Title

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Abstract

This report provides a general approach for adopting a seasonal energy efficiency metric by examining the climate-specific temperature bin distribution for air conditioner use, the seasonal energy efficiency results according to International Standards Organization (ISO) 16358 by climate region, and the relationships in seasonal energy efficiency across regional metrics. This approach could make the seasonal efficiency metric values comparable with those from other countries with standards consistent with ISO 16358. Policy action and market transformation can be accelerated and effectively harmonized with other regional or international efforts by adopting a seasonal energy efficiency metric. The framework and methodology described in this report have been applied in the following publications: Shaffie et al. 2022, Park et al. 2021, Park et al. 2019, and UNEP 2019a.

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List of Acronyms

AC	Air Conditioner
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CC	Cooling Capacity
CDD10	Cooling Degree-Day Base 10°C
CSEC	Cooling Seasonal Energy Consumption
CSPF	Cooling Season Performance Factor
EER	Energy-Efficiency Ratio
FSD	Fixed-Speed Drive
HDD18	Heating Degree-Day Base 18°C
MEPS	Minimum Energy Performance Standard
SEER	Seasonal Energy Efficiency Ratio
U4E	United for Efficiency
UEC	Unit Energy Consumption
VSD	Variable-Speed Drive
WEER	Weighted Energy Efficiency Ratio

List of Reference Standards

ANSI and ASHRAE (American National Standards Institute and the American Society of Heating, Refrigerating and Air-Conditioning Engineers). 2013. Climatic Data for Building Design Standards. ANSI/ASHRAE Standard 169-2013.

India Bureau of Energy Efficiency. 2015. Schedule 19 Variable Capacity Air Conditioners.

ISO (International Organization for Standardization). 2013. ISO 16358-1:2013 Air-cooled air conditioners and air-to-air heat pumps — Testing and calculating methods for seasonal performance factors — Part 1: Cooling seasonal performance factor.

ISO 16358-2:2013 Air-cooled air conditioners and air-to-air heat pumps — Testing and calculating methods for seasonal performance factors — Part 2: Heating seasonal performance factor.

ISO 16358-3:2013 Air-cooled air conditioners and air-to-air heat pumps — Testing and calculating methods for seasonal performance factors — Part 3: Annual performance factor

ISO 16358-1: 2013/Amd:2019 Air-cooled air conditioners and air-to-air heat pumps — Testing and calculating methods for seasonal performance factors — Part 1: Cooling seasonal performance factor — Amendment 1.

Japanese Standards Association. 2013. JIS C 9612:2013. Room Air Conditioners.

Korean Standards Association. 2017. KS C 9306:2017. Air conditioners.

The Standardization Administration of the People's Republic of China. 2004. GB/T 7725-2004. Room air conditioners.

The Standardization Administration of the People's Republic of China. 2019. GB 21455-2019. Minimum allowable values of the energy efficiency and energy efficiency grades for variable speed room air conditioners.

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1. Cooling seasonal performance for air conditioners

Over the past decades, air conditioner (AC) manufacturers have improved the performance and reduced the costs of AC systems. Variable-speed drive (VSD) compressors (also known as inverter-driven) enable an AC unit to respond to changes in cooling requirements by operating at full or partial loads. This flexibility improves performance and reduces refrigerant flow rates compared to the performance and refrigerant flow of conventional ACs with fixed-speed drive (FSD) compressors that cycle on and off (Shah et al. 2013).

Along with this trend toward VSD ACs, seasonal energy efficiency ratio (SEER) metrics have been designed to estimate AC performance based on part- and full-load operation at multiple temperature conditions, depending on climate. Since local climatic conditions affect the amount of time an AC operates at part or full load, climate-specific weighting is used in calculating SEER. This provides a more representative measure of performance than the traditional energy-efficiency ratio (EER) —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 (Park et al. 2017). Climate-specific weighting is used to calculate an AC seasonal energy efficiency that represents performance more realistically than the traditional EER. Seasonal efficiency metrics consider the impact of variations in outdoor temperature on cooling load and energy consumption. They require (or optionally allow) multiple test points to compute a seasonally weighted average efficiency to represent how an AC would perform over a typical cooling season in a representative building type with typical operating characteristics (ANSI and ASHRAE 2013, Park et al. 2020).

The difference in seasonal efficiency metrics is primarily due to the outside temperature profiles used to aggregate steady-state and cyclic ratings into a seasonal efficiency value, and the ways the metric evaluates performance at part-load operation. Specific parameters in each regional standard account for AC performance at part-load and/or lower-temperature operation in the efficiency metric. The cooling seasonal efficiency metrics used in Brazil, China, Japan, India, South Korea, and countries in Southeast Asia are equivalent to, or largely consistent with, ISO 16358-1:2013-defined metrics. Brazil, China, Japan, India, and South Korea use their region-specific outdoor temperature bin hours. Southeast Asian countries use the ISO reference temperature bin hours (Park et al. 2019, Park et al. 2020, Park et al. 2021). Table 1 shows options for evaluating cooling seasonal energy-efficiency using ISO 16358-1:2013 or regional standards.

Table 1. Test Requirements and Options for Evaluating AC Cooling Seasonal Energy Efficiency

Operating condition[a]	Outdoor dry bulb temperature	FSD	VSD
Full capacity and power input	35°C	Required	Required
Half or intermediate capacity and power input[b]		Not applicable	Required
Minimum capacity and power input		Not applicable	Required/optional/ not considered[d]
Full capacity and power input	29°C	Required/optional[b]	Optional[c]
Half or intermediate capacity and power input		Not applicable	Optional[c]
Minimum capacity and power input		Not applicable	Optional/ not considered[d]

[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] While 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: $Capacity(29℃) = Capacity(35℃) \times 1.077$; $Power\ input(29℃) = Power\ input(35℃) \times 0.864$

[d] The SEER calculation in India (ISEER) does not consider minimum capacity tests.

ISO 16358 suggests the minimum capacity test at 29°C to 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.

Source: Authors' work based on ISO 16358:2013; China's GB/T 7725-2004, GB 21455-2019; India's Schedule 19; Japan's JIS C 9612:2013; South Korea's KS C 9306:2017.

Source: Park et al. (2020); Park et al. (2019)

Table 2 shows the parameters used in this analysis for the ISO cooling season performance factor (CSPF) calculation in accordance with ISO 16358:1-2013. For FSD units, the ISO CSPF calculation is based on one set of performance data (capacity and power input) measured at full-capacity operation at 35°C and another set of performance data calculated for full-capacity operation at 29°C by predetermined equations. The ISO CSPF calculation for VSD units is based on two sets of test data at full- and half-capacity operation at 35°C and another two sets of data at 29°C calculated by the ISO 16358-determined equations.

Table 2. Parameters Used in This Analysis for ISO CSPF Calculation with ISO 16358:1-2013

Operating condition	Outdoor dry bulb temperature	FSD	VSD
Full capacity and power input	35°C	Measured	Measured
Half capacity and power input		Not applicable	Measured
Minimum capacity and power input		Not applicable	Not considered
Full capacity and power input	29°C	Calculated[a]	Calculated[a]
Half capacity and power input		Not applicable	Calculated[b]
Minimum capacity and power input		Not applicable	Not considered

[a] $Full\ capacity(29℃) = Full\ capacity(35℃) \times 1.077$; $Full\ power\ input(29℃) = Full\ power\ input(35℃) \times 0.914$

[b] $Half\ capacity(29℃) = Half\ capacity(35℃) \times 1.077$; $Half\ power\ input(29℃) = Half\ power\ input(35℃) \times 0.914$

This study also analyzes AC seasonal efficiency performance according to ISO 16358:1-2013/Amd: 2019. The CSPF calculation for FSD units is based on two sets of test data—measurement of performance (capacity and power input) at full-capacity operation at an outdoor temperature of 46°C and 35°C—and then performance at 29°C is calculated by the predetermined equations. The CSPF calculation for VSD units is based on three sets of test data—measurement of performance (capacity and power input) at full-capacity operation at an outdoor temperature of 46°C, performance at full- and half-capacity operation at an outdoor temperature of 35°C—and then performance at 29°C is calculated by ISO 16358-determined equations. Table 3 shows the parameters used in this analysis for ISO CSPF calculation in accordance with ISO 16358:1-2013/Amd: 2019.

Table 3. Parameters Used in This Analysis for ISO CSPF Calculation with ISO 16358:1-2013/Amd: 2019

Operating condition	Outdoor dry bulb temperature	FSD	VSD
Full capacity and power input	46°C	Measured	Measured
Half capacity and power input		Not applicable	Calculated[a]
Minimum capacity and power input		Not applicable	Not considered
Full capacity and power input	35°C	Measured	Measured
Half capacity and power input		Not applicable	Measured
Minimum capacity and power input		Not applicable	Not considered
Full capacity and power input	29°C	Calculated[b]	Calculated[b]
Half capacity and power input		Not applicable	Calculated[c]
Minimum capacity and power input		Not applicable	Not considered

[a] $Half\ capacity(46℃) = Halfcapacity(35℃) \times 0.859$; $Half\ power\ input(46℃) = Half\ ower\ input(35℃) \times 1.25$

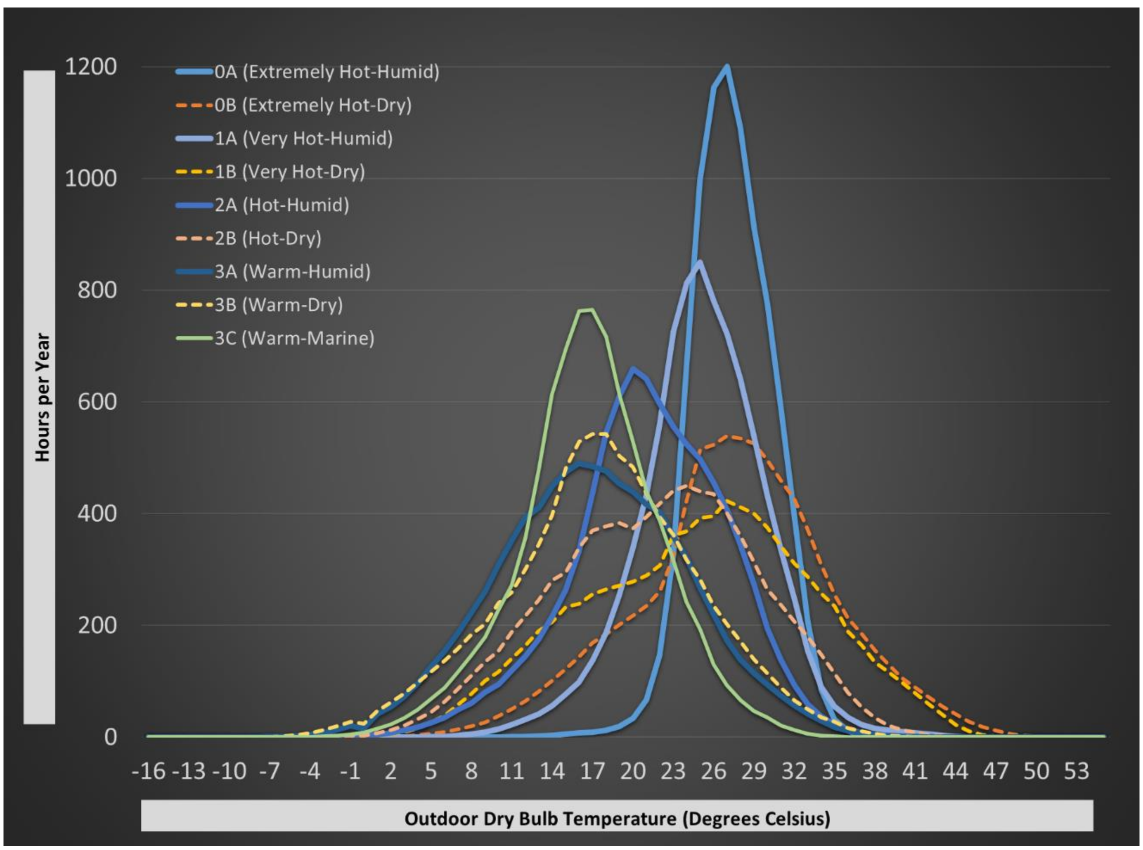
[b] $Full\ capacity(29℃) = Full\ capacity(35℃) \times 1.077$; $Full\ power\ input(29℃) = Full\ power\ input(35℃) \times 0.914$

[c] $Half\ capacity(29℃) = Half\ capacity(35℃) \times 1.077$; $Half\ power\ input(29℃) = Half\ power\ input(35℃) \times 0.914$

2. Developing outdoor temperature bin hours for AC use

The world has diverse climates, varying by region from hot and humid to cold and dry. As a result, outdoor temperature profiles used for calculating AC seasonal efficiency vary by region. A region can adapt a seasonal energy efficiency metric to its regional standard by using the ISO CSPF metric in accordance with ISO 16358-1:2013, based on the ISO 16358 reference temperature bin hours or region-specific temperature bin hours.

In this analysis we refer to outdoor temperature bin hours provided by ISO 16358-1:2013, ISO 16358-1:2013/Amd: 2019, and additionally those included in the United for Efficiency (U4E) Model Regulation Guidelines for Energy-Efficient and Climate-Friendly Air Conditioners (The Guidelines) (UNEP 2019a and 2019b). The Guidelines adopt the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) climate zone definitions, which are based on cooling degree-day base 10°C (CDD10), heating degree-day base 18°C (HDD18), annual precipitation, annual mean temperature, and so forth. We analyzed the outdoor temperature data of 142 weather stations across 34 countries for nine hot/warm climate regions from ASHRAE's weather data viewer 6.0 (UNEP 2019a). Figure 1 shows the average outdoor temperature distribution profiles of the nine hot/warm climate regions.



Source: Authors' work based on data of 142 weather stations available from ASHRAE weather data viewer 6.0. For illustrative purpose, graphs are adjusted to curves from the original bar charts. See Table A3 and Table A4 in Appendix A for bin hours.

Figure 1. Outdoor temperature distribution of nine hot/warm climate regions

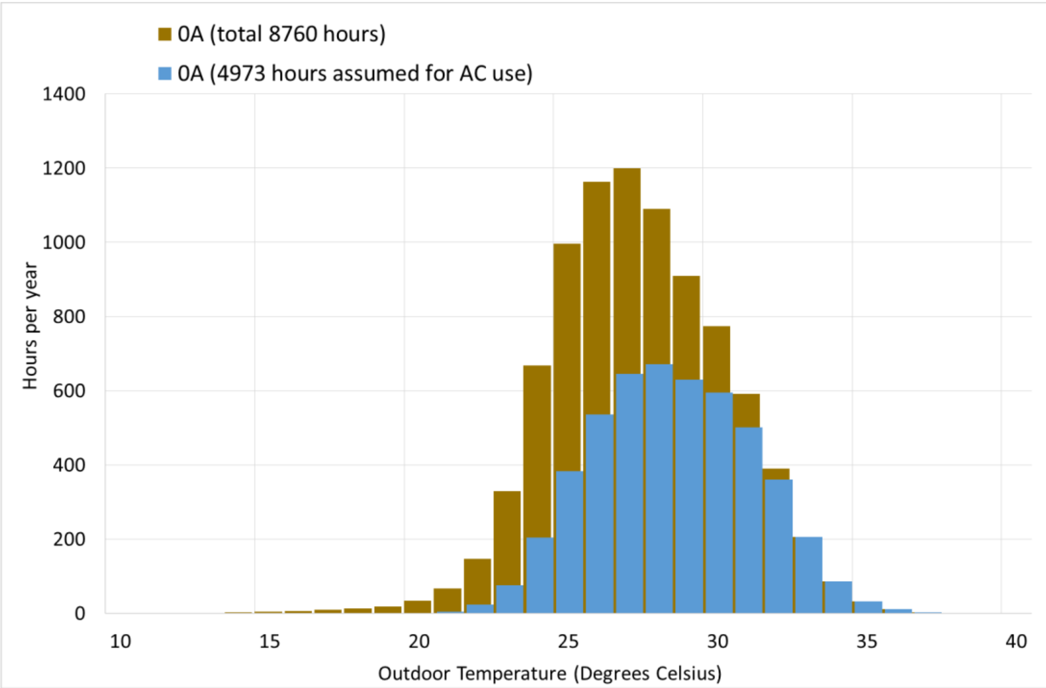
ISO 16358 assumes the cooling load begins at 21°C and reached 100% capacity at 35°C. According to the climate data we analyzed, hours of AC use logged at 21°C or greater account for 85% of the annual outdoor temperature distributions in select 0A and 1A climate regions, while hours logged at over 35°C account for less than 2%. The hours of each temperature bin for AC use can be determined based on the AC use information in a country.

Based on the average annual outdoor temperature bin distributions in various climates, this study estimates hours of room AC use at each outdoor temperature as follows:

- Outdoor temperature at 0% load: t_0=20°C, consistent with ISO 16358.
- Hours for AC use at *t* between 21°C and 33°C are assumed to increase in proportion to the cooling load: the hours of average outdoor temperature profile (i.e., bin hours in Figure 1) times load (%) at *t*.
- Hours of AC use at 33°C or greater are assumed to be equivalent to the hours of the average outdoor temperature profile.

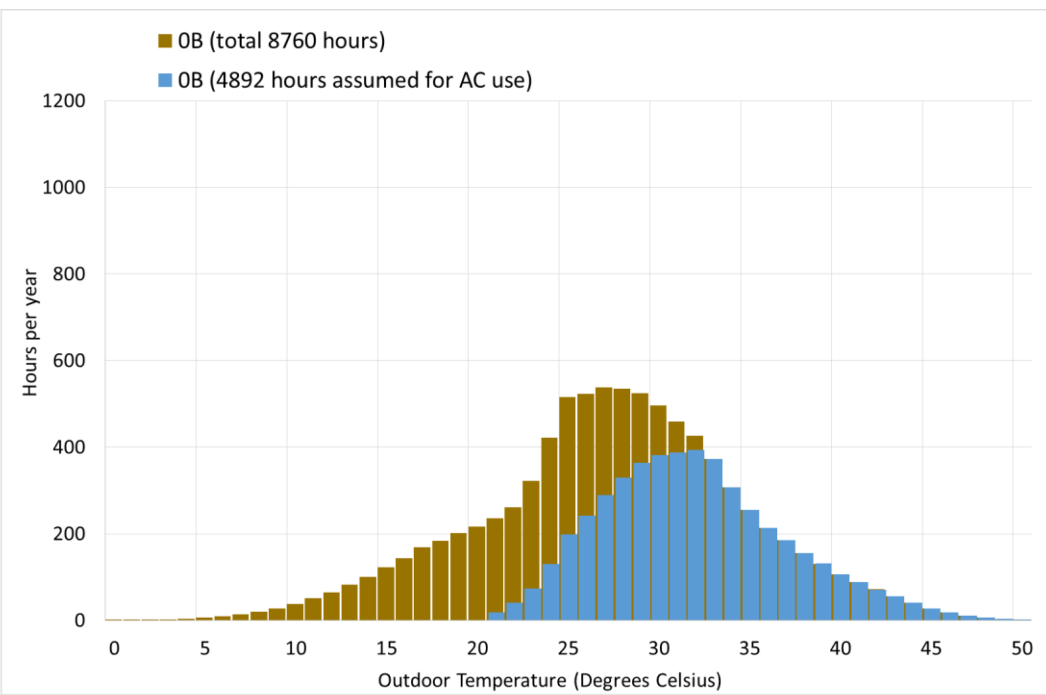
In addition to standard outdoor temperature bin hours for AC use included in ISO 16358-1:2013 and ISO 16358-1:2013/Amd: 2019, we use outdoor temperature bin distributions generated by the first through third bullets. However, the total hours of per-unit AC use in a country can further align with an average AC use (e.g., number of hours per day) based on country-specific market information.

The blue histograms in Figure 2 and Figure 3 show outdoor temperature bin hours estimated for AC use in 0A and 0B climate regions, respectively. See Table A3 and Table A4 in Appendix A for outdoor temperature bin hours estimated for AC use in other climate regions. We divide the climate regions into two groups: the first corresponds to ISO 16358-1:2013 with ISO 5151-defined T1 moderate climate; the second corresponds to ISO 16358-1:2013/Amd: 2019 with ISO 5151-defined T3 hot climate. Table 4 and Table 5 summarize the sets of outdoor temperature bin hours used in the ISO CSPF calculation by climate region.



Source: Authors' work (see Figure A1 in Appendix A for other climate regions).

Figure 2. Annual outdoor temperature bin hours (brown) and temperature bin hours assumed for AC use in 0A (blue)



Source: Authors' work (see Figure A1 in Appendix A for other climate regions).

Figure 3. Annual outdoor temperature bin hours (brown) and temperature bin hours assumed for AC use in 0B (blue)

Table 4. Summary of Outdoor Temperature Bin Hours Used in the ISO CSPF Calculation in Accordance with ISO 16358-1:2013

	ISO	**0A**	**1A**	**2A**	**3A**	**2B**	**3B**	**3C**
Efficiency calculation	ISO 16358-1:2013 CSPF							
Temperature range	21–35°C	21–38°C	21–44°C	21–42°C	21–41°C	21–44°C	21–41°C	21–36°C
Number of temperature bins (1°C per bin)	15	18	24	22	21	24	21	16
Total hours of outdoor temperature bin (Average hours of daily usage)	1,817 (5.0)	4,973 (13.6)	3,630 (9.9)	1,910 (5.2)	1038 (2.8)	2,609 (7.1)	1,178 (3.2)	568 (1.6)

See Tables A3 and A4 in Appendix A or UNEP 2019b Appendix 4 for detailed temperature bin hours

Table 5. Summary of outdoor temperature bin hours used in the ISO CSPF calculation in accordance with ISO 16358-1: 2013/Amd: 2019

	ISO	0B	1B
Efficiency calculation	ISO 16358-1: 2013/Amd: 2019		
Temperature range	21–46°C	21–50°C	21–47°C
Number of temperature bins (1°C per bin)	26	30	27
Total hours of outdoor temperature bin (Average hours of daily usage)	6,493 (17.8)	4,892 (13.4)	3,915 (10.7)

See Tables A3 and A4 in Appendix A or UNEP 2019b Appendix 4 for detailed temperature bin hours

3. Evaluating the efficiency performance of ACs

This study analyzes the efficiency performance of eight room ACs according to the ISO CSPF calculation with the sets of temperature bin hours for AC use by climate region. The ISO CSPF calculation refers to ISO 16358-1:2013 Clause 6.4 for FSD units and Clause 6.7 for VSD units. CSPF is calculated as $\sum(cooling\ load \times hours)/\sum(power\ input \times hours)$ (see Park et al. 2019 and ISO 16358-1:2013 documents for more details). Table 6 summarizes the basic specifications of the eight ACs.

Table 6. Modeled specifications of the eight ACs

Sample	1	2	3	4	5	6	7	8
Compressor type	FSD				VSD			
Nominal CC (kW)	3.5							
EER (W/W)[a]	2.92	3.50	4.27	5.00	2.92	3.50	4.27	5.00

[a] The EER values are based on actual performance data of commercially available products.

For FSD units, the CSPF calculation 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 significant difference between the EER and CSPF values for the FSD units. Given that predetermined equations are used to estimate the performance at 29°C, CSPF for FSD units results in a linear relationship with EER, i.e., CSPF = $\alpha \times$ EER (e.g., α=1.062 with the ISO reference temperature bin hours, α=1.045 with 0A temperature bin hours, α=1.002 with 2B temperature bin hours) (Park et al. 2019).

For VSD units, using a seasonal efficiency metric (such as ISO 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. The CSPF calculation for VSD units is based on two sets of test data at full- and half-capacity operation at 35°C and the other two sets of data at 29°C calculated by ISO 16358-determined equations. This calculation tends to result in CSPFs that are lower than those calculated based on performance data measured at both 35°C and 29°C, including minimum-capacity operation; hence, the results shown here are relatively conservative (Park et al. 2019). Energy consumption depends on the total hours of AC use and the number of hours the AC is in use at each temperature. Table 7, Table 8, and Table 9 show the calculated efficiency and energy consumption results of the eleven ACs modeled.

Table 7. Calculated Efficiency and Energy Consumption of the Four VSD ACs With a Two Set of Modeled Configurations

Model		V1	V2	V3	V4	V1′	V2′	V3′	V4′
		$EER_h(35)$[a] = $EER_f(35)$[b]×1.3				$EER_h(35) = EER_f(35)\times1.5$			
Compressor type		VSD				VSD			
EER (W/W)		2.92	3.50	4.27	5.00	2.92	3.50	4.27	5.00
Temperature bin hours	CSPF and CSEC[c]								
ISO 16358	CSPF	4.31	5.17	6.31	7.39	4.90	5.89	7.18	8.41
	CSEC	596	497	406	347	524	436	357	305
Brazil	CSPF	4.18	5.02	6.13	7.18	4.71	5.66	6.90	8.09
	CSEC	691	576	472	403	614	511	419	358
China	SEER	3.67	4.4	5.38	6.30	3.99	4.79	5.84	6.84
	CSEC	594	495	406	346	547	456	374	319
India	ISEER	3.61	4.33	5.29	6.2	3.91	4.69	5.73	6.71
	CSEC	750	625	512	437	693	577	473	404
U4E 0A (Extremely Hot – Humid)	CSPF	4.08	4.90	5.99	7.01	4.57	5.48	6.69	7.84
	CSEC	2410	2008	1644	1404	2156	1795	1472	1256
U4E 3A (Warm – Humid)	CSPF	3.94	4.73	5.78	6.76	4.35	5.22	6.37	7.46
	CSEC	449	375	307	262	407	339	278	237
U4E 1B (Very Hot – Dry)	CSPF	3.29	3.95	4.82	5.64	3.45	4.14	5.05	5.91
	CSEC	2994	2495	2044	1745	2856	2380	1951	1665

[a] $EER_h(35)$: EER when cooling load is equal to cooling half capacity at 35°C

[b] $EER_f(35)$: EER when cooling load is equal to cooling full capacity at 35°C

[c] CSPF: cooling seasonal performance factor (Wh/Wh); CSEC: cooling seasonal energy consumption (kWh/year)

Table 8. Calculated Efficiency and Energy Consumption of the Four FSD ACs

Sample		F1	F2	F3	F4
Compressor type		FSD			
EER (W/W)		2.92	3.50	4.27	5.00
Temperature bin hours					
ISO 16358	CSPF	3.10	3.72	4.54	5.31
	CSEC	829	690	566	483
Brazil	CSPF	3.08	3.7	4.52	5.29
	CSEC	938	781	640	547
China	SEER	3.01	3.61	4.41	5.16
	CSEC	843	703	576	492
India	ISEER	2.76	3.31	4.04	4.73
	CSEC	981	818	670	572
U4E 0A (Extremely Hot –Humid)	CSPF	3.05	3.66	4.46	5.22
	CSEC	3230	2691	2207	1884
U4E 3A (Warm – Humid)	CSPF	3.02	3.63	4.42	5.18
	CSEC	586	488	400	342
U4E 1B (Very Hot – Dry)	CSPF	2.68	3.22	3.93	4.60
	CSEC	3671	3060	2509	2142
U4E 2B (Hot – Dry)	CSPF	2.92	3.51	4.28	5.01
	CSEC	1922	1601	1313	1121

This study also analyzes the efficiency performance of three VSD ACs according to the Egypt standard ES: 3795-2/2017 as shown in Table 9.

Table 9. Calculated Efficiency and Energy Consumption of the Three VSD ACs for Egypt

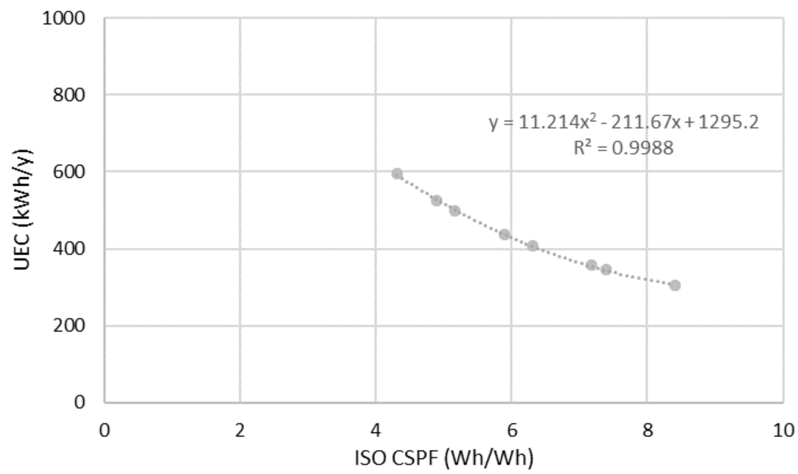
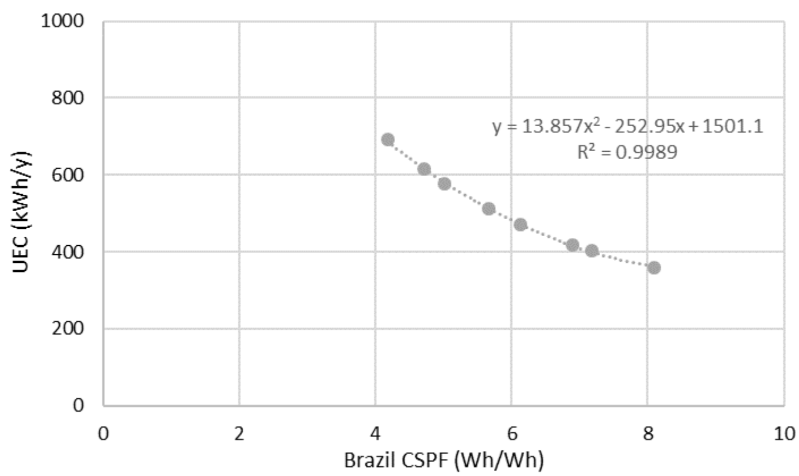
Sample	VE1	VE2	VE3
EER (W/W)	2.64	3.10	3.25
WEER[a]	2.92	3.44	3.56
Unit Energy Consumption (kWh/year)	6535	5399	5185

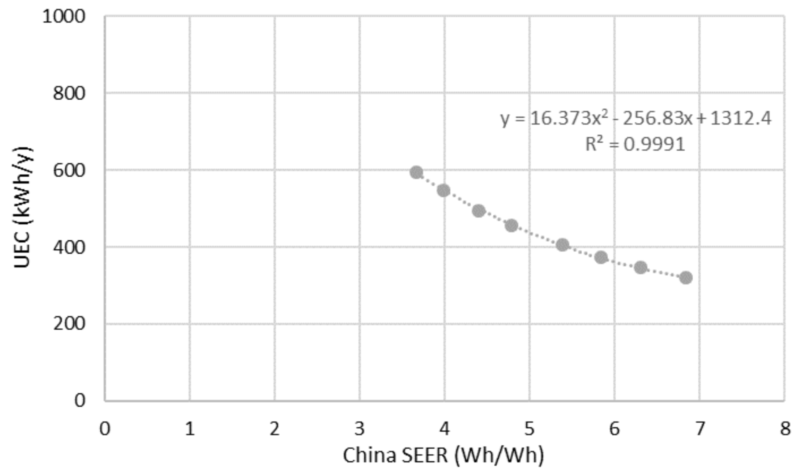
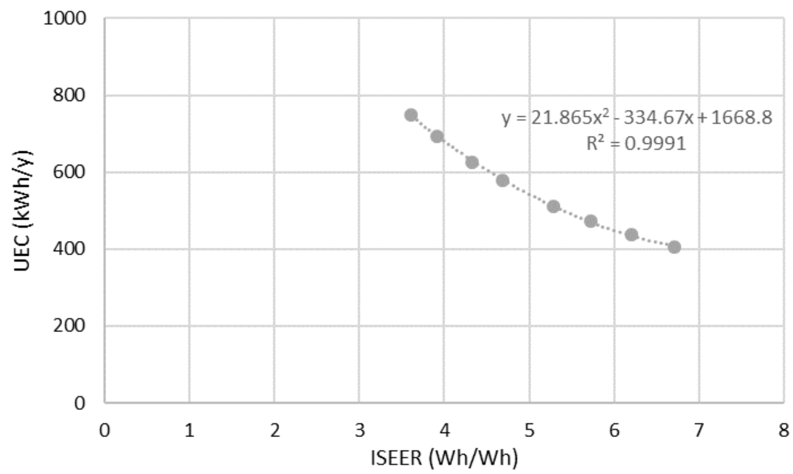
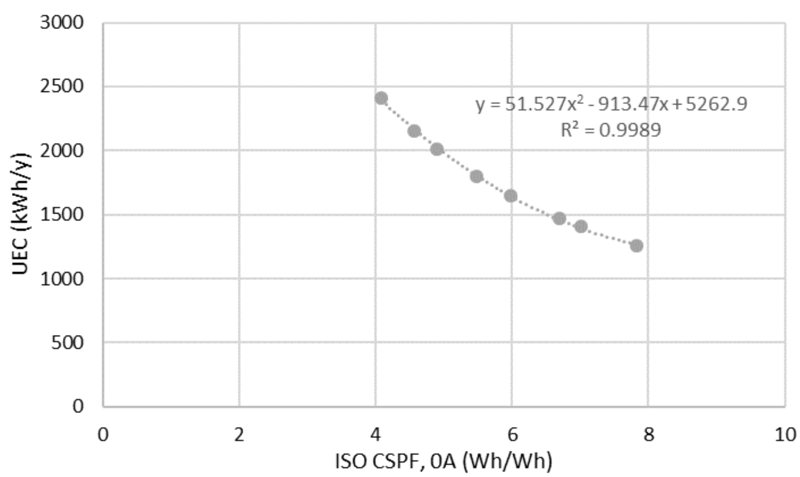
[a] To calculate the weighted energy efficiency ratio (WEER), the Egyptian standard (ES: 3795-2/2017) defines weight factors applied to EERs at different temperatures based on an outdoor temperature profile.

4. Estimated energy consumption from efficiency performance

We calculate the region-specific seasonal efficiency of the modeled AC specifications, and then establish regression relationships between seasonal efficiency metrics and annual unit energy consumption (UEC). All regression equations for estimating annual energy consumption from the seasonal efficiency of ACs are shown in Table 10 and Table 11.

Table 10. Estimated UECs by Efficiency for VSD ACs

ISO 16358 (Indonesia, Malaysia, Philippines, Thailand, Vietnam)	
Brazil	

China	
India	
U4E 0A (Bangladesh, Micronesia, Nigeria)	

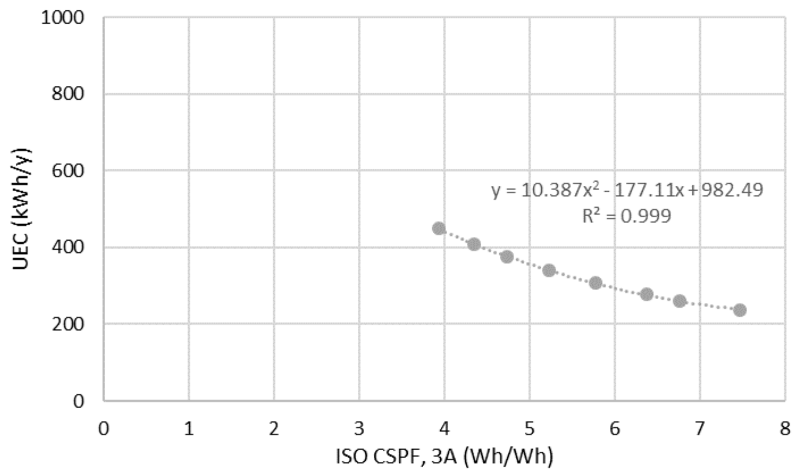
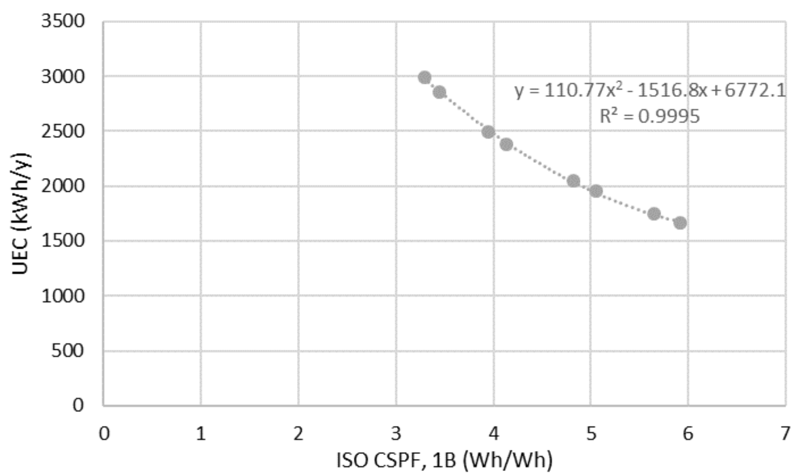
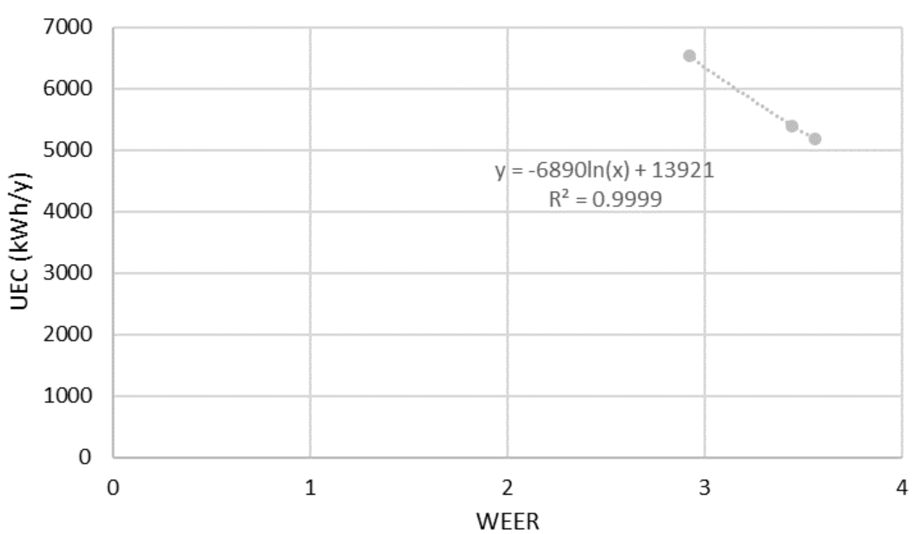
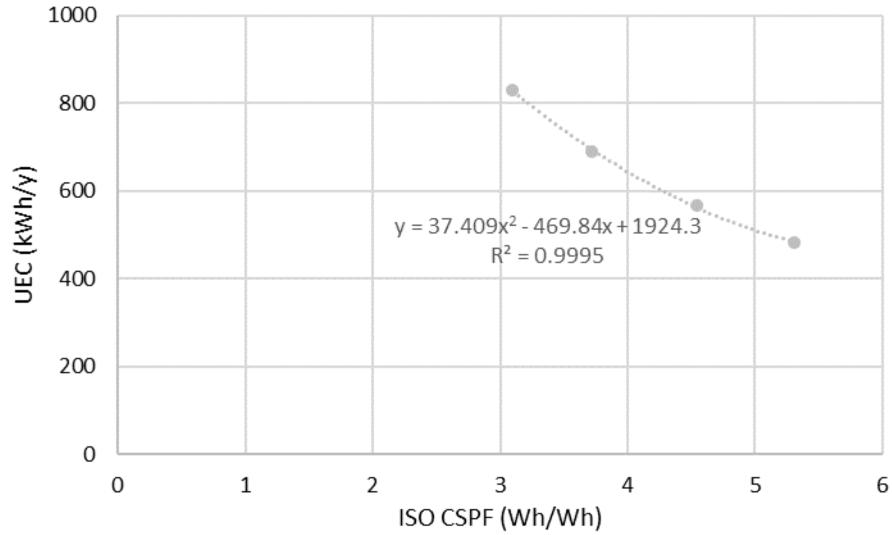
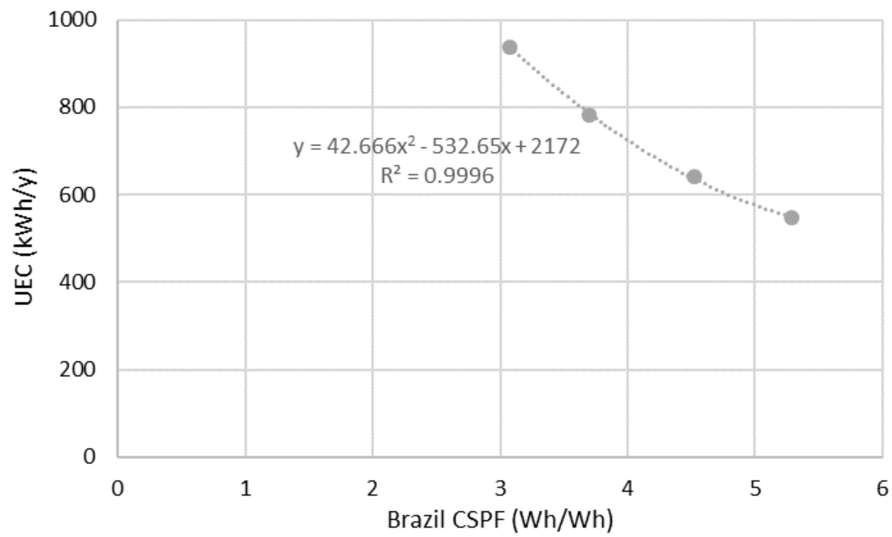
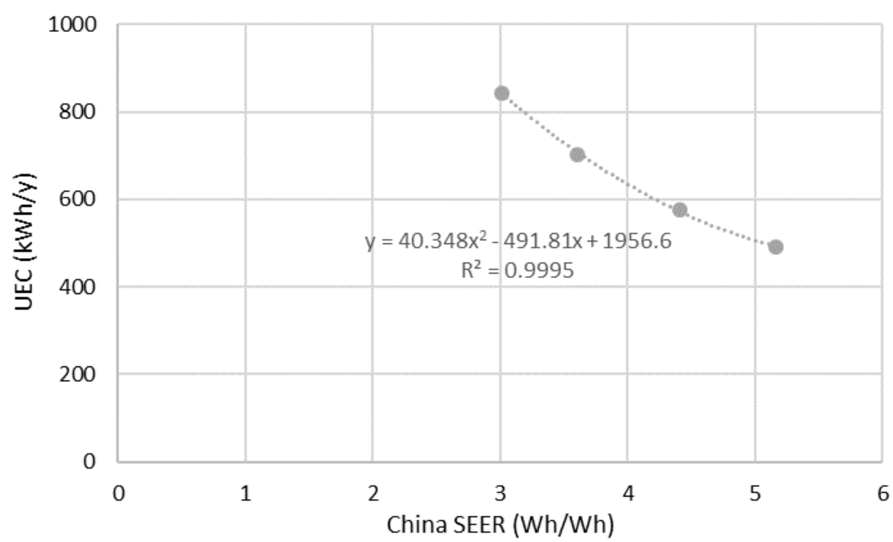
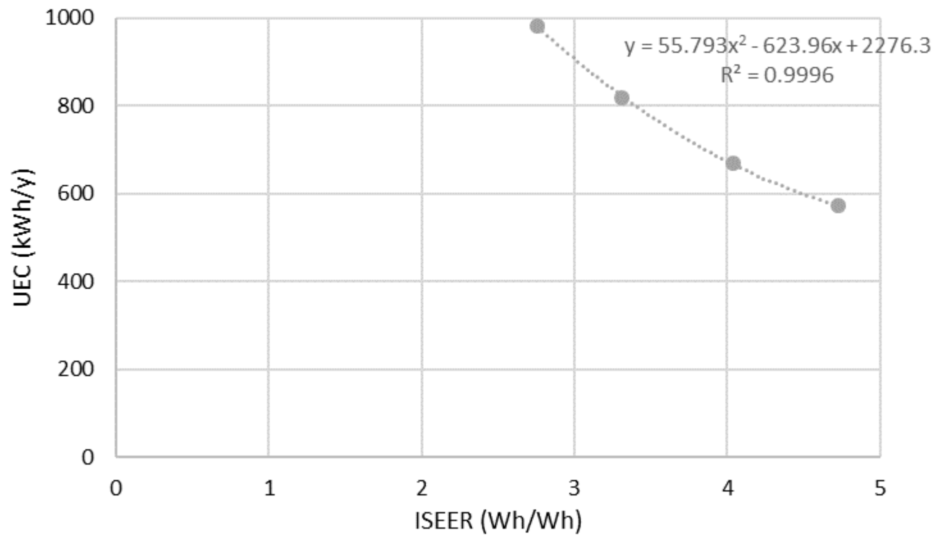
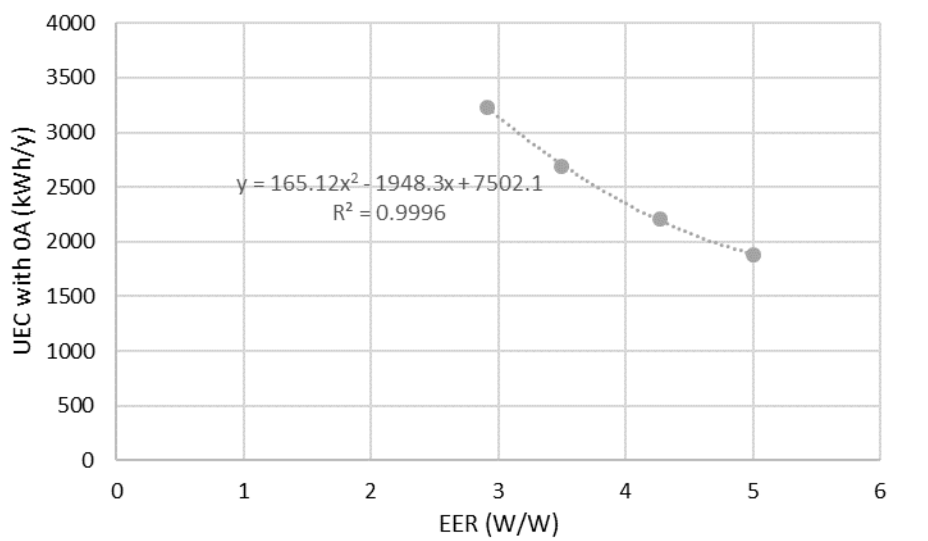
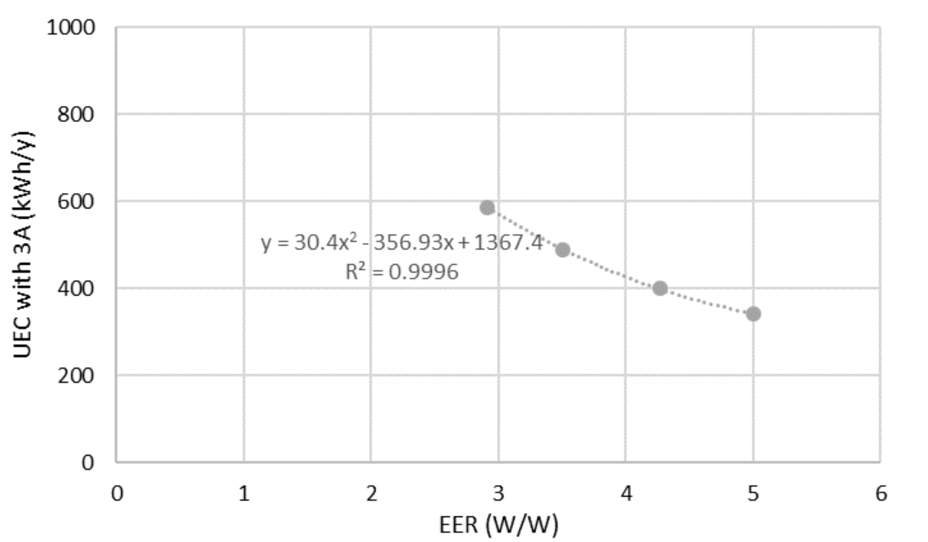
U4E 3A (Mexico)	
U4E 1B (Pakistan)	
Egypt	

Table 11. Estimated UECs by Efficiency for FSD ACs

ISO 16358 (Indonesia, Malaysia, Philippines, Thailand, Vietnam)	
Brazil	
China	

India	
U4E 0A (Bangladesh, Micronesia, Nigeria)	
U4E 3A (Mexico)	

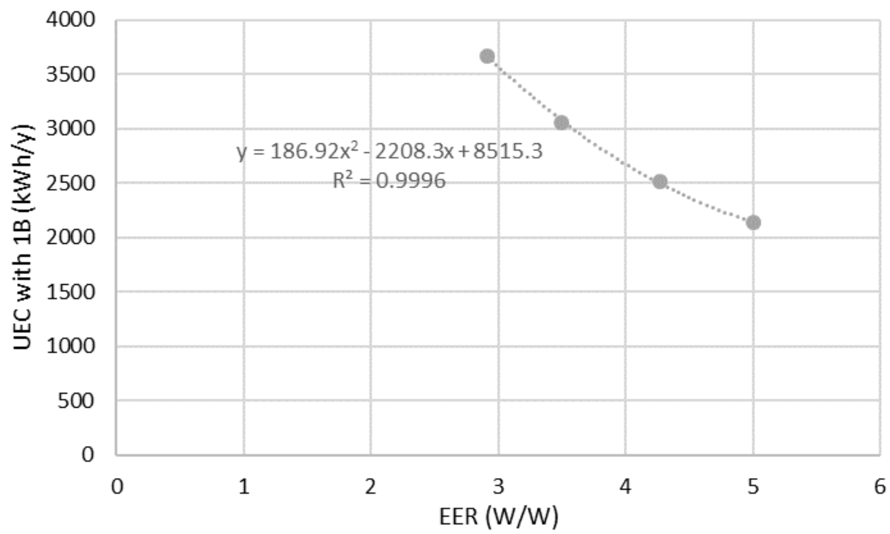
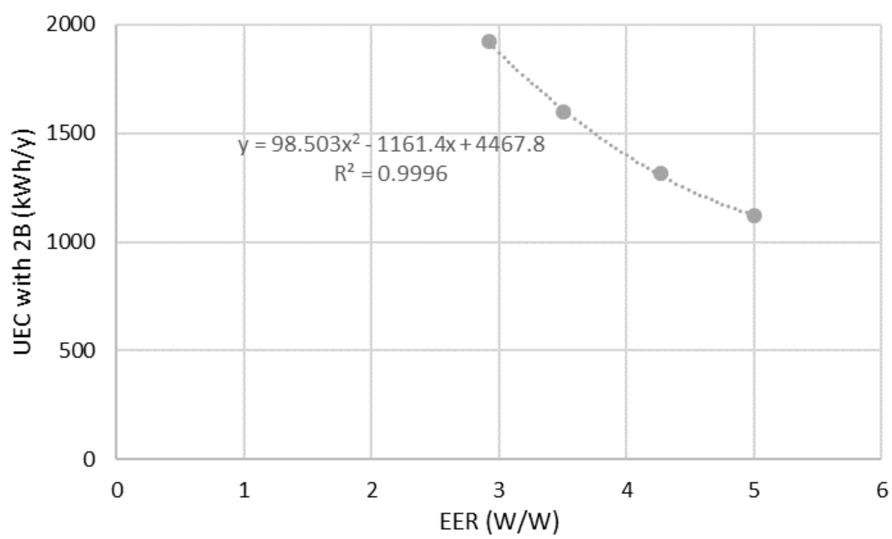
U4E 1B (Pakistan)	
U4E 2B (Egypt)	

Table 12 and Table 13 show estimated UECs by efficiency metric for FSD and VSD ACs, respectively.

Table 12. Estimated UECs by Efficiency for VSD ACs

	$\mathrm{y} = \mathrm{UEC}\ (\mathrm{kWh}/y)$	x	Annual hours of use	Outdoor temperature bin hours[a]
Bangladesh	$\mathrm{y} = 51.3x^2 - 913.5x + 5262.9$	ISO CSPF	4973	U4E 0A
Brazil	$\mathrm{y} = 13.9x^2 - 253.0x + 1501.1$	ISO CSPF	2080	Brazil
China	$\mathrm{y} = 16.4x^2 - 256.8x + 1312.4$	China SEER	1136	China
Egypt	$\mathrm{y} = -6890\ln(x) + 13921$	Egypt WEER	3600	Egypt
Indonesia	$\mathrm{y} = 11.2x^2 - 211.7x + 1295.2$	ISO CSPF	1817	ISO 16358
India	$\mathrm{y} = 21.9x^2 - 344.7x + 1668.8$	ISEER	1600	India
Malaysia[b]	$\mathrm{y} = (11.2x^2 - 211.7x + 1295.2) \times \frac{4380}{1817}$	ISO CSPF	4380	ISO 16358
Mexico	$\mathrm{y} = 10.4x^2 - 177.1x + 982.5$	ISO CSPF	1038	U4E 3A
Micronesia	$\mathrm{y} = 51.3x^2 - 913.5x + 5262.9$	ISO CSPF	4973	U4E 0A
Nigeria	$\mathrm{y} = 51.3x^2 - 913.5x + 5262.9$	ISO CSPF	4380	U4E 0A
Pakistan	$\mathrm{y} = 51.3x^2 - 913.5x + 5262.9$	ISO CSPF	3915	U4E 1B
Philippines	$\mathrm{y} = 110.8x^2 - 1516.8x + 6772.1$	ISO CSPF	1817	ISO 16358
Thailand	$\mathrm{y} = 11.2x^2 - 211.7x + 1295.2$	ISO CSPF	1817	ISO 16358
Vietnam	$\mathrm{y} = 11.2x^2 - 211.7x + 1295.2$	ISO CSPF	1817	ISO 16358

[a] We use the efficiency metrics and outdoor temperature bin hours defined in the national standards for Brazil, China, Egypt, Indonesia, India, Malaysia, Philippines, Thailand, and Vietnam. For Bangladesh, Mexico, Micronesia, Nigeria, and Pakistan, we use ISO CSPF and outdoor temperature bin hours defined in the U4E Model Regulation Guidelines for Air Conditioners.

[b] While the Malaysian minimum energy performance standard (MEPS) and labeling requirements are based on the ISO temperature bin hours, the standard calculates the annual energy consumption of an AC system as 4,380 hours (12 hours per day × 365 days).

Table 13. Estimated UECs by Efficiency for FSD ACs

	$y = \text{UEC (kWh}/y)$	x	Annual hours of use	Outdoor temperature bin hours[a]
Bangladesh	$y = 165.1x^2 - 1948.3x + 7502.1$	EER	4973	U4E 0A
Brazil	$y = 42.7x^2 - 469.8x + 1924.3$	ISO CSPF	2080	Brazil
China	$y = 40.3x^2 - 491.8x + 1956.6$	China SEER	1136	China
Egypt[b]	$y = (98.5x^2 - 1161.4x + 4467.8) \times \frac{3600}{2609}$	EER	3600	U4E 2B
Indonesia	$y = 37.4x^2 - 469.8x + 1924.3$	ISO CSPF	1817	ISO 16358
India	$y = 55.8x^2 - 624.0x + 2276.3$	ISEER	1600	India
Malaysia[c]	$y = (37.4x^2 - 469.8x + 1924.3) \times \frac{4380}{1817}$	ISO CSPF	4380	ISO 16358
Mexico	$y = 30.4x^2 - 356.9x + 1367.4$	EER	1817	U4E 3A
Micronesia	$y = 165.1x^2 - 1948.3x + 7502.1$	EER	4973	U4E 0A
Nigeria	$y = 165.1x^2 - 1948.3x + 7502.1$	EER	4973	U4E 0A
Pakistan	$y = 186.9x^2 - 2208.3x + 8515.3$	EER	3915	U4E 1B
Philippines	$y = 37.4x^2 - 469.8x + 1924.3$	ISO CSPF	1817	ISO 16358
Thailand	$y = 37.4x^2 - 469.8x + 1924.3$	ISO CSPF	1817	ISO 16358
Vietnam	$y = 37.4x^2 - 469.8x + 1924.3$	ISO CSPF	1817	ISO 16358

[a] We use the efficiency metrics and outdoor temperature bin hours defined in the national standards for Brazil, China, Indonesia, India, Malaysia, Philippines, Thailand, and Vietnam. For Bangladesh, Mexico, Micronesia, Nigeria, and Pakistan, we use EER (at 35°C) and outdoor temperature bin hours defined in the U4E Model Regulation Guidelines for Air Conditioners.
[b] While the Egyptian MEPS and labeling requirements for FSD units are based on the EER, this study calculates annual energy consumption of an AC system with outdoor temperature bin hours defined in the U4E Model Regulation Guidelines for Air Conditioners and have the consumption adjusted to annual 3,600 hours (300 hours per month × 12 months).
[c] While the Malaysian MEPS and labeling requirements are based on the ISO temperature bin hours, the standard calculates the annual energy consumption of an AC system at 4,380 hours (12 hours per day × 365 days).

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Appendix A. Climate Data

Table A1. Criteria of Climate Region and Weather Stations Included in this Analysis

Climate Region		CDD_{10} / HDD_{18}	Number of weather stations analyzed	Countries included in this analysis
0A	Extremely Hot-Humid	$6000<CDD_{10}$	28	Bangladesh, Brazil, Colombia, Dominican Republic, India, Indonesia, Kenya, Malaysia, Panama, Philippines, Sri Lanka, Thailand, Trinidad and Tobago, Venezuela, and Vietnam
0B	Extremely Hot-Dry		14	Egypt, Ghana, India, Kuwait, Pakistan, Qatar, Saudi Arabia, UAE, and Venezuela
1A	Very Hot–Humid	$5000<CDD_{10}\leq6000$	20	Bahamas, Bangladesh, Brazil, China, Colombia, Cuba, Dominican Republic, India, Indonesia, Mexico, Philippines, Tanzania, Thailand, and Vietnam
1B	Very Hot–Dry		10	Egypt, India, Mexico, Pakistan, Saudi Arabia, and South Africa
2A	Hot-Humid	$3500<CDD_{10}\leq5000$	23	Argentina, Brazil, China, Costa Rica, India, Kenya, Lebanon, Mexico, Pakistan, Philippines, Vietnam, and Venezuela
2B	Hot-Dry		11	China, Egypt, India, Mexico, Pakistan, Saudi Arabia, and South Africa
3A	Warm-Humid	$2500<CDD_{10}\leq3500$ And $HDD_{18}\leq2000$	11	Argentina, Algeria, China, Colombia, Lebanon, Morocco, South Africa, Uruguay
3B	Warm-Dry		10	Argentina, Chile, Egypt, Mexico, Morocco, Saudi Arabia, and South Africa
3C	Warm-Marine	$CDD_{10}\leq2500$ And $HDD_{18}\leq2000$	7	Chile, China, Kenya, Mexico, and South Africa

CDD10 - 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

HDD18 - Heating Degree-Day base 18°C (65°F)

- Daily mean temperature minus 18°C (65°F)
- Annual HDDs 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 four 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 and ASHRAE 2013

Table A2. Countries by Climate Region

Climate	Countries
0A	Antigua and Barbuda, Bangladesh, Belize, Benin, Brunei Darussalam, Cambodia, Cameroon, Central African Republic, Comoros, Côte d'Ivoire, Dominica, Dominican Republic, El Salvador, Equatorial Guinea, Federated States of Micronesia, Gabon, Gambia, Grenada, Guinea, Guyana, Haiti, India*, Indonesia, Jamaica, Kiribati, Lao People's Democratic Republic, Malaysia, Maldives, Mali, Marshall Islands, Myanmar, Nicaragua, Nigeria, Panama, Papua New Guinea, Philippines*, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Seychelles, Singapore, Solomon Islands, Somalia, Sri Lanka, Suriname, Thailand, Timor-Leste, Togo, Trinidad and Tobago, Viet Nam*
1A	Angola, Bahamas, Bolivia*, Burundi, Cuba, Democratic Republic of the Congo, Fiji, Guinea-Bissau, Liberia, Mauritius*, Mozambique, Republic of Congo, Sao Tome and Principe, Sierra Leone, Tonga, United Republic of Tanzania*, Vanuatu
2A	Brazil*, China*, Costa Rica, Ethiopia, Guatemala*, Honduras*, Israel*, Kenya*, Lebanon, Paraguay, Rwanda, Tunisia*, Uganda
3A	Albania, Algeria*, Argentina*, Colombia, Ecuador, Madagascar, Malawi, Mexico*, Montenegro*, Morocco*, State of Palestine, Swaziland, Tajikistan*, Uruguay, Zambia, Zimbabwe
2B	Botswana, Egypt*, Libya, Namibia, Peru*
3B	Iran*, Jordan*, Lesotho, Syrian Arab Republic*, Turkmenistan*, Yemen
3C	Chile*, South Africa*
0B	Burkina Faso, Chad, Djibouti, Eritrea, Ghana, Kuwait, Mauritania, Niger, Oman*, Qatar, Saudi Arabia*, South Sudan, Sudan, United Arab Emirates, Venezuela*
1B	Cape Verde, Iraq, Pakistan*, Senegal*

Authors' work based on ASHRAE weather data viewer 6.0.

- * Indicates countries with three or more climates.
- Climate zone of countries that have multiple climate zones is determined based on the climate of the largest population city.

Source: UNEP 2019b

Table A3. Temperature Bins for Calculating ISO CSPF (ISO 16358-1:2013)

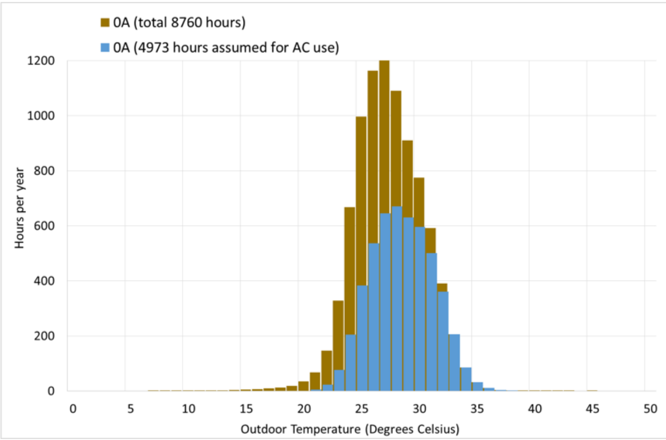
Outdoor temperature	Climate Group 1							
	Reference	0A	1A	2A	3A	2B	3B	3C
℃	Bin hours	Bin hours	Bin hours	Bin hours	Bin hours	Bin hours	Bin hours	Bin hours
21	ISO 16358-1: 2013 Table 3	5	33	49	32	30	34	34
22		23	86	92	62	64	60	60
23		76	167	128	83	102	84	73
24		205	250	161	99	138	98	75
25		383	327	191	103	169	108	74
26		537	360	210	101	201	109	60
27		646	388	219	93	216	109	50
28		671	395	212	85	221	105	41
29		630	371	188	79	217	97	32
30		596	332	149	72	203	88	27
31		501	285	118	63	200	75	18
32		361	227	86	52	191	61	12
33		206	153	58	41	180	50	6
34		86	90	37	29	147	36	3
35		32	55	22	18	113	27	2
36		11	35	13	11	80	16	1
37		3	22	8	7	53	10	0
38		1	16	4	4	34	6	0
39		0	12	3	2	21	3	0
40		0	10	1	1	13	1	0
41		0	7	1	1	8	1	0
42		0	5	1	0	4	0	0
43		0	3	0	0	3	0	0
44		0	1	0	0	1	0	0
45		0	0	0	0	0	0	0
46		0	0	0	0	0	0	0
47		0	0	0	0	0	0	0
48		0	0	0	0	0	0	0
49		0	0	0	0	0	0	0
50		0	0	0	0	0	0	0
Total	1817	4973	3630	1951	1038	2609	1178	568

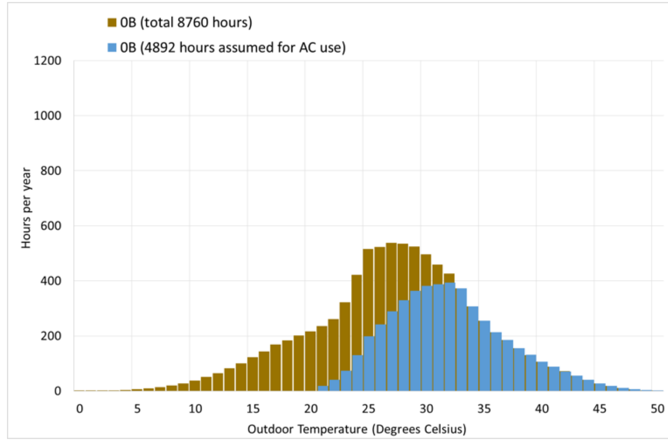
Source: UNEP 2019b

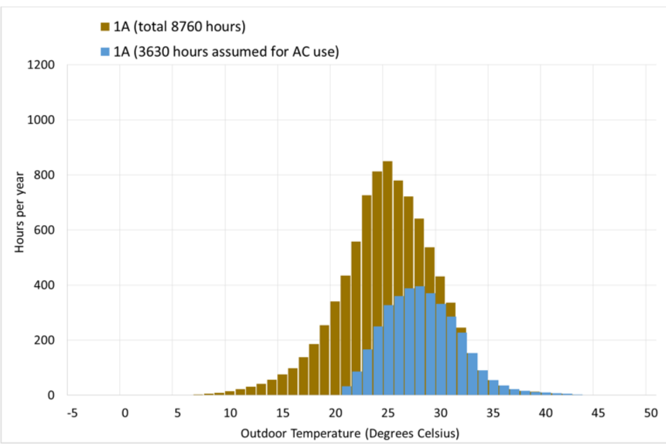
Table A4. Temperature Bins for Calculating ISO CSPF (ISO 16358-1:2013/Amd: 2019)

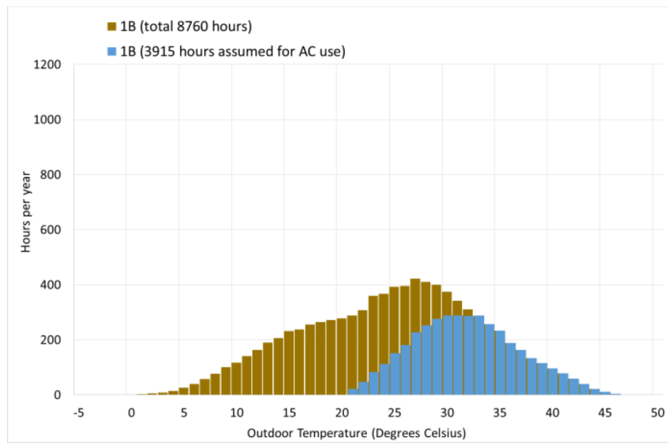
Outdoor temperature	Climate Group 2		
	Reference	0B	1B
℃	Bin hours	Bin hours	Bin hours
21	ISO 16358-1: 2013/Amd:2019 Table F2	18	22
22		40	47
23		74	83
24		130	113
25		198	151
26		241	182
27		290	228
28		329	253
29		364	277
30		381	289
31		388	289
32		393	287
33		372	288
34		307	257
35		255	234
36		213	189
37		185	164
38		155	134
39		131	116
40		106	97
41		88	78
42		71	59
43		55	40
44		41	22
45		27	11
46		19	4
47		11	1
48		6	0
49		3	0
50		1	0
Total	6493	4973	3630

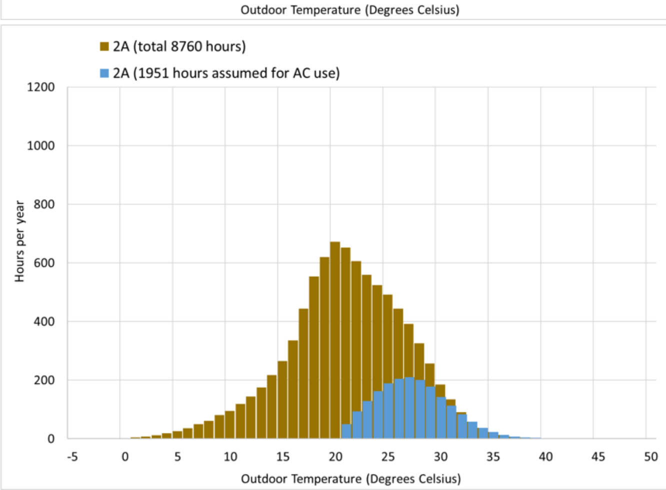
Source: UNEP 2019b

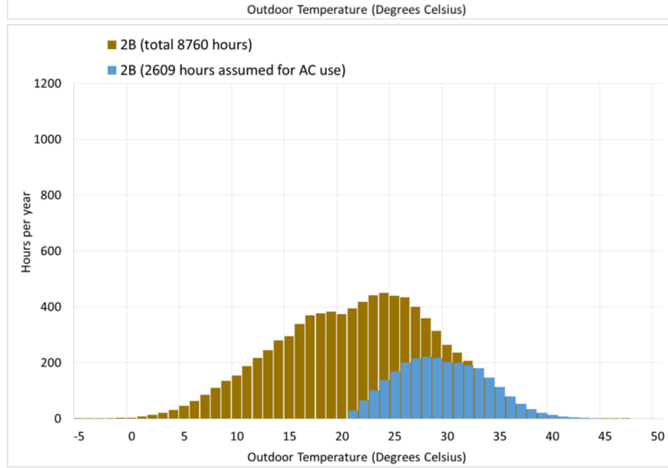

0A (total 8760 hours)
0A (4973 hours assumed for AC use)
Hours per year
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
45
50
Outdoor Temperature (Degrees Celsius)


0B (total 8760 hours)
0B (4892 hours assumed for AC use)
Hours per year
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
45
50
Outdoor Temperature (Degrees Celsius)


1A (total 8760 hours)
1A (3630 hours assumed for AC use)
Hours per year
1200
1000
800
600
400
200
0
-5
0
5
10
15
20
25
30
35
40
45
50
Outdoor Temperature (Degrees Celsius)


1B (total 8760 hours)
1B (3915 hours assumed for AC use)
Hours per year
1200
1000
800
600
400
200
0
-5
0
5
10
15
20
25
30
35
40
45
50
Outdoor Temperature (Degrees Celsius)


2A (total 8760 hours)
2A (1951 hours assumed for AC use)
Hours per year
1200
1000
800
600
400
200
0
-5
0
5
10
15
20
25
30
35
40
45
50
Outdoor Temperature (Degrees Celsius)


2B (total 8760 hours)
2B (2609 hours assumed for AC use)
Hours per year
1200
1000
800
600
400
200
0
-5
0
5
10
15
20
25
30
35
40
45
50
Outdoor Temperature (Degrees Celsius)

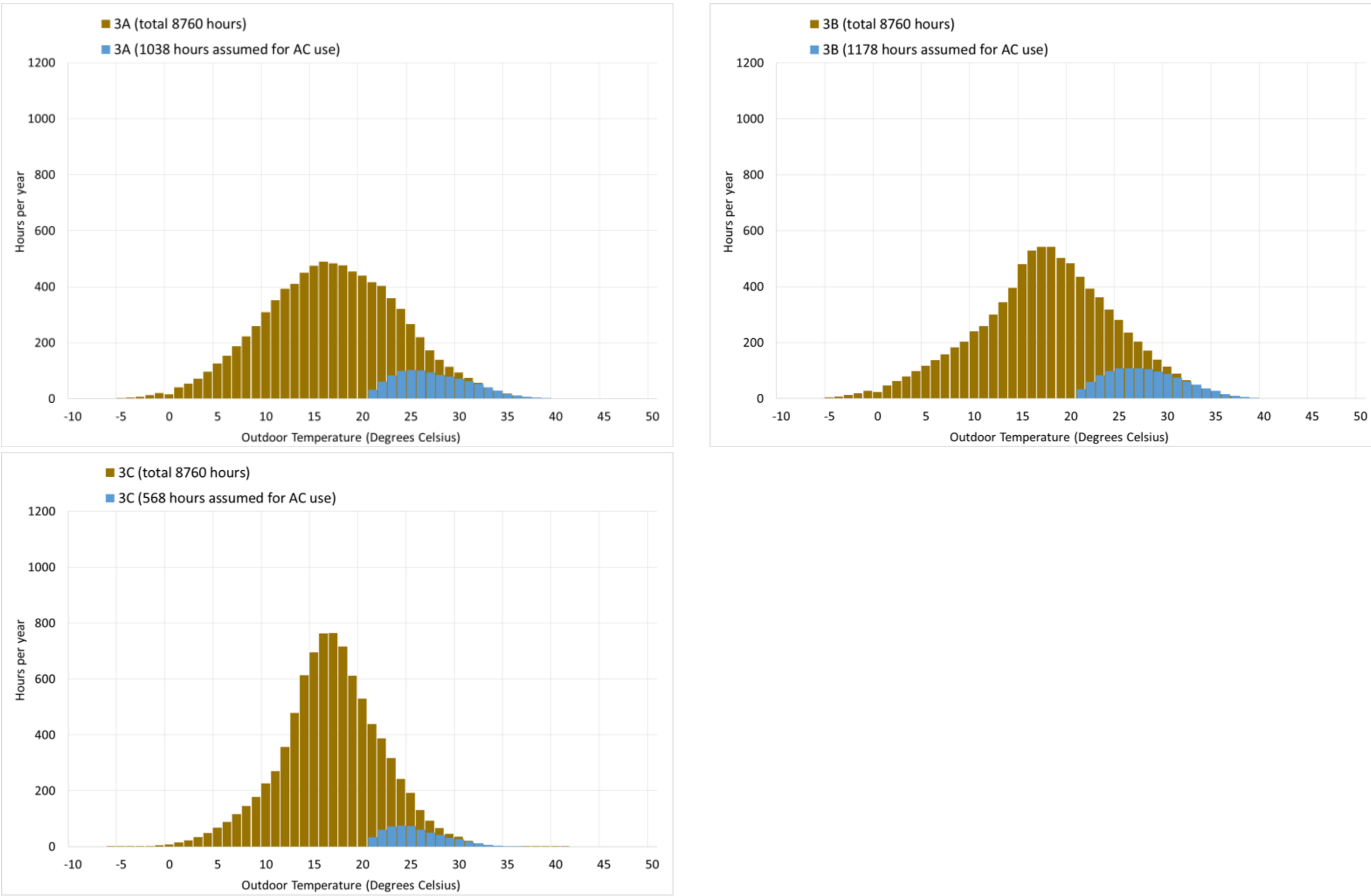


Figure A1. Annual outdoor temperature bin distribution and temperature bin hours for AC use