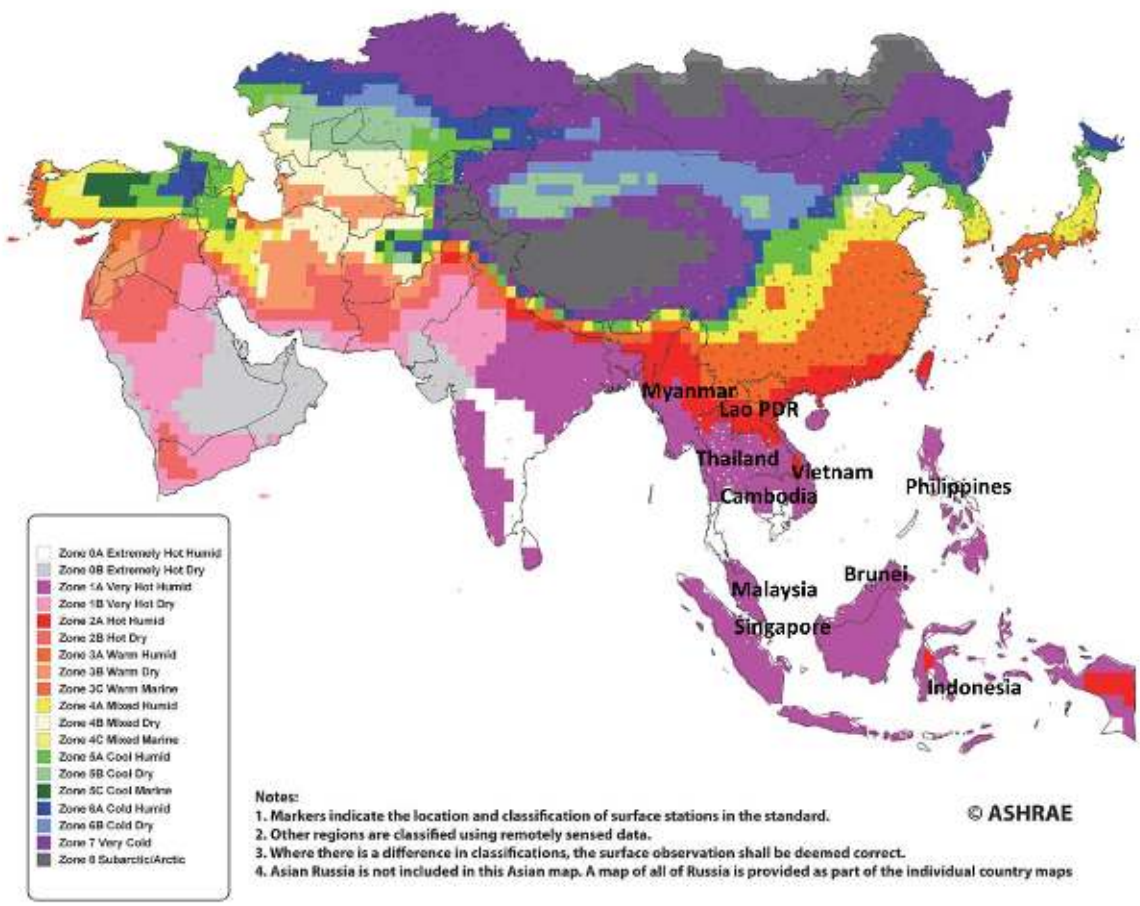
Table 7. A Comparison of WEER and CSPF Calculations for One Variable-Speed AC

Operating condition		**One variable-speed AC**	
		WEER	**CSPF**
Full capacity / power input (EER_{ful35}) at 35°C	W (W/W)	3600 / 1080 (3.33)	
Half capacity / power input (EER_{haf35}) at 35°C	W (W/W)	1800 / 432 (4.17)	
Full capacity / power input at 29°C	W (W/W)	Not considered	Calculated[a]
Half capacity / power input at 29°C	W (W/W)		
Annual hours of use	Hours	1817 hours[b]	1817 hours (ISO 16358, 21–35°C)
EER	W/W	3.33	3.33
WEER	W/W	3.83	3.83
CSPF	Wh/Wh	-	4.76
Annual Energy Consumption	kWh	691[c]	555[c]

[a] Capacity(29°C)=Capacity(35°C)×1.077; Power input(29°C)=Power input(35°C)×0.914
[b] Assumed the total hours of use equivalent to the total of IS0 16358 temperature bin hours.
[c] $\frac{3600}{3.33} \times 0.4 + \frac{1800}{4.17} \times 0.6$
[d] In accordance with ISO 16358-1: 2013 Clause 6.7 (see Annex C)

3. Outdoor Temperature Bin Hours for Room AC Use in ASEAN

To adopt a seasonal AC energy-efficiency metric and improve the standards of ASEAN countries, ASEAN can use the ISO CSPF metric in accordance with ISO 16358-1:2013, based on ISO 16358 reference temperature bin hours or ASEAN-specific temperature bin hours. As shown in Figure 2, ASEAN countries have similar climates, varying from extremely hot-humid (Zone 0A) to hot-humid (Zone 2A).[5] These American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) climate zone definitions are based on cooling degree-day base 10°C (CDD_{10}), heating degree-day base 18°C (HDD_{18}), annual precipitation, annual mean temperature, and so forth (see Annex A for details).[6]



Source: ANSI/ASHRAE Standard 169-2013

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[5] There are countries that set AC efficiency requirements varying by climate zone in their countries. For example, the U.S. standard for residential units divides the country into three different climate zones and sets efficiency requirements varying by climate zone and sub-product category. However, manufacturers produce their products to meet the most stringent requirements in the country so that their products can be sold any region in the country. Regardless, it has been useful to consider variations in absolute impacts, e.g., energy use, electricity cost, lifecycle cost, emissions, etc. with multiple regional climates in the country.

[6] Cooling or heating degree days are the sum of differences between daily average temperatures and the base temperature (e.g., 10°C or 18°C) over the course of a year.

Figure 2. Climates in ASEAN countries by ASHRAE Climate Zone

Table 8 summarizes the climate zone and climate characteristics of 10 ASEAN locations that best represent the largest population cities in each country. Figure 3 shows annual outdoor temperature distributions of the 10 locations as analyzed by the authors.

Table 8. Climate Summary for 10 ASEAN Locations

Country	Location[a] (Largest population city)	ASHRAE Climate Zone[b]	CDD_{10} (days)	$CDD_{18.3}$ (days)	Annual Average Dry Bulb Temperature (°C)	Annual Average Precipitation (mm)
Brunei Darussalam	Bandar Seri Begawan	0A	6,527	3,486	27.9	2,922
Cambodia	Phnom Penh	0A	>6,000	>3,000	28.3	1,371
Indonesia	Jakarta	0A	6,896	3,854	28.9	1,883
Lao PDR	Vientiane	0A	6,274	3,235	27.2	1,665
Malaysia	Kuala Lumpur	0A	6,724	3,683	28.4	2,366
Myanmar	Yangon	0A	6,541	3,499	27.9	2,719
Philippines	Manila	0A	6,768	3,727	28.5	2,134
Singapore	Bedok	0A	6,647	3,605	28.2	2,054
Thailand	Bangkok	0A	7,027	3,986	29.3	1,537
Vietnam	Ho Chi Minh	0A	6,639	3,598	28.2	1,666

[a] The data are based on the following weather stations: Brunei/Bandar Seri Begawan—BRUNEI INTL, Cambodia/Phnom Penh (not specified), Indonesia/Jakarta—JAKARTA OBSERVATORY, Lao PDR/Vientiane—VIENTIANE WATTAY INTL, Malaysia/Kuala Lumpur—KUALA LUMPUR SUBANG, Myanmar/Yangon—YANGON INTL, Philippines/Manila—MANILA, Singapore/Bedok—CHANGI INTL, Thailand/Bangkok—BANGKOK METROPOLIS, Vietnam/Ho Chi Minh—HO CHI MINH TAN SON NHAT INTL.

[b] All these specific locations fall into the white (0A) zones on the map in Figure 2.

Source: ASHRAE Weather Data 6.0 and authors' estimate for Phnom Penh based on meteoblue data (www.meteoblue.com)

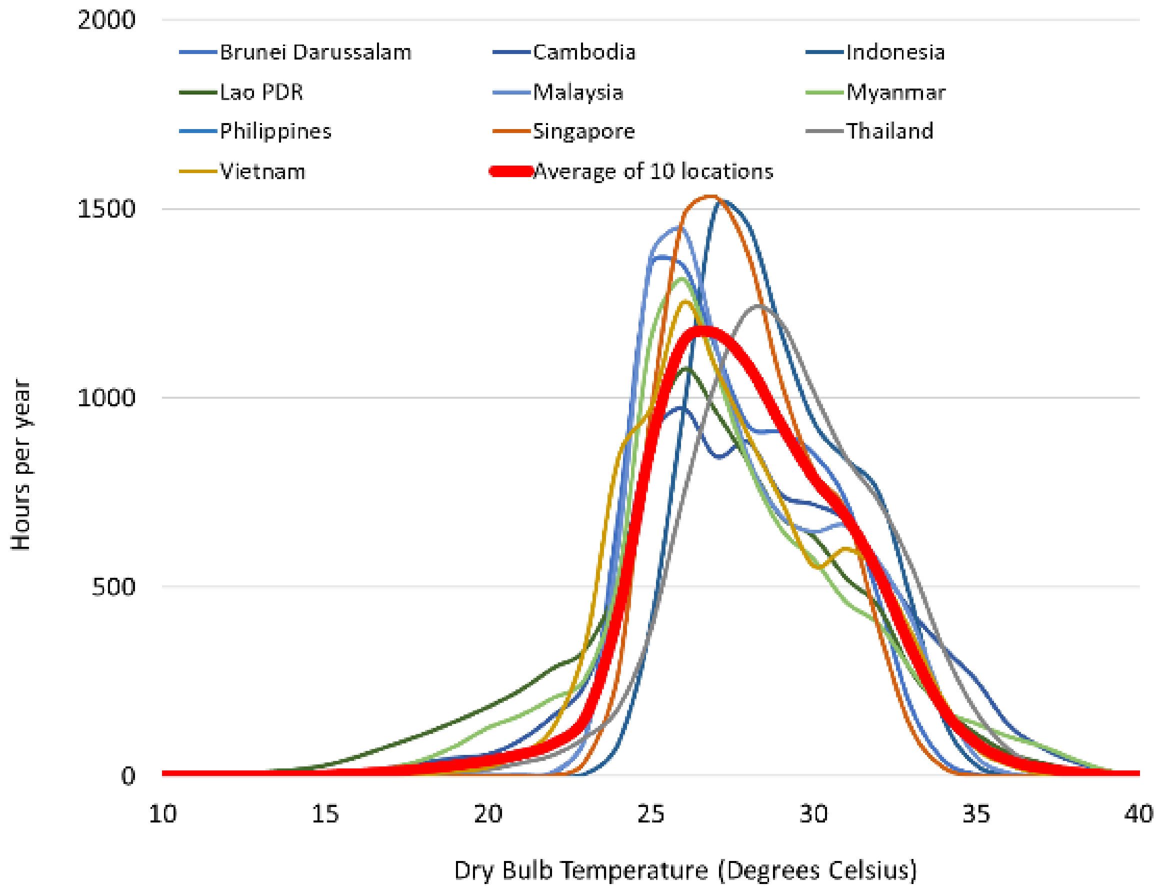


Figure 3. Outdoor temperature distributions of 10 ASEAN locations

According to the climate data, hours at temperatures between 21°C and 35°C account for 99% of the annual outdoor temperature distributions in the 10 ASEAN locations on average (93%–100% by location), while hours over 35°C account for less than 1% on average. Based on these climate data, this study estimates hours of room AC use at each outdoor temperature as follows:

a) Outdoor temperature at 0% load $t_0 = 20$°C, consistent with ISO 16358.
b) Hours of AC use at temperatures between 21°C and 33°C[7] are assumed to increase in proportion to cooling load. Above 33°C, hours of AC use are assumed to be equivalent to the annual bin hours.
c) The total hours of per-unit annual AC use result in 5,361 hours (14.7 hours per day, orange histogram in Figure 4).
d) The total hours of AC use can be adjusted based on AC use information in each country. For example, while the Malaysian MEPS and labeling requirements are based on CSPF

[7] At 35°C building load is assumed to be 100% according to the ISO 16358 standard. 33°C we used here is the temperature where hours of AC use are assumed to be equivalent to the annual bin hours, for estimating hours of AC use only.

with the ISO temperature bin hours (1,817 hours), it calculates annual energy consumption of an AC system for annual 4,380 hours (12 hours per day × 365 days) of use. In this case, the hours of AC use in each temperature bin can be further adjusted by using the below equation:

$$\text{Bin hours (t)} = \text{annual bin hours (t)} \times \left[\frac{4380 - \sum_{t=34}^{t=40} annual\ bin\ hours\ (t)}{5361 - \sum_{t=34}^{t=40} annual\ bin\ hours\ (t)}\right]$$

where t = 21 to 33

Figure 4 shows the temperature bin hours assumed for AC use in c) and d) derived from Malaysia's annual 4,380 hours used for AC energy consumption calculation.

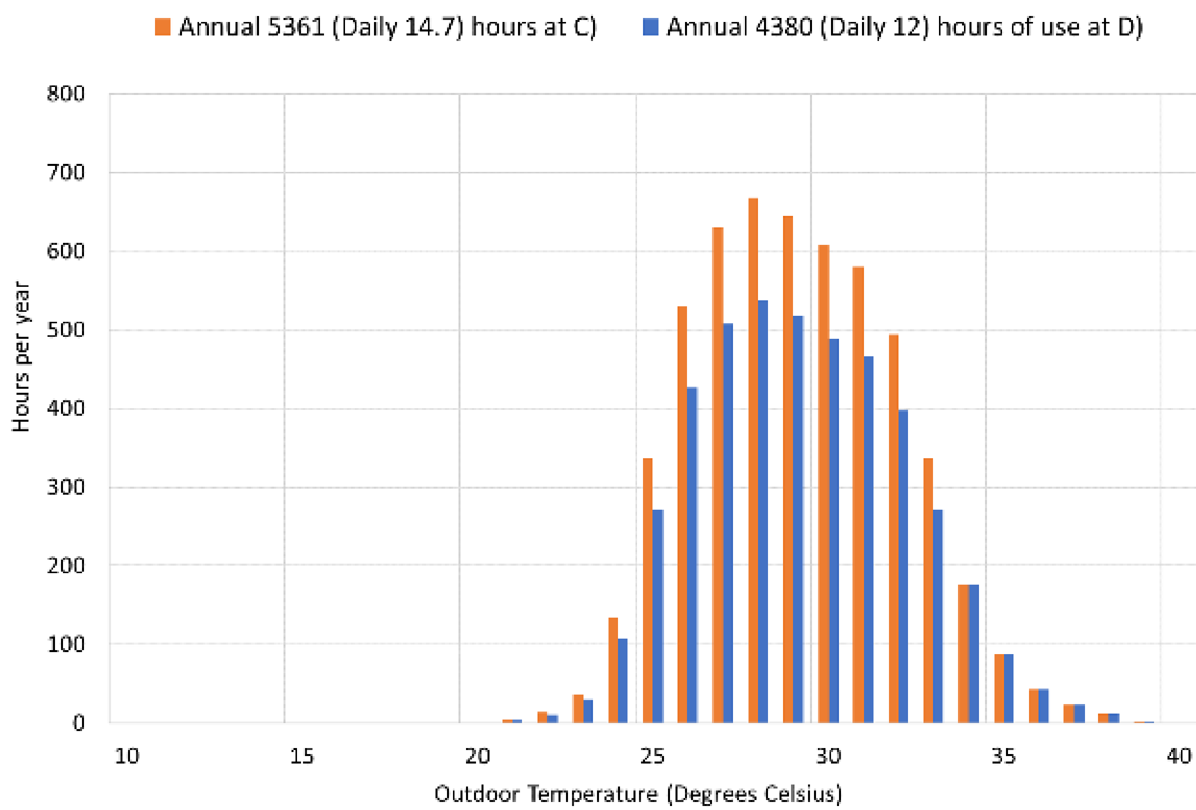


Figure 4. Annual temperature bin hours assumed for AC use at c) (orange) and d) (blue)

Figure 5 shows the temperature bin hours assumed for AC use derived from Malaysia's annual 4,380 hours used for AC energy consumption calculation (blue histogram) and ISO 16358-reference outdoor temperature bin hours (yellow histogram).

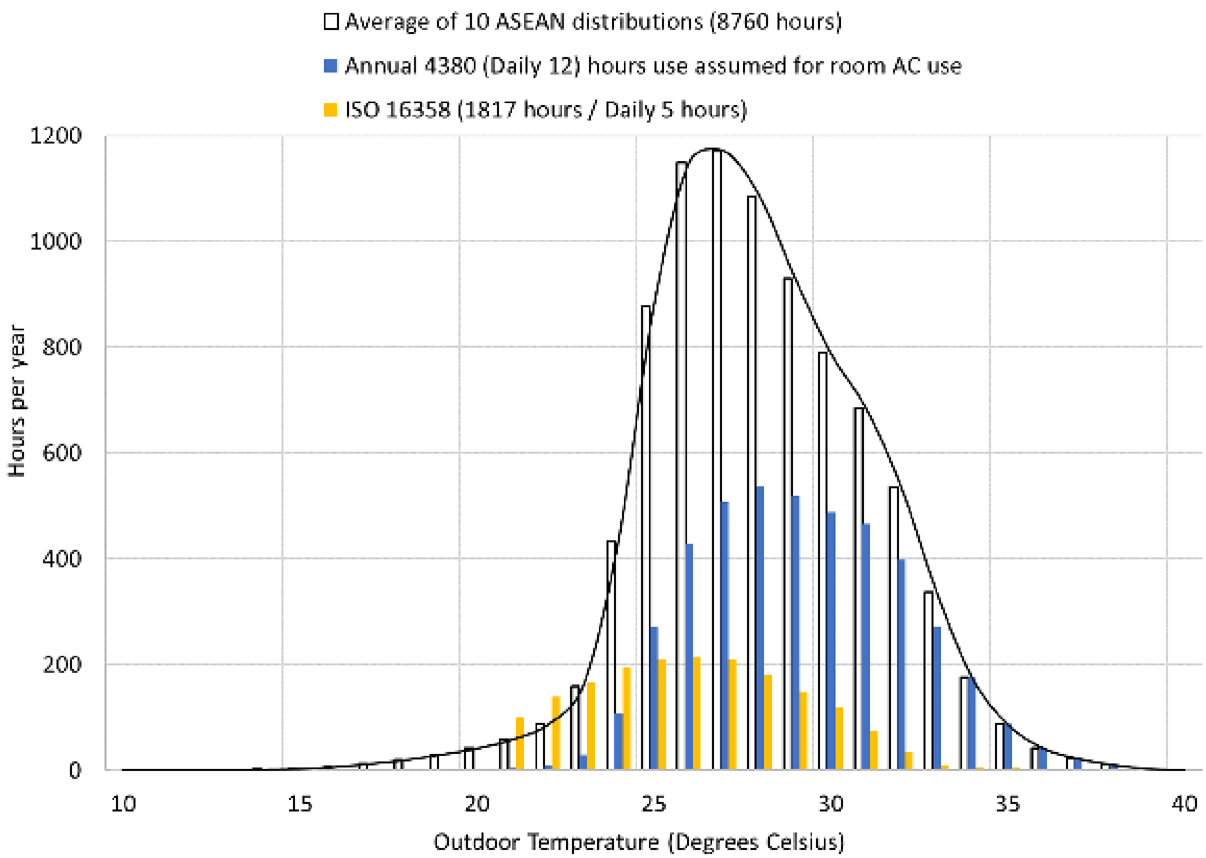


Figure 5. Annual outdoor temperature distribution (black), temperature bin hours assumed for AC use in ASEAN countries (blue), and ISO 16358-reference outdoor temperature bin hours (yellow)

The ISO 16358 standard also provides fractional bin hours. Bin hours of each outdoor temperature may be calculated by multiplying the fractional bin hours by the total annual cooling hours if the fractional bin hours are applicable (see Table B1).

4. Evaluating the Efficiency Performance of Room ACs

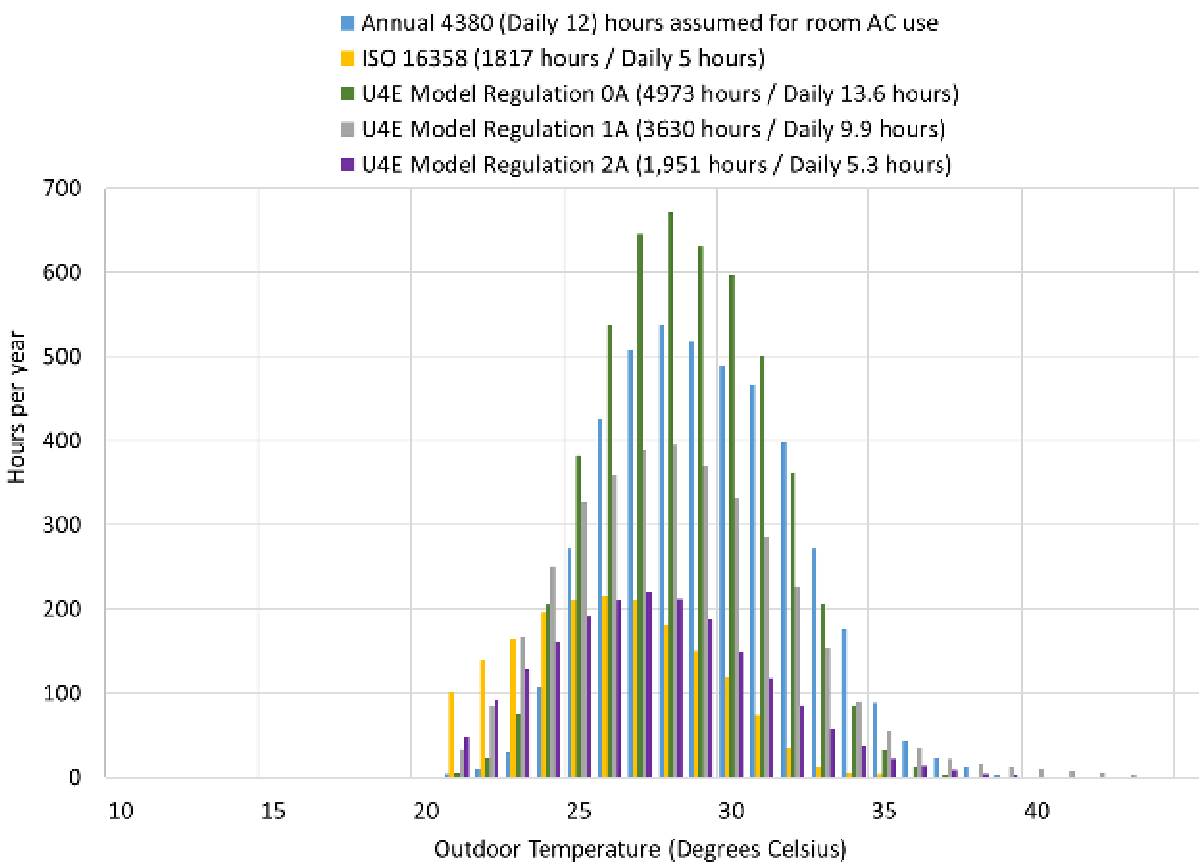
This study analyzes the efficiency performance of five room AC models according to the ISO CSPF calculation with four sets of temperature bin hours for AC use, based on:

1) ISO 16358-1: 2013
2) U4E Model Regulation 0A (Extremely Hot-Humid)
3) U4E Model Regulation 1A (Very Hot-Humid)
4) U4E Model Regulation 2A (Hot-Humid)

The United for Efficiency (U4E) Model Regulation Guidelines offers outdoor temperature bin hours by climate region. These choices were made because some ASEAN countries have already adopted ISO 16358 temperature bin hours, but the ASEAN climate falls into 0A, 1A, and 2A climate zones—so the U4E Model Regulation temperature bin hours should reflect real-world performance more accurately. The ASEAN AC-use distribution (blue histogram in Figure 6) is similar to the U4E Model Regulation 0A (extremely hot-humid climate) AC-use distribution (green histogram in Figure 6). Table 9 summarizes the sets of outdoor temperature bin hours used in the ISO CSPF calculation.

Table 9. Summary of Outdoor Temperature Bin Hours Used in the ISO CSPF Calculation

	ISO 16358	U4E Model Regulation 0A	U4E Model Regulation 1A	U4E Model Regulation 2A
Efficiency calculation	ISO 16358-1:2013 CSPF			
Temperature range	21–35°C	21–38°C	21–44°C	21–42°C
Number of temperature bins	15 bins (1°C per bin)	18 bins (1°C per bin)	24 bins (1°C per bin)	22 bins (1°C per bin)
Total hours of outdoor temperature bin	1,817 (5.0 hr/d)	4,973 (13.6 hr/d)	3,630 (9.9 hr/d)	1,951 (5.3 hr/d)



See Table 5 and Table B1 for details.

Figure 6. Temperature bin hours assumed for AC use in ASEAN countries (blue), ISO 16358-reference outdoor temperature bin hours (yellow), and U4E Model Regulation 0A/1A/2A bin hours

Table 10 summarizes basic specifications of the five analyzed room AC models. Detailed information about temperature bin hours is available in Annex B.

Table 10. Basic Specifications of the Five Room AC Models Analyzed

Sample	1	2	3	4	5
Compressor type	Fixed speed		Variable speed		
Nominal CC (kW)	3.5–3.6				
EER (W/W)	3.2	3.6	3.3	3.9	5.0

4.1. CSPF Calculation

The ISO CSPF calculation refers to ISO 16358-1:2013 Clause 6.4 for fixed-speed units and Clause 6.7 for variable-speed units. The CSPF calculation for fixed-speed units is based on one set of test data—measurement of performance (capacity and power input) at full-capacity operation at an outdoor dry bulb temperature of 35°C—and then performance at 29°C is calculated by the predetermined equations. The CSPF calculation for variable-speed units is based on two sets of test data—measurement of performance (capacity and power input) at full- and half-capacity operation at an outdoor dry bulb temperature of 35°C—and then performance at 29°C is calculated by ISO 16358-determined equations. Detailed CSPF calculation is available in Annex C.

Figure 7 shows the EER and ISO CSPF results with all five sets of temperature bin hours for all five AC samples.

For fixed-speed units, the CSPF calculation in this analysis is based on one set of test data at full operation at 35°C and another set of data points at 29°C calculated by predetermined equations. There is no large difference between the EER and CSPF values for the fixed-speed units. Given that predetermined equations are used to estimate the performance at 29°C, CSPF for fixed-speed units results in a linear relationship with EER, i.e., CSPF = $\alpha \times$ EER (e.g., $\alpha = 1.062$ with the ISO temperature bin hours and $\alpha = 1.045$ with the 0A temperature bin hours).

For variable-speed units, using a seasonal efficiency metric (CSPF) better reflects real energy performance by capturing full-load and part-load performance and by helping better estimate savings gained from the seasonal performance. CSPF for variable-speed units is greater than EER by 36%–65%, with the 0A temperature bin hours. The CSPF results with U4E Model Regulation 0A, 1A, and 2A climates are lower by 5%–13% than those with the ISO 16358 temperature bin hours.

Note that the CSPF calculation for variable-speed units in this section is based on 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-determined equations.

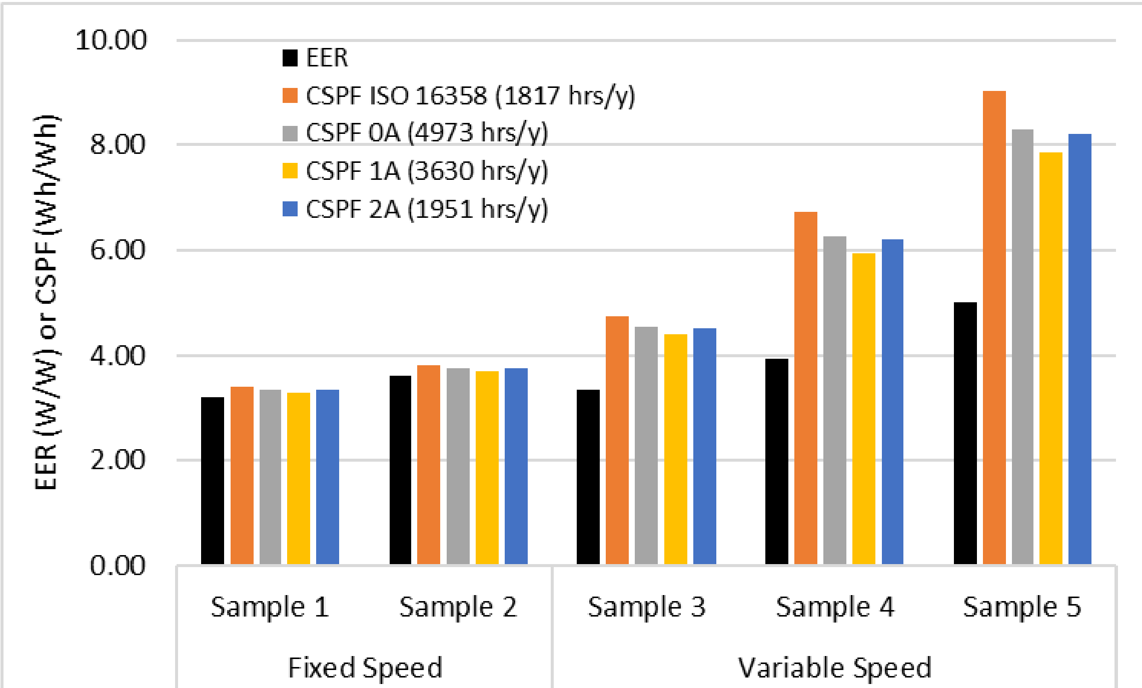


Figure 7. EER and ISO CSPF of five room AC models by different temperature bin hours

4.2. Seasonal Energy Consumption and Savings Potential

Energy consumption depends on equipment efficiency, the total hours of AC use, and the number of hours at each temperature when the AC is in use. Figure 8 shows the estimated annual energy consumption of all five room AC models by different temperature bin hours. Variable-speed units consume approximately 25% (Sample 3) to 60% (Sample 5) less energy compared with the lowest-efficiency fixed-speed unit (Sample 1). In a similar way, Table 11 shows per-unit energy savings potential in improving a minimum efficiency requirement from EER 2.90 (or CSPF 3.08) to CSPF 6.10 (the U4E Model Regulation Guidelines low-efficiency requirement) for 1-RT ACs. In Brazil that has climates (0A, 1A, and 2A) similar to the ASEAN member countries, field experiments performed at Mauá Institute of Technology, Pontifical Catholic University of Rio de Janeiro, and Federal University of Santa Catarina showed energy savings of 21%–70% for variable-speed units compared with fixed-speed units, depending on efficiency performance and operating conditions (Park et al. 2019).

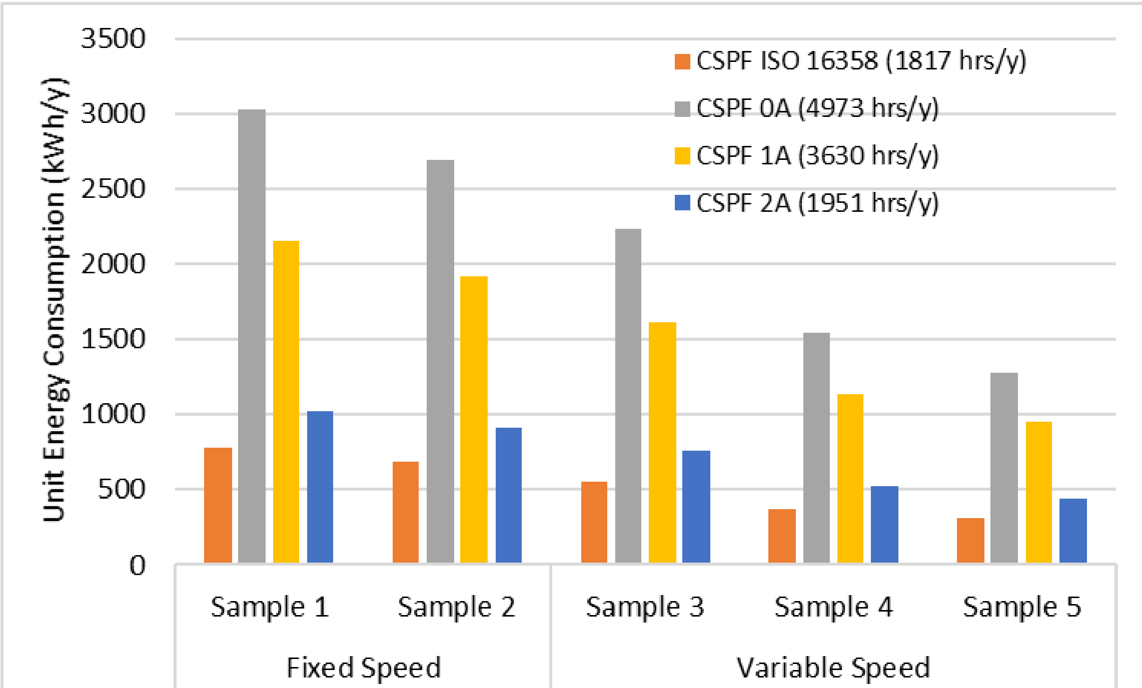


Figure 8. Estimated annual energy consumption of five room AC models by different temperature bin hours

Table 11. Per-unit Energy Savings Potential in Switching to the U4E Model Regulation Guidelines Low-Efficiency Requirement

Operating condition	Outdoor dry / wet bulb temperature	CSPF 3.08 (EER 2.90, Fixed speed)	CSPF 6.10 (EER 3.80[a], Variable-speed)
Full capacity / power input (EER_{ful35})	35/24°C	3600 / 1240	3600 / 948
Half capacity / power input (EER_{haf35})		NA	1800 / 332
Full capacity / power input	29/19°C	NA	Calculated[b]
Half capacity / power input			
Hours of use	Hours	1817 (ISO 16358, 21–35°C)	1817 (ISO 16358, 21–35°C)
EER	W/W	2.90	3.79
CSPF	Wh/Wh	3.08	6.10
Annual Energy Consumption	kWh	856[c]	433[d]

[a] Based on one of authors' modeled specifications that achieve CSPF 6.10.
[b] Capacity(29°C)=Capacity(35°C)×1.077; Power input(29°C)=Power input(35°C)×0.914
[c] In accordance with ISO 16358-1: 2013 Clause 6.4
[d] In accordance with ISO 16358-1: 2013 Clause 6.7

5. Policy Insights

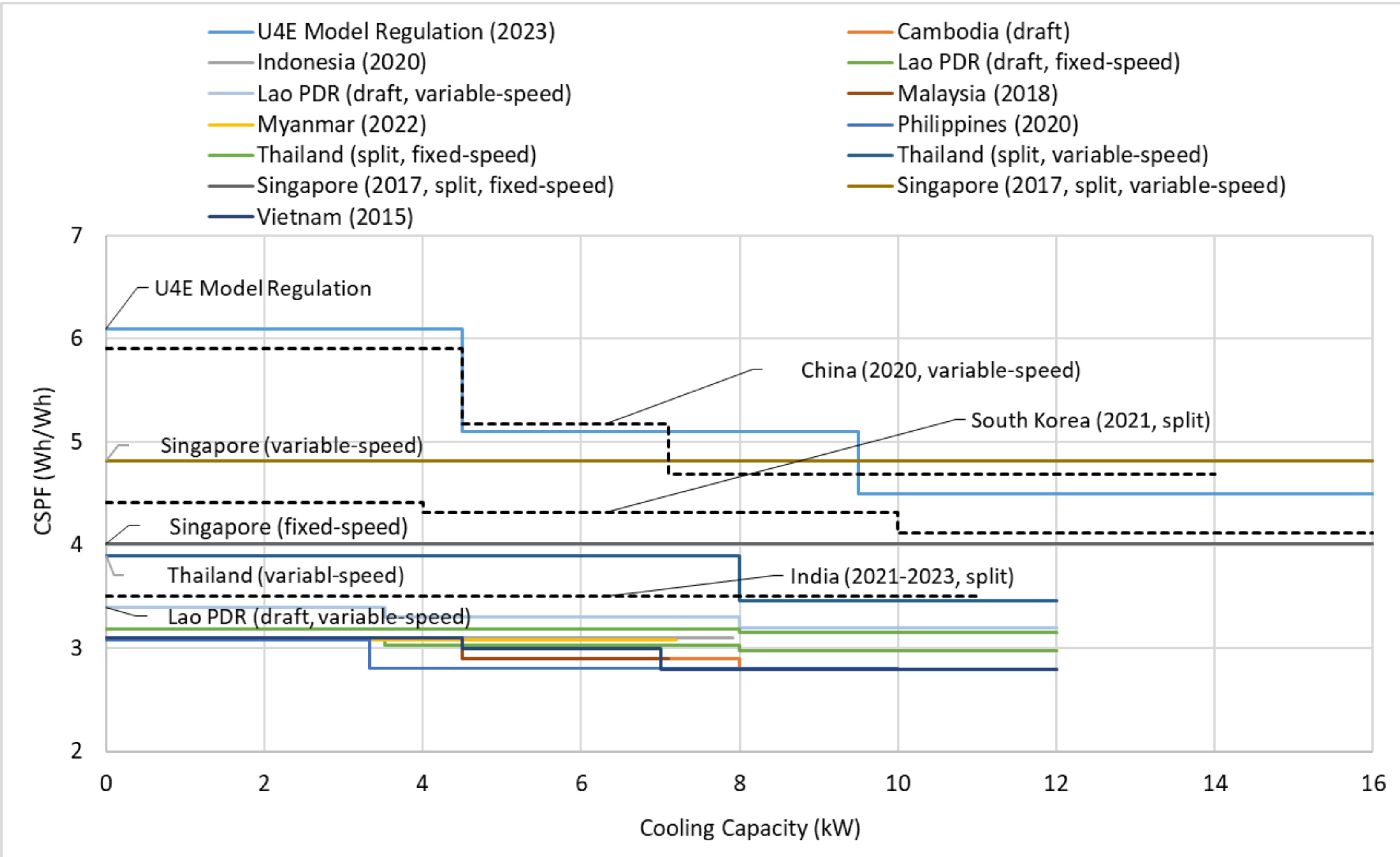
5.1. Minimum Energy Performance Standards (MEPS)

The majority of ASEAN member countries have put in place MEPS for room ACs. The current or planned MEPS requirements for various types of ACs are shown in Table 12.

The ASEAN SHINE program has worked with all ASEAN economies to harmonize standards across the region, and it has supported ASEAN countries' AC MEPS. The goal of this harmonization initiative is to have a common test method and set of MEPS and tiers for use in each country's comparative label. This harmonization has multiple potential benefits, including reducing the burden on manufacturers, who only need to test a product once to sell it in multiple countries, and promoting economies of scale to reduce manufacturing and supply chain costs as well as retail prices. Although the MEPS for variable-speed ACs in Singapore and Thailand are close to the U4E Model Regulation least-efficiency levels, there is no single MEPS level yet in ASEAN countries. The ASEAN SHINE 2020 targets that most ASEAN countries have adopted remain below the MEPS China adopted in 2010 (EER 3.20 W/W or 10.91 Btu/hr/W) and well below those adopted in 2020 and 2022, which align largely with the U4E Model Regulation (Figure 9). Because China produces about 70% of the world's room ACs, and its domestic market accounts for roughly 40%–50% of global AC sales, a low ASEAN MEPS would not achieve the economies of scale, low upfront costs, and significantly higher life-cycle savings and environmental benefits that could be realized by aligning with China's standards.

Table 12. MEPS Levels for ACs in ASEAN Countries

<table>
<tr><th></th><th>CC Covered by Standards</th><th colspan="2">MEPS</th></tr>
<tr><td>Brunei Darussalam</td><td colspan="3">Under development</td></tr>
<tr><td>Cambodia</td><td>CC ≤ 12.0 kW</td><td colspan="2">(Draft)
CC ≤ 4.5 kW CSPF 3.08
4.5 < CC ≤ 8.0 kW CSPF 2.90
8.0 < CC ≤ 12.0 kW CSPF 2.80</td></tr>
<tr><td>Indonesia</td><td>CC ≤ 7.9 kW</td><td colspan="2">CSPF 3.10</td></tr>
<tr><td rowspan="2">Lao PDR</td><td rowspan="2">CC ≤ 12.0 kW</td><td>(Draft)
Fixed-speed</td><td>CC ≤ 3.52 kW CSPF 3.08
3.52 kW < CC ≤ 8.0 kW CSPF 3.03
8.0 kW < CC ≤ 12.0 kW CSPF 2.97</td></tr>
<tr><td>(Draft)
Variable-speed</td><td>CC ≤ 3.52 kW CSPF 3.4
3.52 kW < CC ≤ 8.0 kW CSPF 3.3
8.0 kW < CC ≤ 12.0 kW CSPF 3.2</td></tr>
<tr><td>Malaysia</td><td>CC ≤ 7.1 kW</td><td colspan="2">CC < 4.5 kW CSPF 3.10
4.5 kW ≤ CC ≤ 7.1 kW CSPF 2.90</td></tr>
<tr><td>Myanmar</td><td>CC ≤ 7.2 kW</td><td colspan="2">EER 2.9 or CSPF 3.08
(voluntary in 2021, mandatory in 2022)</td></tr>
<tr><td>Philippines</td><td>CC ≤ 10.0 kW (current)
CC ≤ 14.0 kW (planned for labeling)</td><td colspan="2">CC < 3.33 kW CSPF 3.08
3.33 kW ≤ CC < 10.0 kW CSPF 2.81
10.0 kW ≤ CC < 14.0 kW No MEPS</td></tr>
<tr><td>Singapore</td><td>CC ≤ 8.8 kW (casement and window)</td><td colspan="2">Casement and window (up to 8.8 kW) EER 2.90
Single-split (non-inverter) EER 3.78
Single-split (inverter) WEER 3.78 & EER 3.34</td></tr>
<tr><td rowspan="5">Thailand</td><td rowspan="5">CC ≤ 12.0 kW</td><td>Window</td><td>CC ≤ 8.0 kW EER 2.82
8.0 kW < CC ≤ 12.0 kW EER 2.53</td></tr>
<tr><td>Split</td><td>CC ≤ 8.0 kW EER 2.82
8.0 kW < CC ≤ 12.0 kW EER 2.82</td></tr>
<tr><td>(New draft)
Window</td><td>CC ≤ 8.0 kW CSPF 3.19
8.0 < CC ≤ 12.0 kW CSPF 3.15</td></tr>
<tr><td>Split-Fixed speed</td><td>CC ≤ 8.0 kW CSPF 3.19
8.0 < CC ≤ 12.0 kW CSPF 3.15</td></tr>
<tr><td>Split-Inverter</td><td>CC ≤ 8.0 kW CSPF 3.90
8.0 < CC ≤ 12.0 kW CSPF 3.46</td></tr>
<tr><td>Vietnam</td><td>CC ≤ 12.0 kW (non-ducted)
CC ≤ 8.0 kW (ducted)</td><td colspan="2">Unitary CSPF 2.80
Single-split
CC < 4.5 kW CSPF 3.10
4.5 kW ≤ CC < 7.0 kW CSPF 3.00
7.0 kW ≤ CC < 12.0 kW CSPF 2.80</td></tr>
</table>



a. For fixed-speed units in Singapore, we use the linear relationship CSPF = 1.062 × EER with the ISO temperature bin hours.

b. This analysis uses regression equations to convert the efficiency in regional metrics (China, India, South Korea, and Singapore) into ISO CSPF, based on Park et al. (2020) and additional data. For example, for variable-speed units in Singapore, this analysis uses a regression linear relationship CSPF = 1.192 × WEER + 0.311 with the ISO temperature bin hours, based on test data authors have (see Annex D). These conversion results are only estimates, and they are most useful for making broad initial comparisons.

Figure 9. MEPS for ACs in ASEAN economies compared with the U4E Model Regulation and selected countries

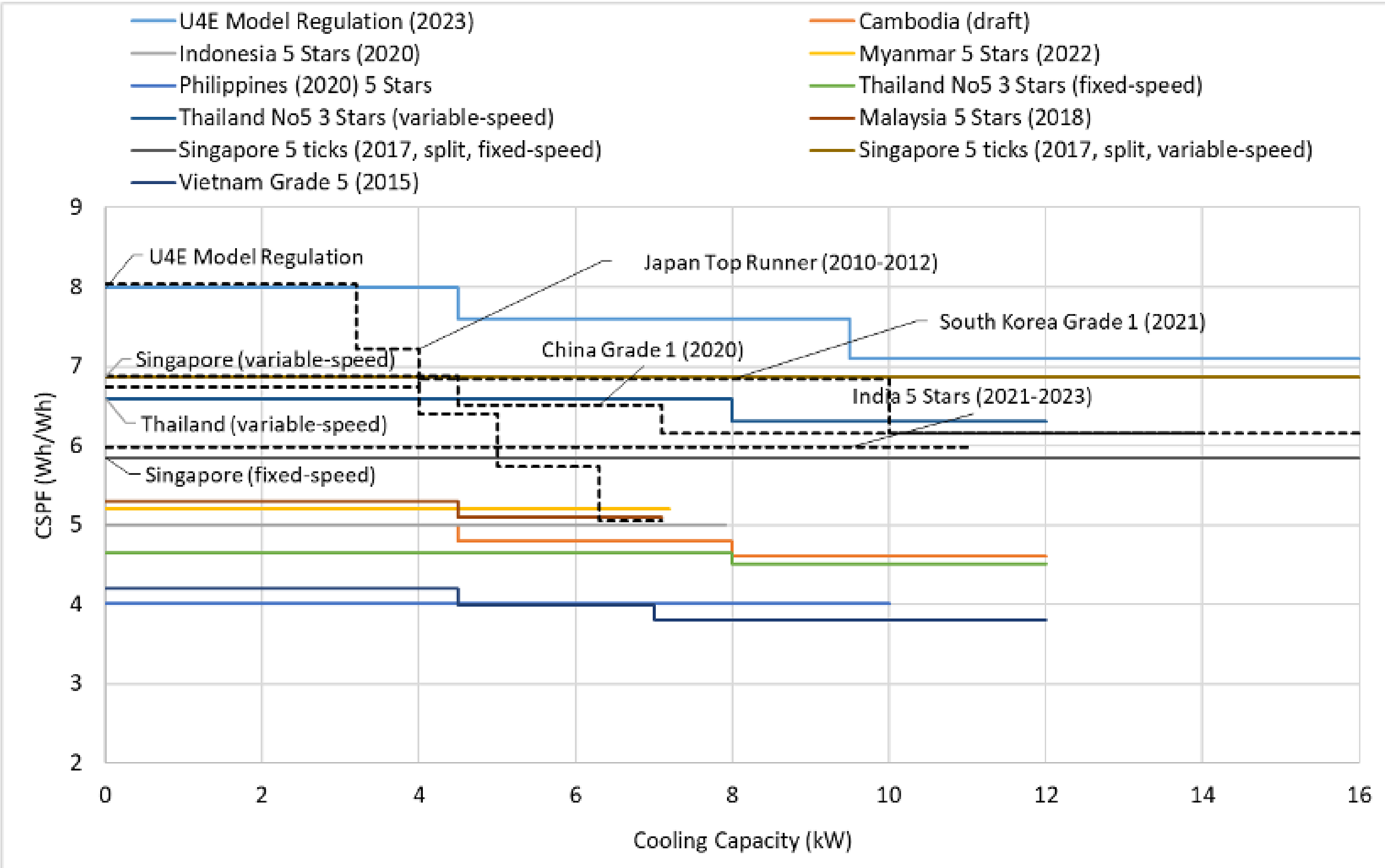
5.2. Labeling Program

The majority of ASEAN countries have put in place MEPS and labeling for room ACs. The current and planned most stringent labeling requirements for various types of ACs are shown in Table 13. Although the most stringent labeling requirements for variable-speed ACs in Singapore and Thailand are close to the U4E Model Regulation high-efficiency levels, those in most ASEAN countries remain below the U4E Model Regulation's high-efficiency levels (Figure 10).

Table 13. Most Stringent Labeling Requirement for ACs in ASEAN Countries

	CC Covered by Labeling	Most Stringent Label	
Brunei Darussalam	Under development		
Cambodia	CC ≤ 12.0 kW	No. 5 (Draft)	CC ≤ 4.5 kW CSPF ≥ 5.00 4.5 < CC ≤ 8.0 kW CSPF ≥ 4.80 8.0 < CC ≤ 12.0 kW CSPF ≥ 4.60
Indonesia	CC ≤ 7.9 kW	5 Stars CSPF ≥ 5.00	
Lao PDR	CC ≤ 12.0 kW	No5 (Draft) Fixed-speed	CC ≤ 3.52 kW CSPF ≥ 3.5 3.52 kW < CC ≤ 8.0 kW CSPF ≥ 3.45 8.0 kW < CC ≤ 12.0 kW CSPF ≥ 3.40
		(Draft Variable-speed	CC ≤ 3.52 kW CSPF ≥ 5.0 3.52 kW < CC ≤ 8.0 kW CSPF ≥ 4.9 8.0 kW < CC ≤ 12.0 kW CSPF ≥ 4.8
Malaysia	CC ≤ 7.1 kW	5 Stars	CC < 4.5 kW CSPF ≥ 5.30 4.5 kW ≤ CC ≤ 7.1 kW CSPF ≥ 5.10
Myanmar	CC ≤ 7.2 kW	5 Stars	Fixed-speed EER ≥ 4.9 Variable-speed CSPF ≥ 5.2
Philippines	CC ≤ 14.0 kW (planned for labeling)	5 Stars	CC < 3.33 kW CSPF ≥ 4.01 3.33 kW ≤ CC < 9.99 kW CSPF ≥ 4.01 10.0 kW ≤ CC < 14.0 kW CSPF ≥ 4.01
Singapore	CC ≤ 8.8 kW (casement and window)	5 ticks	Casement and window (up to 8.8 kW) EER ≥ 5.50 & standby-mode power ≤ 4 W Single-split (non-inverter) EER ≥ 5.50 & standby-mode power ≤ 4 W Single-split (inverter) WEER ≥ 5.50&EER ≥ 4.86&standby-mode power ≤ 4 W
Thailand	CC ≤ 12.0 kW	No. 5 (3 Stars)	Fixed-speed CC ≤ 8.0 kW CSPF ≥ 4.644 8.0 kW < CC ≤ 12.0 kW CSPF ≥ 4.512 Variable-speed CC ≤ 8.0 kW CSPF ≥ 6.593 8.0 kW < CC ≤ 12.0 kW CSPF ≥ 6.300

Vietnam	CC ≤ 12.0 kW (non-ducted) CC ≤ 8.0 kW (ducted)	Grade 5	Unitary CSPF ≥ 3.60 Single-split CC < 4.5 kW CSPF ≥ 4.20 4.5 kW ≤ CC < 7.0 kW CSPF ≥ 4.00 7.0 kW ≤ CC < 12.0 kW CSPF ≥ 3.80

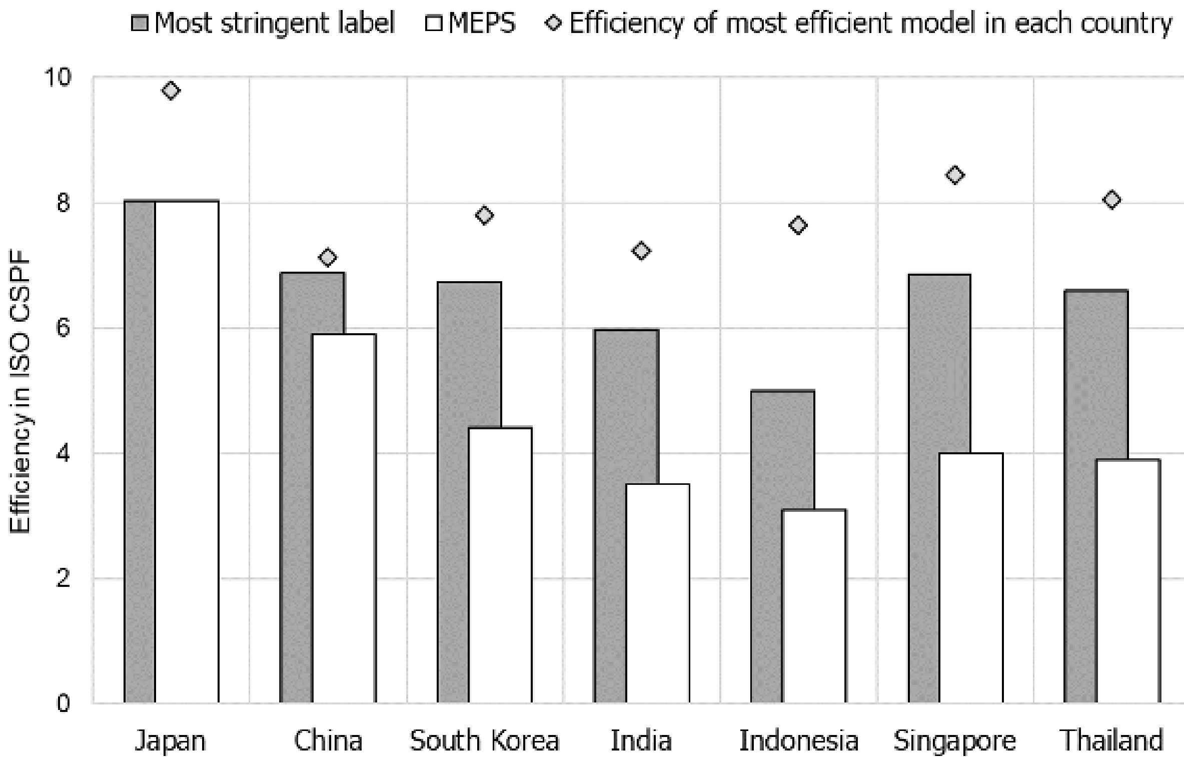


a. For fixed-speed units in Singapore, we use the linear relationship CSPF = 1.062 × EER with the ISO temperature bin hours.

b. This analysis uses regression equations to convert the efficiency in regional metrics (China, India, Japan, South Korea, and Singapore) into ISO CSPF, based on Park et al. (2020) and additional data. For example, for variable-speed units in Singapore, this analysis uses a regression linear relationship CSPF = 1.192 × WEER + 0.311 with the ISO temperature bin hours, based on test data authors have (see Annex D). These conversion results are only estimates, and they are most useful for making broad initial comparisons.

Figure 10. Most stringent labeling requirements for ACs in ASEAN economies compared with the U4E Model Regulation and selected countries

Figure 11 shows regional efficiency standards converted into the ISO CSPF metric. Because efficiency standards in some countries vary by capacity, we select most stringent and least stringent classes that apply to the identified split AC models. Based on these findings and estimates, in most countries, the gap between the efficiencies of the highest-efficiency models and the MEPS is substantial.



This analysis uses regression equations to convert the efficiency of the identified most efficient AC models into ISO CSPF and other regional metrics, based on the regional metric/conditions under which the model was originally evaluated (Park et al. 2020). These conversion results are only estimates, with uncertain precision—they are most useful for making broad initial comparisons. To validate the performance of an AC model under metrics/conditions other than those under which its performance was initially measured, detailed performance data must be collected under the new metrics/conditions.

Figure 11. Efficiency of most efficient models and regional S&L in ISO CSPF

5.3. Availability of U4E Model Regulation Compliant ACs

It is important to conduct detailed market assessments and various analyses of energy use, cost efficiency, lifecycle cost, national impact, and manufacturer impact related to potential MEPS and labeling levels for each ASEAN country or the whole region. However, these analyses are outside the scope of this report.[8] Instead, this section shows how many AC models currently available in selected ASEAN countries meet the U4E Model Regulation efficiency requirements.

[8] Letschert et al. (2020) provide such analyses for Indonesia.

To identify energy-efficient room ACs with both lower-global-warming-potential (e.g., R-32, R-290) and conventional (e.g., R-410A) refrigerants, AC products available in two countries are assessed: Singapore and Thailand. The data are from country-specific databases (Table 14).

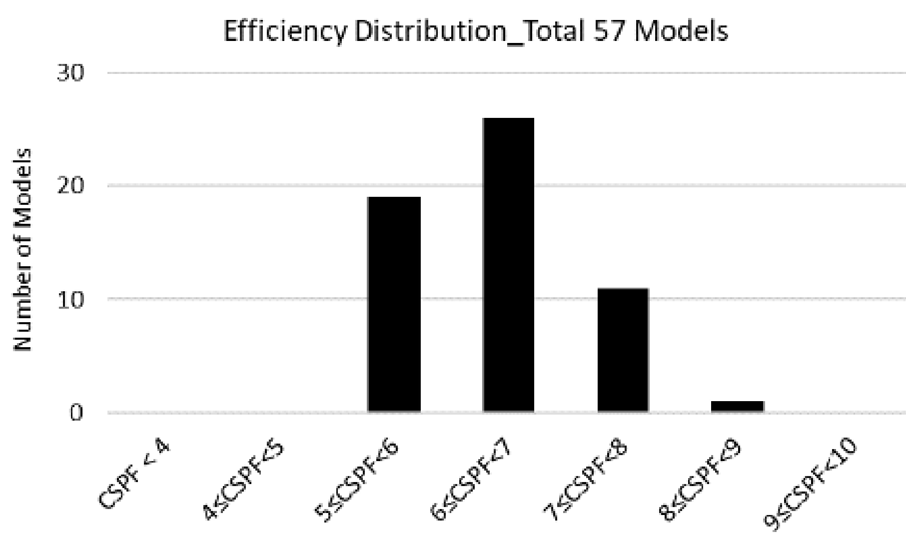
Table 14. Summary of Data Sources

Country	Sources	Models Analyzed	Refrigerant	Efficiency Data	Data Access
Singapore	Energy Labeling Scheme database	410 variable-speed AC models	R32, R410A	Authors calculated using performance data of all models[a]	May 5, 2020
Thailand	Label No. 5 database	1,777 variable-speed AC models	Unspecified	CSPF as is in the database	May 12, 2020

[a] 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 (see Annex D for the conversion between WEER and ISO CSPF).

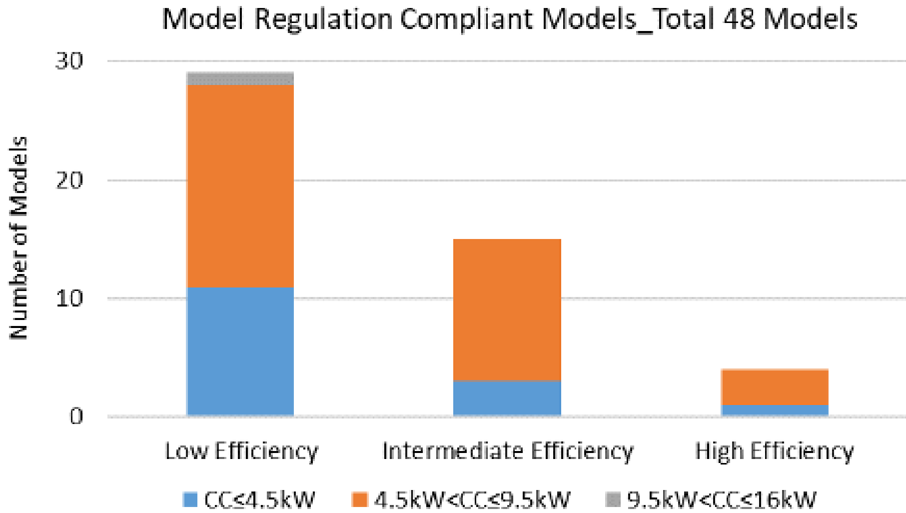
Singapore

Of 57 non-ducted, single-split, variable-speed AC models in Singapore that use R32 refrigerant and have full- and half-capacity performance data, 48 models meet the U4E Model Regulation CSPF requirements (Figures 12 and 13).



- Total 57 AC models registered as of May 2020
- Number of brands/manufacturers: 7
- CSPF (min/average/max): 5.09/6.42/8.33
- CC (min/average/max): 2.4/5.1/11.0

Figure 12. CSPF distribution of R32 ACs in Singapore in 2020

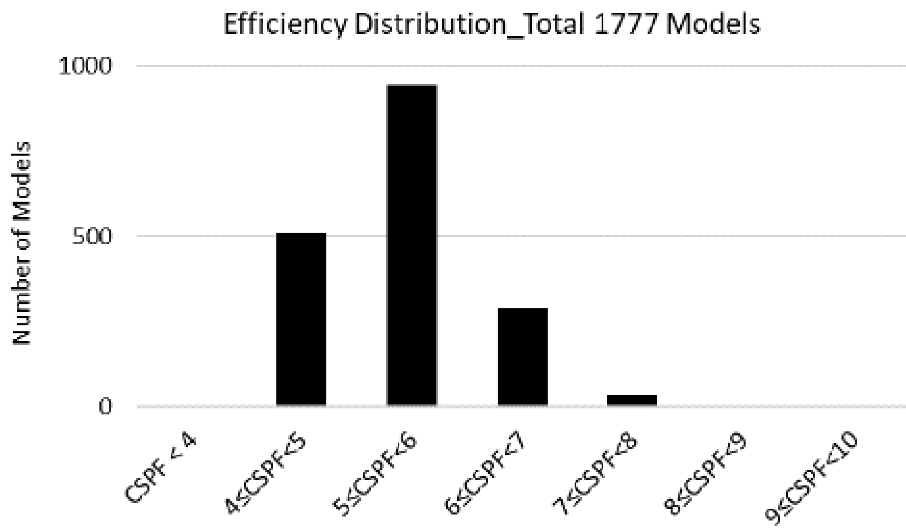


U4E Model Regulation Labeling Requirements (ISO 16358 temperature bin hours)	Low Efficiency	Intermediate Efficiency	High Efficiency
CC ≤ 4.5 kW	6.10 ≤ CSPF < 7.00	7.10 ≤ CSPF < 8.00	CSPF ≥ 8.00
4.5 kW < CC ≤ 9.5 kW	5.10 ≤ CSPF < 6.40	6.40 ≤ CSPF < 7.60	CSPF ≥ 7.60
9.5 kW < CC ≤ 16.0 kW	4.50 ≤ CSPF < 5.80	5.80 ≤ CSPF < 7.10	CSPF ≥ 7.10

Figure 13. CSPF of 48 R32 AC models in Singapore that meet the U4E Model Regulation Guidelines

Thailand

Of 1,777 single-split, variable-speed AC models (refrigerant unspecified) in Thailand with performance data described in Table 12, 1,068 models meet the U4E Model Regulation CSPF requirements (Figures 14 and 15).



- Total 1,777 AC models listed as of May 2020
- Number of brands/manufacturers: 55
- CSPF (min/average/max): 4.16/5.40/8.06
- CC (min/average/max): 2.5/6.9/12.0

Figure 14. CSPF distribution of ACs in Thailand in 2020

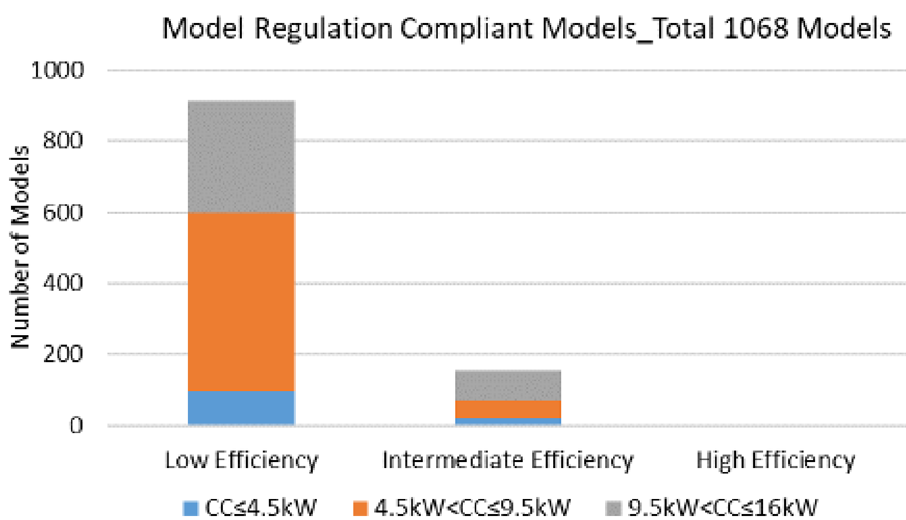


Figure 15. CSPF of 1,068 AC models in Thailand that meet the U4E Model Regulation Guidelines

5.4. Country Savings Assessments

U4E has developed Country Savings Assessments (updated as of November 2020) showing the savings potential of energy-efficient and climate friendly room air conditioners for ASEAN member states. According the assessment, the AC standards in ASEAN are estimated offer a savings potential of 144 TWh of electricity consumption by 2040, which is equivalent to 66 500-

MW power stations, 101 million tonnes of CO_2, and 16 Billion USD on electricity bills. These savings are summarized in the below Table and Annex E.

Table 15. Savings Opportunity of Energy-Efficient Room ACs in 2040

Country	Electricity Savings [TWh]	CO_2 Savings [Million tonnes]	Financial Savings [Billion US$]
Brunei Darussalam	0.3	0.2	0.02
Cambodia	1.0	0.8	0.22
Indonesia	57.4	40.8	5.74
Lao PDR	0.4	0.2	0.03
Malaysia	13.1	8.4	1.01
Myanmar	2.0	0.6	0.07
Philippines	21.1	17.8	3.84
Singapore	3.0	1.5	0.56
Thailand	18.1	10.4	2.10
Viet Nam	27.9	19.8	2.20
Total	**144**	**101**	**16**

PART B: RECOMMENDATIONS FOR STANDARDS HARMONIZATION

6. Recommendations

The following policy roadmap is provided as a basis for discussion amongst the ASEAN member states.

1. Consider adopting the ISO CSPF metric. Many ASEAN countries have already moved to, or are planning to, adopt the ISO 16358. Adopting this widely used metric would improve ASEAN's room AC standards and labeling while facilitating harmonization with international AC-efficiency efforts. Determining CSPF based on the test conditions specified in ISO 16358 would make the CSPF values comparable with those from other countries whose standards are based on or consistent with ISO 16358. Countries such as Singapore who use WCOP (WEER) can consider transition from WCOP (WEER) to ISO 16358 based CSPF in accordance with their policy framework.
2. Combine fixed-speed and variable-speed AC product categories under the same metric so that consumers clearly differentiate between the two and benefit from the energy savings from variable-speed ACs. An AC system that meets the U4E Model Regulation Guidelines low-efficiency requirement (CSPF 6.10, largely aligned with the expected Chinese 2022 MEPS), compared to an EER 2.90 (or CSPF 3.08) fixed-speed AC system, offers annual savings potential in energy consumption of ~420 kWh and emissions reduction of XX gCO_2 per unit for 1 refrigeration ton (3.5-3.6 kW cooling capacity) ACs.
3. For determining the CSPF of fixed-speed units, 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 predetermined equations. ISO 16358 requires testing a fixed-speed AC at full-capacity operation at both 35°C and 29°C. However, using calculated data points at 29°C reduces additional testing requirements (beyond the requirements for determining EER)—thus reducing compliance costs. The CSPF values of fixed-speed units are calculated in a linear relationship with the EER values: $CSPF = \alpha \times EER$ *(α = 1.062 with the ISO temperature bin hours)*
4. For variable-speed units, 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-determined equations, without considering minimum-capacity operation. The equations are:

   $Capacity(29℃) = Capacity(35℃) \times 1.077;$

   $Power\ input(29℃) = Power\ input(35℃) \times 0.914$
5. Consider using ISO 16358 temperature bin hours as the single set of temperature bin hours for all ASEAN countries. The CSPF results with U4E Model Regulation 0A, 1A, and 2A climates are lower by 5%–13% than those with the ISO 16358 temperature bin hours. Using a single set of bin hours would reduce additional costs for manufacturers, regulatory complexity for government agencies, and confusion for consumers, compared with using multiple sets of bin hours for different climate zones.

6. Consider additionally using the ISO CSPF metric based on U4E Model Regulation 0A climate, or temperature bin hours of AC use further tailored for ASEAN for assessing and informing absolute impacts (energy use, electricity cost, emissions, etc.). The ISO 16358 temperature bin hours could be used for efficiency standard purposes without much impact on the relative order of efficiency ratings, given that several ASEAN countries have already implemented the CSPF metric based on ISO 16358 temperature bin hours. However, hours of AC use and total energy use in ACs may need to be adjusted to more accurately reflect the ASEAN context.
7. Develop a regional policy roadmap to adopt common and more stringent MEPS and labeling levels for ACs aligned with the U4E Model Regulation, which is estimated to roughly offer savings potential of 144 TWh of electricity consumption, which is equivalent to 66 500-MW power stations, 101 million tonnes of CO_2, and 16 Billion USD on electricity bills. China plans to adopt common MEPS levels for variable- and fixed-speed ACs in 2022. These levels align largely with the U4E Model Regulation Guidelines' minimum efficiency requirements for ACs. Adopting the minimum requirements would give the ASEAN market ample time to effectively transition to higher standards, and to benefit from any cost reductions associated with economies of scale driven by China.
8. Update standards periodically to mitigate risk of obsolete technology being deployed in markets without updated standards, as well as reflect benefits of commercially available and emerging technology. There is on-going research and international effort to harmonize existing methods and at the same time develop new methods, e.g., load-based testing, that more reliably capture how the AC control system behaves and whether the controls properly off-load the compressor to achieve half and minimum cooling capacities (see Cadeo Group 2020). For example, there was a voluntary test standard developed by Canada (CSA EXP07). In addition, the United States is in the midst of finalizing a Controls Verification Procedure (CVP) to be used for the testing of variable refrigerant flow systems (see Karali et al. 2020b). The CVP is not a true load-based test but attempts to capture whether the system will properly unload the compressors during part load conditions. Since international testing and rating standards will continue to evolve to account for such ongoing research and harmonization efforts, it is important for the ASEAN countries to revisit these standards and update them periodically as necessary.

Although this report focuses on improving energy-efficiency standards by adopting a seasonal efficiency metric, the following additional recommendations could help ASEAN countries effectively run energy-efficiency standards programs.

1. Strengthen the compliance regime. There might be a large, informal sector assembling low-cost, inefficient ACs, or large import of used inefficient products from other countries, which will likely pose a challenge to increasing the stringency of AC energy-efficiency requirements if not addressed in parallel. A regularized monitoring system for tracking compliance with the mandatory standard and energy information labeling programs would

accelerate the replacement of less-efficient products, and facilitate the transformation of the regional market for energy-efficient products. A stronger compliance regime should encompass, at a minimum: round-robin testing, more frequent monitoring and testing of ACs, and even negative incentives such as publicly identifying non-compliant companies. Furthermore, existing test laboratories must seek proper accreditation and upgrade capacity where needed.

2. Assist small and medium AC manufacturers. ASEAN should prioritize the transition of small and medium manufacturers to variable-speed ACs to (1) give these manufacturers competitive advantage including exporting to other countries, (2) incentivize informal markets and small and medium manufacturers to participate in the compliance regime and adhere to standards, and (3) increase public outreach and awareness of efficient equipment.

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Annex A. ASHRAE Climate Zone Definitions

Table A1. ASHRAE Climate Zone Criteria

Zone	Name	SI units	I-P units
0	Extremely Hot-Humid (0A), Dry (0B)	6,000 < CDD_{10}	10,800 < CDD_{50}
1	Very Hot-Humid (1A), Dry (1B)	5,000 < CDD_{10} ≤ 6,000	9,000 < CDD_{50} ≤ 10,800
2	Hot-Humid (2A), Dry (2B)	3,500 < CDD_{10} ≤ 5,000	6,300 < CDD_{50} ≤ 9,000
3A and 3B	Warm-Humid (3A), Dry (3B)	2,500 < CDD_{10} ≤ 3,500 and HDD_{18} ≤ 2,000	4,500 < CDD_{50} ≤ 6,300 and HDD_{65} ≤ 3,600
3C	Warm-Marine (3C)	CDD_{10} ≤ 2,500 and HDD_{18} ≤ 2,000	CDD_{50} ≤ 4,500 and HDD_{65} ≤ 3,600
4A and 4B	Mixed-Humid (4A), Dry (4B)	1,500 < CDD_{10} ≤ 3,500 and 2,000 < HDD_{18} ≤ 3,000	2,700 < CDD_{10} ≤ 6,300 and 3,600 < HDD_{65} ≤ 5,400
4C	Mixed-Marine (4C)	CDD_{10} ≤ 1,500 and 2,000 < HDD_{18} ≤ 3,000	CDD_{50} ≤ 2,700 and 3,600 < HDD_{65} ≤ 5,400
5A and 5B	Cool-Humid (5A), Dry (5B)	1,000 < CDD_{10} ≤ 3,500 and 3,000 < HDD_{18} ≤ 4,000	1,800 < CDD_{50} ≤ 6,300 and 5,400 < HDD_{65} ≤ 7,200
5C	Cool-Marine (5C)	CDD_{10} ≤ 1,000 and 3,000 < HDD_{18} ≤ 4,000	CDD_{50} ≤ 1,800 and 5,400 < HDD_{65} ≤ 7,200
6A and 6B	Cold-Humid (6A), Dry (6B)	4,000 < HDD_{18} ≤ 5,000	7,200 < HDD_{65} ≤ 9,000
7	Very Cold (7)	5,000 < HDD_{18} ≤ 7,000	8,000 < HDD_{65} ≤ 12,600
8	Subarctic/Arctic (8)	7,000 < HDD_{18}	12,600 < HDD_{65}

CDD_{10} (CDD_{50}) = cooling degree-day base 10°C (50°F)

- Daily mean temperature minus 10°C (50°F)
- Annual CDDs are the sum of the degree-days over a calendar year.

Marine Zone (C)

- Mean temperature of coldest month between –3°C (27°F) and 18°C (65°F)
- Warmest month mean < 22°C (72°F)
- At least 4 months with mean temperatures over 10°C (50°F)
- Dry season in summer.

Dry Zone (B)

- Not Marine (C)
- The dry/humid threshold is determined primarily by annual precipitation and annual mean temperature.

Humid Zone (A) = locations that are not Marine (C) and not Dry (B).

Source: ANSI/ASHRAE Standard 169-2013

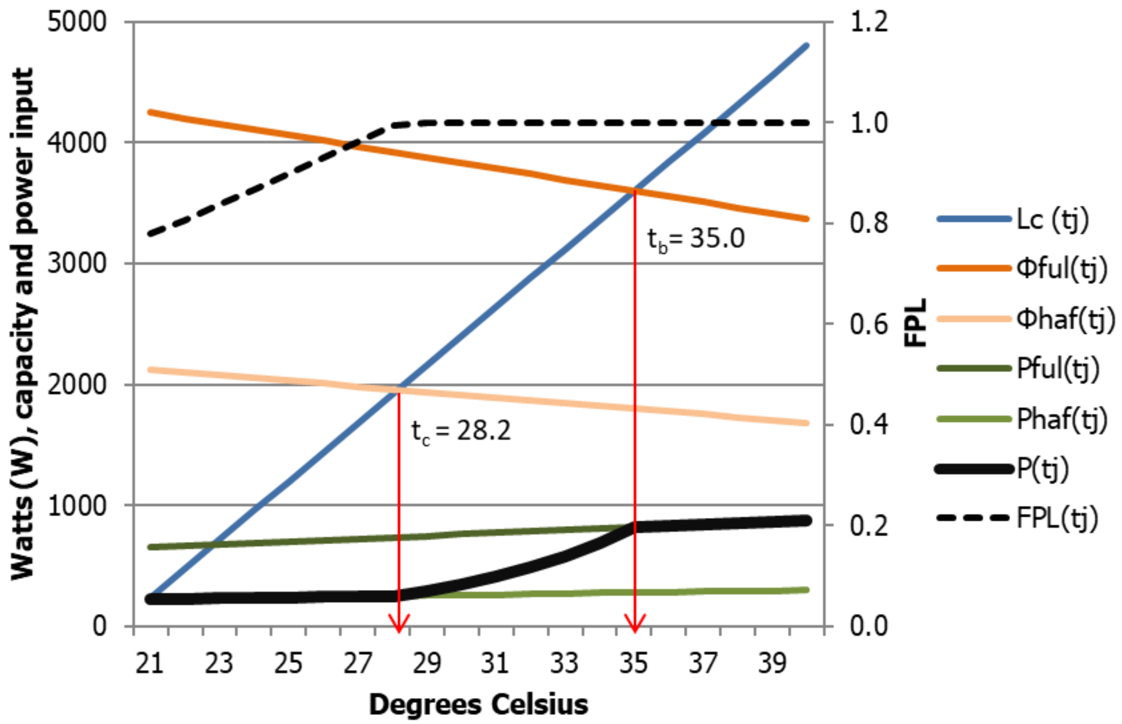
Annex B. Outdoor Temperature Bin Hours

Table B1. Temperature Bins for Calculating ISO CSPF

Outdoor temperature	ISO Reference	Average of ASEAN 10 Locations		U4E Model Regulation 0A		U4E Model Regulation 1A	U4E Model Regulation 2A
°C	Bin hours	Bin hours	Fractional Bin Hours	Bin hours	Fractional Bin Hours	Bin hours	Bin hours
21	ISO 16358-1: 2013 Table 3	5	0.001	5	0.001	33	49
22		13	0.002	23	0.005	86	92
23		37	0.007	76	0.015	167	128
24		134	0.025	205	0.041	250	161
25		337	0.063	383	0.077	327	191
26		530	0.099	537	0.108	360	210
27		630	0.118	646	0.130	388	219
28		668	0.125	671	0.135	395	212
29		644	0.120	630	0.127	371	188
30		607	0.113	596	0.120	332	149
31		580	0.108	501	0.101	285	118
32		494	0.092	361	0.073	227	86
33		337	0.063	206	0.041	153	58
34		176	0.033	86	0.017	90	37
35		88	0.016	32	0.006	55	22
36		43	0.008	11	0.002	35	13
37		23	0.004	3	0.001	22	8
38		11	0.002	1	0.000	16	4
39		3	0.001			12	3
40		1	0.000			10	1
41						7	1
42						5	1
43						3	
44						1	
Total	1,817	5,361	1.000	4,973	1.000	3,630	1,951

Annex C. An Example of CSPF Calculation

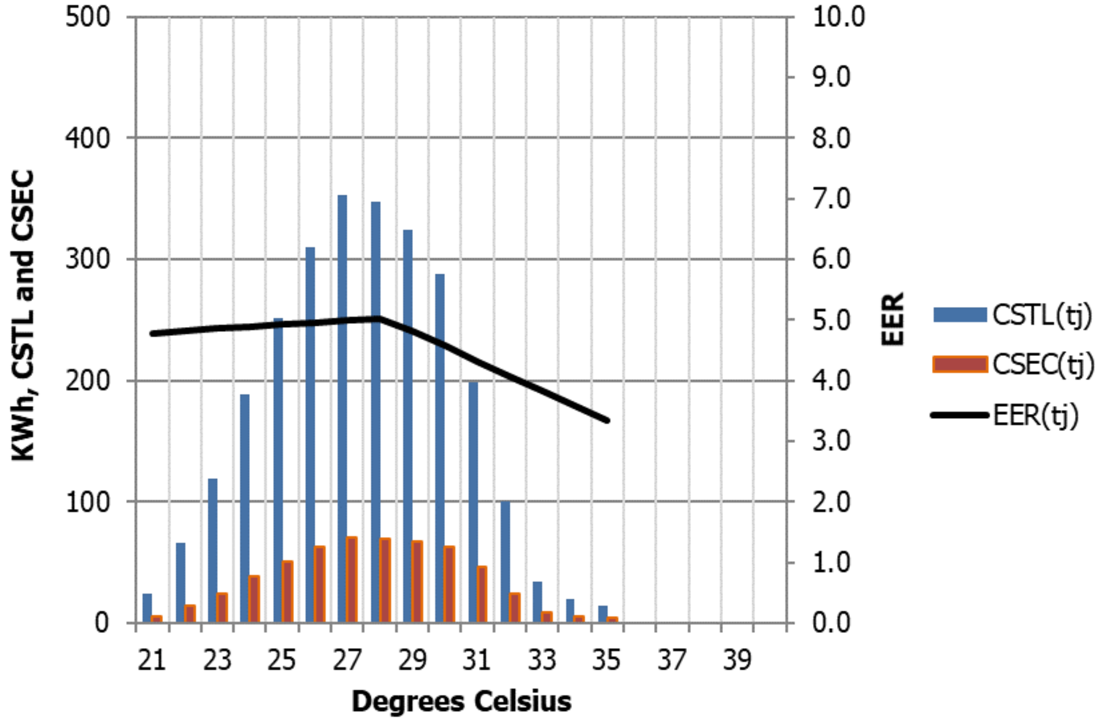
As an example, Figure C1 shows key parameters—including cooling load, performance at full and half capacity, and part load factor[9]—used for the Sample 3 AC unit CSPF calculation with ISO 16358 bin hours. The black bold line in Figure 5 represents cooling power input calculated based on the parameters. Figure C2 shows cooling load and energy consumption in kWh at each temperature. CSPF is calculated as $\sum(cooling\ load \times hours)/\sum(power\ input \times hours)$.



t_j = outdoor temperature corresponding to each temperature bin
$Lc(t_j)$ = defined cooling load at outdoor temperature t_j
t_b = outdoor temperature when cooling load is equal to cooling full capacity
t_c = outdoor temperature when cooling load is equal to cooling half capacity
$\phi_{ful}(t_j)$ = cooling full capacity at outdoor temperature t_j
$\phi_{haf}(t_j)$ = cooling half capacity at outdoor temperature t_j
$P_{ful}(t_j)$ = cooling full power input at outdoor temperature t_j
$P_{haf}(tj)$ = cooling half power input at outdoor temperature t_j
$P(t_j)$ = cooling power input applicable to any capacity at outdoor temperature t_j
$FPL(t_j)$ = part load factor at outdoor temperature t_j
Note that this CSPF calculation is based on 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-determined equations.

Figure C1. CC, power input, and cooling load of Sample 3 (variable-speed) AC unit with ISO 16358 temperature bin hours

[9] ISO 16358 defines part load factor as the ratio of the performance when the equipment is cyclically operated to the performance when the equipment is continuously operated, at the same temperature and humidity conditions.



CSTL(t_j) = cooling load times hours at outdoor temperature t_j
CSEC(t_j) = cooling power input times hours at outdoor temperature t_j
EER(t_j) = EER at outdoor temperature tj
CSPF = $\sum CSTL(tj)/\sum CSEC(tj)$

Figure C2. Cooling seasonal total load and cooling seasonal energy consumption of Sample 3 (variable-speed) AC unit with ISO 16358 temperature bin hours

Annex D. A Regression Relationship between WEER and ISO CSPF

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 (see Table D1). Figure D1 shows a regression relationship of WEER and ISO CSPF based on 57 AC models.

Table D1. Summary of performance data and calculation of ACs in Singapore

Operating condition	Parameter	Singapore (57 models)	
		WEER [A]×0.4 + [D]×0.6	CSPF (ISO 16358)
Full capacity (35°C)	EER [A]	Data available	Data available
	Capacity [B]		Data available
	Power input [C]		Calculated by [B]/[A]
Half capacity (35°C)	EER [D]	Data available	Data available
	Capacity [E]		[B] × 0.5
	Power input [F]		Calculated by [E]/[D]
Full capacity (29°C)	EER [G]	Not applicable	Calculated by [H]/[I]
	Capacity [H]		[B] × 1.077
	Power input [I]		[C] × 0.914
Half capacity (29°C)	EER [J]	Not applicable	Calculated by [K]/[L]
	Capacity [K]		[E] × 1.077
	Power input [L]		[F] × 0.914
Temperature bin hours		Not applicable	ISO 16358

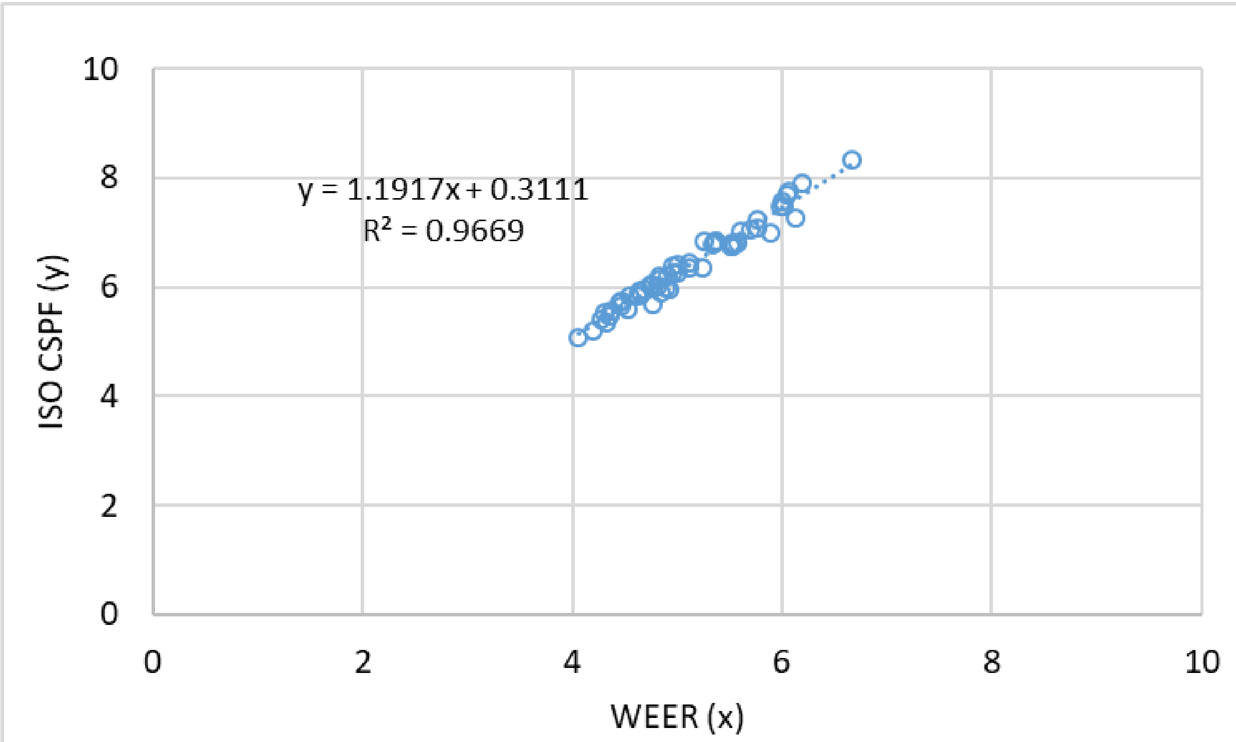


Figure D1. A linear regression between WEER and ISO CSPF based on 57 R32 AC models in Singapore

Annex E. Savings Opportunity of Energy-Efficient ACs

The U4E Country Savings Assessments aim to show the financial, energy, and environmental benefits of energy-efficient lighting, appliances and equipment. For room ACs, the analysis uses a stock model to forecast the impacts of implementing policies that improve the energy efficiency of new room ACs. This is a bottom-up approach, in which the potential energy savings are obtained by defining the average unit energy consumption of new models in different scenarios and estimating the stock and sales of the room ACs in the assessment country over time. From this, the financial and environmental savings and benefits are calculated by using the countries' macroeconomic indicators and other associated data.

The Assessments include three scenarios have been conducted based on the level of energy efficiency of products sold on the market:

- Business as Usual or base case scenario – The energy efficiency of the underlying technology improves at 1 per cent per year. Further, an increasing market share of variable speed models is assumed to improve overall efficiency at an additional 2% per year until new sales are entirely from that product type.
- Minimum Ambition Scenario– based on MEPS levels defined in the U4E Model Regulation Guidelines.
- High Ambition Scenario– based on the Top-tier performance levels in the U4E Model Regulation Guidelines.

The results for each ASEAN member states is available on the U4E Website, along with a summary in Figure E1 and E2.

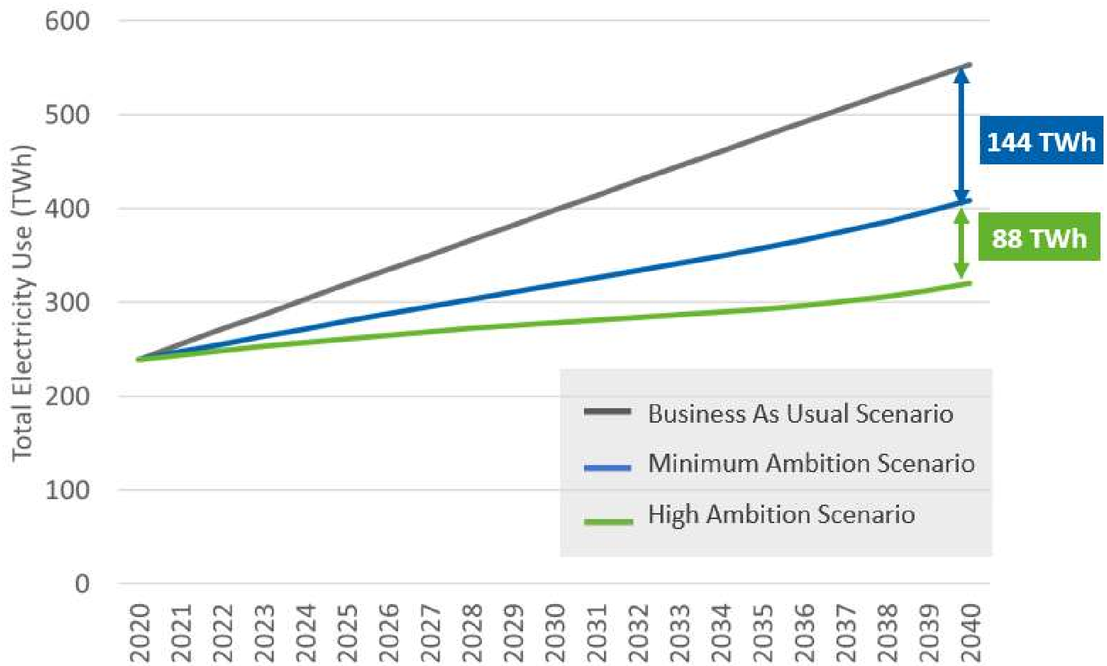


Figure E1. ASEAN Savings Potential of Energy-Efficient Air Conditioners (Three Scenarios)

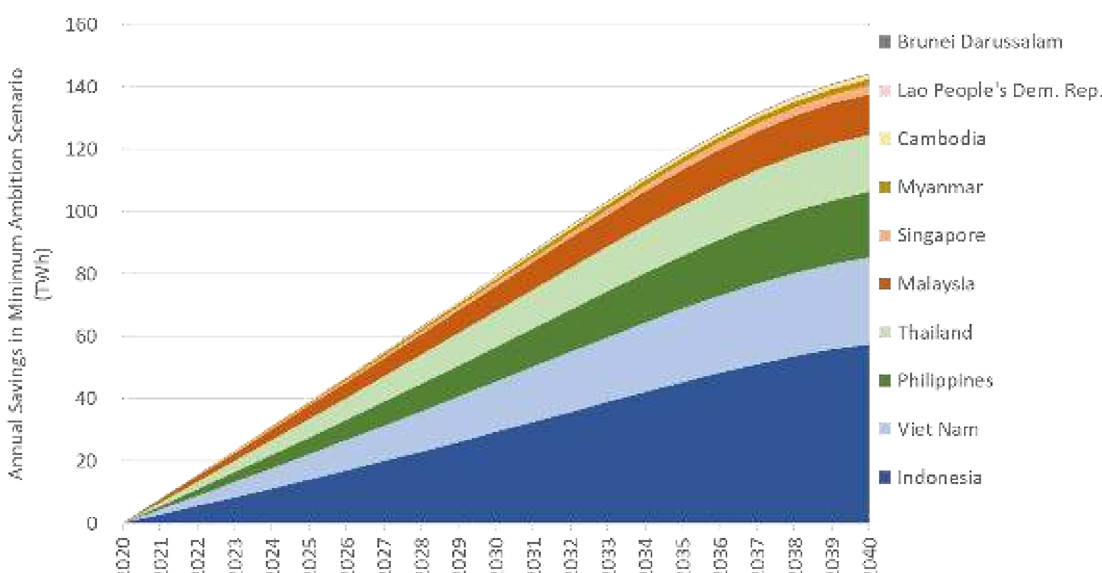


Figure E2. ASEAN Savings Potential of Energy Efficient Air Conditioners (By Country)