Domestic Air Conditioner Test Standards and Harmonization

Final Report

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Executive Summary

The energy consumption and peak demand impact of air conditioning continues to grow faster than any other building end-use, challenging electrical grids around the globe. Minimum Energy Performance Standards (MEPS) programs represent one of the most potent and cost-effective strategies for meeting the challenges presented by the ever-increasing demand for space cooling. Test procedures form the basis of effective MEPS programs and their consistency may offer benefits to policy makers, manufacturers, and consumers alike. This report is a comparative review of test procedures and efficiency metrics for room air conditioners across six countries, as well as the ISO standard. (The Canada test procedure is also referenced occasionally herein due to its validity on the topic of variable capacity testing, but it is not specifically covered in the scope of this report.)

The findings of this report are intended to inform the efforts of policy makers to evaluate where greater consistency between test methods and metrics may be beneficial. Below is a summary of the key findings of the team's review:

1. **Globally, air conditioner test methods for non-ducted split system air conditioners are reasonably well aligned.** Recent progress has been made in several areas including: the greater adoption of seasonal efficiency metrics which aids end users in choosing efficient air conditioning equipment; the tightening and clarification of test procedures to prevent manufacturers from artificially inflating reported efficiencies; and the establishment of multiple climate zone distinctions for calculating seasonal energy efficiency metrics. Guidance on calculating season efficiency metrics based on region or climate zone for countries that do not have their own established test procedures would advance international harmonization efforts.

2. **The research team did identify several opportunities for harmonization of test procedures, including test temperature adjustments, standardized reporting, and nomenclature standardization.** Regional variations in temperature conditions required for testing and calculating seasonal efficiency metrics do affect calculated seasonal performance but are viewed as necessary to accurately represent usage in each climate. Standardizing on a low temperature test condition that allows for interpolation in calculating seasonal efficiency metrics (rather than extrapolation) would lead to more accurate results. Therefore, the research team recommends a standard low temperature test condition of 20°C. In addition, standardization on the number and reporting of performance at different test temperatures, as well as interim energy variables (e.g., standby energy use), would allow for easier and more transparent translation of one seasonal efficiency metric to another between various climates and economies. Measuring the degradation coefficient rather than using a constant value is a best practice but does require more test points. Guidance on calculating season efficiency metrics based on region or climate zone for countries that do not have their own established test procedures would also advance international harmonization efforts.

   Other opportunities for harmonization include standardizing installation procedures and nomenclature used in test procedures. Room air conditioners and associated metrics are referred to by many names across the globe, as well as in international test procedures.

Establishing standard naming conventions would facilitate better understanding of the equipment under discussion, metric comparisons, and calculation methods.

3. **In addition to near term harmonization opportunities, there are opportunities to improve representativeness of test procedures in the future, especially for variable capacity equipment.** Testing of variable capacity ACs at part load conditions has proven to be problematic, from the perspective of both the test procedure and the accuracy of results. Current proposed changes to test methods for variable capacity units in some economies to introduce load-based testing may help alleviate testing issues requiring manufacturer input and control and improve the accuracy and representativeness of the results. However, additional work is required to refine the proposed test methods to ensure the results are repeatable and benefits of the improved test procedure are effectively balanced with the additional burden associated with transitioning and implementing the new approach. Efforts to improve test procedures and transition to calorimetric testing should be balanced against existing harmonization efforts and infrastructure based on current testing approaches and product ratings.

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Abbreviated Terms

AC	Air Conditioner / Air Conditioning
ANSI	American National Standards Institute
AHRI	Air-Conditioning, Heating, Refrigeration Institute
APF	Annual Performance Factor
CFR	Code of Federal Regulations
COP	Coefficient of Performance
CSPF	Cooling Seasonal Performance Factor
DB	Dry Bulb (temperature)
DOE	Department of Energy
EER	Energy Efficiency Ratio
EU	European Union
HSPF	Heating Seasonal Performance Factor
ISO	International Standards Organization
kWh	Kilowatt-hour
MEPS	Minimum Energy Performance Standard
RAC	Room Air Conditioner
RH	Relative Humidity
SCOP	Seasonal Coefficient of Performance
Pa	Pascal
SEER	Seasonal Energy Efficiency Ratio
US	United States
VRF	Variable Refrigerant Flow
WB	Wet Bulb (temperature)

1. Introduction

As the quality of life steadily increases around the world, so too has the desire for and utilization of air conditioning. Energy consumed by air conditioning systems has tripled since 1990: no other building end-use is growing as fast. Air conditioning not only makes up a significant and growing share of energy consumption, it is also the primary contributor to peak demand in many geographies. More than 70 percent of residential peak electrical demand on a distribution system can be attributed to air conditioning equipment (IEA 2018). Peak electrical demand stresses distribution systems around the world, and often disproportionately impacts developing economies because their transmission grids may be ill-equipped to handle high demand occurrences. Building and maintaining the infrastructure to accommodate increasing peak demand requires significant investments, which are only necessary for brief periods each year.

Programs that set minimum energy performance standards (MEPS) for energy-consuming equipment, including air conditioning products, are proven, cost-effective strategies for slowing the growth of energy consumption and reducing peak demand on electrical systems around the world. Across the globe there are numerous governing bodies that currently regulate and test air conditioners (ACs).

While successful MEPS initiatives have several components, test procedures form their essential foundation. Test procedures establish the basis for comparing the energy performance of covered products (e.g., AC units) available in a market subject to MEPS. The energy performance of a product is described by one or more efficiency metrics.

More than 60 countries have regulatory requirements on the energy performance of ACs (CLASP 2018). However, the test procedures and metrics established by these different countries often vary—sometimes dramatically—making it difficult or impossible to compare the energy performance of ACs across jurisdictions. This can lead to confusion in the marketplace when trying to identify efficient equipment, as well as the potential for increased testing burden on manufacturers attempting to comply with many different regulatory schemes.

Any effort to mitigate this issue must start with a comparison of the governing test procedures in different MEPS programs for air conditioners. That comparison is the subject of this report. Specifically, this report seeks to address the following questions:

- Where do the test procedures differ, and which differences impact the representation of energy performance?
- Which AC test procedures provide thorough energy performance metrics, and which are missing operational aspects that impact overall energy consumption?
- Can certain aspects of each test method be harmonized to facilitate the accurate testing and rating of ACs on a global level?

Based on a review of global air conditioner standards, this report seeks to address these questions. First, it presents a comparative review of the test methods of seven different global air conditioning economies, along with an international test standard. Next, this report reviews the applicability of energy efficiency metrics across these same global economies, with an emphasis on effectiveness in characterizing energy consumption. Finally, the report applies the findings from the test procedure and efficiency metrics review to present recommendations on opportunities for the harmonization of test procedures and metrics across global economies. This review leverages the report "Benchmarking RAC" published in 2011 (Econoler, Navigant, CEIS and ACEEE 2011) and incorporates any changes to each country's test procedure since then.

2. Domestic Air Conditioner Equipment Definition

This report focuses on air conditioning equipment that is most commonly used in the residential sector. While there are some smaller commercial facilities that use units of this size, the vast majority are concentrated in single family, multifamily, and manufactured (mobile) homes. Almost 70% of all ACs are in the residential sector.

The term "residential air conditioners" covers many different products. Depending on the specific test procedure or country one is evaluating, "residential air conditioners" may refer to differ equipment types, complicating any effort to compare the test procedures to which they are subject.

This section reviews the terms and definitions used to describe different residential ACs, compares the scope of the test procedure reviewed for each country, and, based on the observed similarities and differences, describes the scope of products that are specifically addressed in this report.

2.1 Air Conditioner System Types

Air conditioners can be distinguished across several dimensions. This report focuses on five primary delineations:

1) Air Conditioner vs Heat Pump
2) Ducted vs Non-ducted
3) Variable Capacity vs Constant Speed
4) Split System vs Packaged Systems
5) Split System Type

In combination, each distinction listed below defines the type and configuration of a cooling unit. Some are broad categories of equipment (e.g., variable capacity vs constant speed or AC vs heat pump), whereas other distinctions refer to different configurations of the same general piece of equipment (e.g., split system type). These different configurations and control methods are all used to determine which equipment is covered by the test procedures in each country.

2.1.1 Air Conditioner versus Heat Pump

An "air conditioner" is a unit that, most commonly, uses the vapor compression refrigeration cycle to lower the temperature air in a space, rejecting the heat to the outside. A "heat pump" uses the same vapor compression cycle but is able to reverse the cycle so that heat can be pulled from the outside air and "rejected" into a space. Heat pumps are capable of operating as both a cooling and heating system. The reverse cycle capability is an internal function of the equipment, so there is no visible difference between an AC and a heat pump.

2.1.2 Ducted versus Non-ducted

A ducted AC unit uses a distribution fan to blow conditioned air through ductwork to the desired space. A non-ducted AC unit incorporates an evaporator unit mounted in the space being conditioned so that conditioned air is delivered to the room directly from the evaporator unit. Some examples of non-ducted ACs include packaged terminal AC units, window AC units, and ductless split system AC units shown in the following Figure 1, Figure 2, and Figure 3.

Figure 1: Typical Packaged Terminal Air Conditioner or Heat Pump Unit

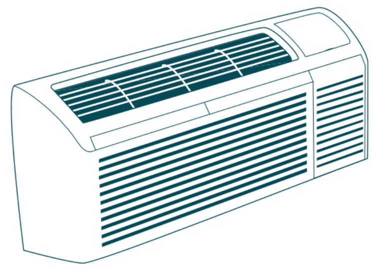


Figure 2: Typical Window Air Conditioner Unit

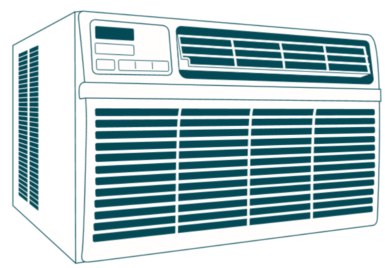
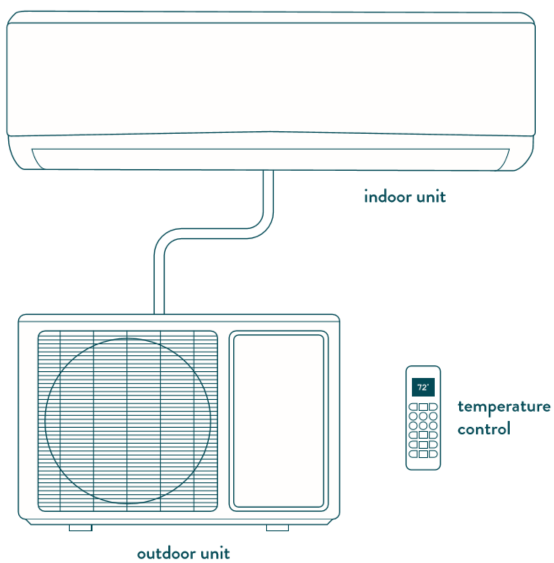


Figure 3: Typical Non-Ducted Split System AC or Heat Pump



2.1.3 Variable Capacity versus Constant Speed

Traditionally, AC compressors run at a single speed and either operate at full speed to satisfy a cooling load or turn off completely when the cooling load is met. Today, variable capacity ACs represent an increasing share of the market. These units have compressors with variable speed drives that can adjust the compressor speed to match the required amount of heating or cooling a space requires. As with AC and heat pump units, there is no way to visually tell whether an AC compressor is single speed or variable speed.

2.1.4 Split System versus Packaged System

A packaged AC unit is a piece of equipment where the evaporator and condenser are contained in the same unit (or package). A typical packaged ducted AC or heat pump unit is shown in Figure 4 below. A split system is an AC in which the condenser and evaporator are separate pieces of equipment, connected by refrigerant piping and electronic controls. A packaged unit must be ducted[1] because the unit will almost always be located outside, moving air into the conditioned space via ducting. A split system can be either ducted or non-ducted. A non-ducted split system can be seen in Figure 3 above, while Figure 5 below shows a typical ducted split system.

Figure 4: Typical Packaged Ducted AC or Heat Pump

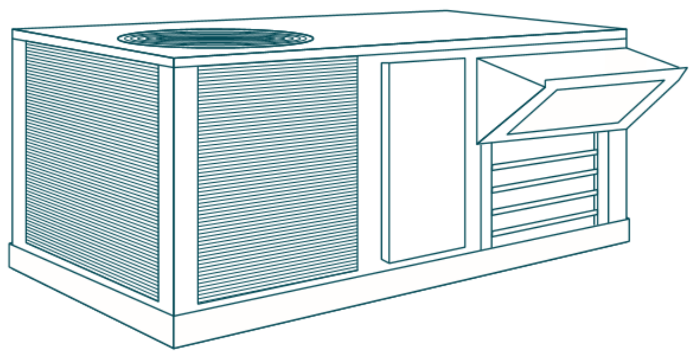
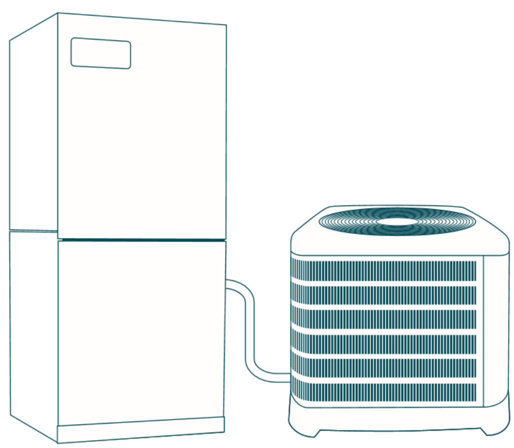


Figure 5: Ducted Split System AC or Heat Pump



[1] The exceptions to this statement are Packaged Terminal AC/HPs and AC's designed to be installed in windows. These units are designed to be mounted through the plane of the building (i.e., and exterior wall) and can therefore operate as a packaged, non-ducted unit.

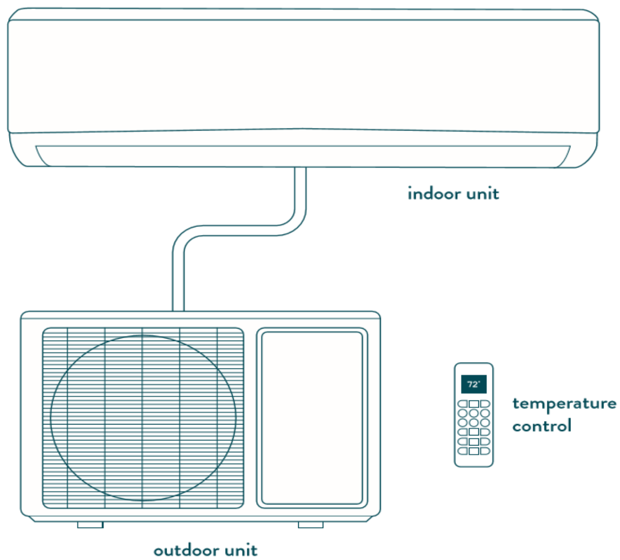
2.1.5 Split System Type

The flexibility of the non-ducted split system has made it very popular in many countries. This flexibility facilitates a variety of possible set-up configurations. There are four main categories of split systems:

Single Split

All ducted split system AC units are single-splits and it is also the most common type of non-ducted AC.

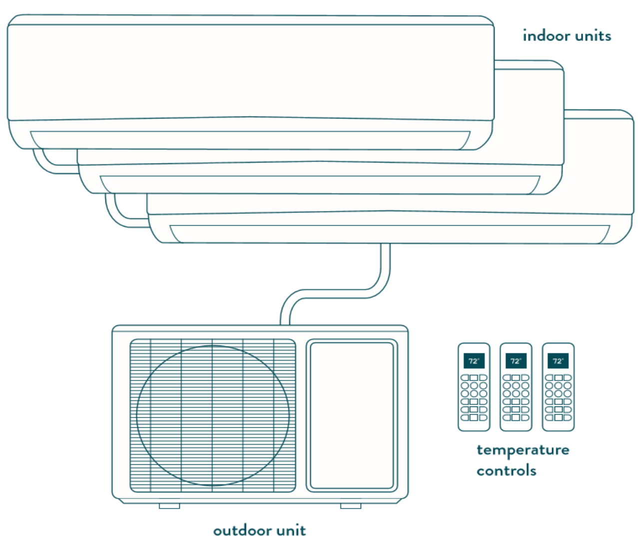
Figure 6: Single Split System AC or Heat Pump (Non-Ducted)



Multi-split

A multi-split system is a system with one refrigerant loop with two or more indoor units that can be operated independently. This usually implies that more than one thermostat can control the operation of both the evaporator and the condenser.

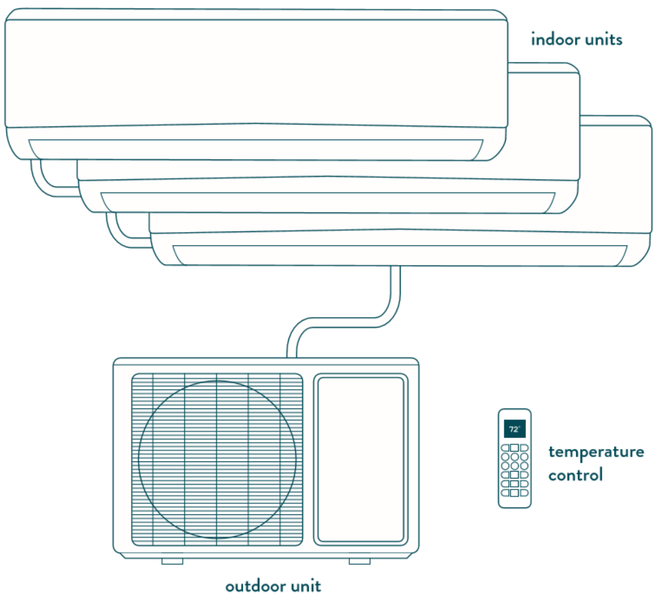
Figure 7: Multi-Split System AC or Heat Pump (Non-Ducted)



Multi-head

A multi-head split system has one refrigerant loop with two or more evaporator units attached. A multi-head system differs from a multi-split system in that all the indoor units are controlled by the same thermostat.

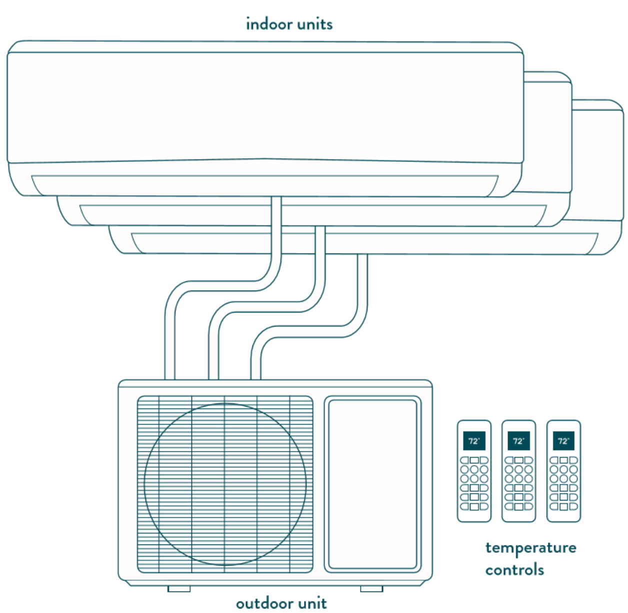
Figure 8: Multi-Head Split System AC or Heat Pump (Non-Ducted)



Multi-circuit

A multi-circuit system is the most complex type of split system. The system has two or more evaporator units served by the same condenser, but each indoor unit has a dedicated refrigerant loop and thermostat.

Figure 9: Multi-Circuit Split System AC or Heat Pump (Non-Ducted)



2.2 Scope of Covered Countries

The test procedures for Domestic Air Conditioners are slightly different between each governing body. The test procedures are often tailored to test the products that are most common in each geography. With different climates and equipment markets in each country, the high and low temperature test conditions each test procedure are slightly different. This section discusses the scope of each test procedure and reviews their similarities and differences across six countries, as well as the ISO standard. The Canada test procedure is referenced on occasion in this report due to its validity on the topic of variable capacity testing, but it was not specifically covered in the scope of this report. Table 1: summarizes and compares the scope of each country's test procedure. It is worthwhile to note that while specific labeling standards of each country are discussed briefly in Section 4, they were not the subject of this research.

2.2.1 ISO

The ISO standard 5151, which is incorporated either by reference or in full by many countries, applies to non-ducted air-cooled ACs and air-to-air heat pumps, and small ducted ACs and heat pumps (rated less than 8 kW and intended to operate with an external static pressure of less than 25 Pascals). The scope of the standard covers both packaged and split systems but limits the split systems to multi-split systems controlled by a single thermostat (however, ISO 5151 references ISO 15042 test method for these products). The standard specifies that single capacity, variable capacity, and multiple capacity (e.g., a product that can operate at 2-3 discrete points) units are also covered.

2.2.2 Australia

The Australian standard, AU/NZ 3823.4.1, covers air-cooled ACs and air-to-air heat pumps. This test method is the ISO 16358 standard, which incorporates the entire scope of ISO 5151, ISO 13253, and ISO 15042. ISO 13253 covers ducted air-cooled air conditioners and ducted air-to-air heat pumps. ISO 15042 is the test procedure that covers multi-split and multi-circuit non-ducted systems. Both single and variable capacity systems are covered.

2.2.3 China

The Chinese test procedure applies to non-ducted units with a cooling capacity below 14 kW. The units can be either water-cooled or air-cooled.

2.2.4 European Union

The EU test procedure covers both packaged and split system ACs and heat pumps. These products can be variable capacity by any means, ducted or non-ducted, single-split or multi-split systems. The definition for multi-split from the EU aligns with the US definition (below).

2.2.5 Japan

The Japanese standard applies to packaged and split system ACs with a rated cooling capacity of 10 kW or less. Japan references ISO 5151 for its standard, with country specific adjustments to the testing conditions.

2.2.6 Korea

Korea's test procedure is limited to packaged and split systems with a rated cooling capacity of 35 kW or less. The main deviation in scope from the other countries is the exclusion of split systems with multiple indoor units.

2.2.7 United States

The test procedure established by the United States was updated in 2017, and a new test procedure will go into effect in 2023. The current test procedure covers both heat pumps and ACs configured as single package units and split system units. The standard specifies that the split system units can be designed as multi-head mini split, multi-split (including VRF), and multi-circuit systems. The definitions include specification of air source heat pumps.

2.3 Scope of Covered Products

The seven test procedures described in the previous section cover a wide range of products, with significant overlap. As the main goal of this report is to provide a comparative review of the test procedures and metrics, the research team aligned the scope of the equipment included to provide as much overlap as possible, while also being as comprehensive and inclusive as possible so as not to leave equipment out unnecessarily. Table 1 lists each test procedure and the AC configurations it covers.

Scope of Covered Equipment

This report covers the performance of variable and constant capacity split system, non-ducted heat pumps and ACs. This includes single-split, multi-split, multi-circuit, and multi-head mini-split units.

After reviewing the scope of the test procedures in various countries, the team determined that greatest consistency and coverage would be achieved by considering all permanently installed space conditioning units designed to cool a specific room of a home. This general definition was established to exclude portable ACs and window units (they are not permanently installed), as well as units that are designed to condition an entire dwelling (central, packaged systems). While many countries refer to these as "Room Air Conditioners" (as opposed to central AC units that cool an entire home), it should be noted that a "Room Air Conditioner" defined by the United States is a portable unit installed in a window or through a wall. This report does not discuss these "window units."

Using the terminology presented in Section 2.1, this definition covers variable and constant capacity split system, non-ducted heat pumps and ACs. Very small ducted split systems (i.e., short duct rung mini-split units) fall into this category as well. This comparison will not extend to packaged units, window units, or portable AC units. While there is different coverage of split system types between the standards, the comparison will cover all split system types. Throughout this report, we use the generic term **air conditioners** or **ACs** to refer to these permanently installed, split system, non-ducted units.

Table 1: AC Test Standards Scope

Country	Referenced Test Procedure	Scope of Products Covered	Test Method	Secondary Energy Uses Tested	Fixed/ Variable Speed
Australia/ New Zealand	AU/NZS 3823.1.1:2012 AU/NZS 3823.4.1:2014 AU/NZS 3823.4.2:2014	Non-ducted Single-split AC or HP Up to 8 kW	Air Enthalpy Calorimetric*	Defrost, Crankcase Heater, Standby	Fixed Variable
China	GB/T 7725-2004	Non-ducted Single- and Multi-split AC or HP Up to 14 kW	Air Enthalpy Calorimetric*	Defrost	Fixed Variable
EU	BS EN 14511:2018	Ducted or Non-ducted Single-split AC or HP Up to 35 kW	Air Enthalpy Calorimetric	Defrost	Fixed Variable
Japan	JIS B 8615-1:2013 JIS B 9612:2013	Non-ducted Single-split AC or HP Up to 10 kW	Air Enthalpy Calorimetric*	Defrost	Fixed Variable
Korea	KS C 9306 2017	Ducted or Non-ducted Single-split AC or HP Up to 35 kW	Air Enthalpy Calorimetric	Defrost	Fixed Variable
US	10 CFR 430 Subpart B Appendix M/Appendix M1	Ducted or Non-ducted Single-split AC or HP Up to 19 kW	Air Enthalpy	Defrost, Crankcase Heater, Off Power	Fixed Variable
International	ISO 5151	Non-ducted Single- and Multi-Split AC or HP Up to 10 kW	Air Enthalpy Calorimetric*	Defrost	Fixed Variable

*For non-ducted units only, limited to <25 Pa.

3. Test Method Comparative Review

The research team performed a detailed review of the differences between the test procedures from the seven separate governing bodies, with the Canadian test procedure included for reference. The team identified the following areas of focus to describe differences in test procedures. First, the difference in the type of test required and how it plays into test burden and reproducibility is discussed. Second, the team addresses full load test temperature conditions and how these can lead to uncertainty of results. The next two sections discuss variable capacity test considerations and secondary energy use, respectively. Finally, Section 3.5 includes a brief summary of recent changes to the test procedures referenced.

Table 2 provides a brief summary comparison of the test procedures referenced. Note that test efficiency metrics are included in this table for reference only. Refer to Section 4 for more detailed descriptions of efficiency metrics.

Table 2: Test Procedure Comparison Summary

	Test Method	Test Efficiency Metric Outputs	Test Type	Full Load Test Conditions (°C)	Secondary Energy Use	# of Clg Test Points
Australia/ New Zealand	AU/NZS 3823.4.1:2014	EER, CSPF (Cooling) HSPF (Heating)	Air Enthalpy Calorimetric	Entering Indoor: 27 (DB) / 19 (WB) Entering Outdoor: 35 (DB)	Defrost, Crankcase Heater, Standby	2
China	GB/T 7725-2004	EER, SEER (Cooling) HSPF (Heating)	Air Enthalpy Calorimetric	Entering indoor: 27 (DB)/19 (WB) Entering outdoor: 35 (DB)	Defrost	2
EU	BS EN 14511:2018	SEER (Cooling) SCOP (Heating)	Air Enthalpy Calorimetric	Entering indoor: 27 (DB)/19 (WB) Entering outdoor: 35 (DB)	Defrost	4
Japan	JIS B 8615-1:2013 JIS B 9612:2013	CSPF (Cooling) HSPF (Heating) APF (Cooling and Heating)	Air Enthalpy Calorimetric	Entering indoor: 27 (DB)/19 (WB) Entering outdoor: 35 (DB)	Defrost	5
Korea	KSC 9306 2017	CSPF, EER (Cooling) HSPF, COP (Heating)	Air Enthalpy Calorimetric	Entering indoor: 27 (DB)/19 (WB) Entering outdoor: 35 (DB)	Defrost	3
US	10 CFR 430 Subpart B Appendix M/Appendix M1	EER, SEER (Cooling) HSPF (Heating) SEER2 (Cooling) HSPF2 (Heating)	Air Enthalpy	Test A: Entering indoor: 26.7(DB)/ 19.4 (WB), Entering outdoor: 35 (DB) Test B: Entering indoor: 27 (DB)/19 (WB) Entering outdoor: 28 (DB)	Defrost, Crankcase heater, off power	5
Canada (For reference only)	CSA EXP07	SCOP, ICOP (Heating and Cooling)	Air Enthalpy Calorimetric	Entering indoor: 27C (DB)/19C (WB) Entering outdoor: 35C DB	Defrost, Crankcase heater, Standby, Off Power	5
ISO	ISO 5151	EER	Air Enthalpy Calorimetric	Entering Indoor: 27 (DB) / 19 (WB) Entering Outdoor: 35 (DB)	Defrost	3

3.1 Test Type and Relative Test Burden

There are two main methods to test AC Units: the calorimeter room method and the indoor air enthalpy (or psychrometric) method.

1. The calorimeter room method measures the energy input to a room that is being temperature controlled with an AC unit. The energy used to maintain the air temperature at a constant value is equivalent to the cooling capacity.

2. The indoor air enthalpy method measures the air enthalpy as it enters and exits the AC's indoor unit. The change in enthalpy multiplied by the flow rate of air equals the cooling capacity of the unit.

A 2011 Report on Air Conditioners identified advantages and disadvantages to these two measurement methods. The calorimeter room method is very accurate and has a low risk of error but is more expensive and takes longer to conduct. The converse is true for the indoor air enthalpy method: it is cheaper and quicker to conduct but not as accurate (Pierrot and Conde 2011). A detailed estimate of relative test burden by test type and number of test points is discussed below.

3.1.1 Relative Test Burden

The test burden associated with performing each of the tests included in the scope of this report is directly related to the number of hours required to perform the test. With the test procedure differences mentioned in Section 3.1, a relative comparison of the burden of each test procedure is summarized in Table 3.

Table 3: Relative Test Burden by Test Method

Country	Test Method	# of Test Points	Calorimetric Duration (hrs)	Relative Cost	Psychometric Duration (hrs)	Relative Cost
Australia/ New Zealand	AU/NZS 3823.4.1:2014	2	14	1.16	12	1.0
China	GB/T 7725-2004	2	14	1.16	12	1.0
EU	BS EN 14511:2018	2	14	1.16	12	1.0
Japan	JIS B 8615-1:2013 JIS B 9612:2013	5*	23	1.92	18	1.5
Korea	KSC 9306 2017	2	14	1.16	12	1.0
US	10 CFR 430 Subpart B Appendix M/Appendix M1	5	N/A	N/A	18	1.5

* Comprising 3 points for cooling and 2 points for heating.

In general, calorimetric tests take longer to perform than psychometric / indoor air enthalpy tests, but burden is also determined by the number of test points required to be measured.

3.2 Test Temperatures

The research team has identified test temperatures required for the full load test and has also identified outdoor air temperatures and weighted average outdoor air temperatures used to measure part load performance and calculate seasonal efficiency metrics, respectively.

3.2.1 Full Load Test Conditions

As shown in Table 2 above, all countries studied are nearly aligned with ISO 5151 regarding full load test temperature. However, note that control of outdoor air wet bulb temperature is not required for the equipment covered in the scope of this report. Outdoor wet bulb temperatures are prescribed by the ISO standard, but these only apply to the testing of air-cooled condensers which evaporate the condensate. The effect of uncontrolled outdoor wet bulb temperature on cooling efficiency is not well defined and presents a source of uncertainty in both full-load and seasonal cooling performance. This effect becomes even more uncertain in variable capacity units, as dehumidification capacity drops off quickly at part-load conditions.

3.2.2 Part Load Test Conditions

Seasonal efficiencies are calculated by testing efficiency at part-load and full-load capacity, and then using regional heating and cooling load hours to calculate a seasonal heating or cooling load. Since the part-load conditions and heating and cooling load hours are defined independently for each country, there is more variability in both the test conditions and the equipment response than for a full-load efficiency metric calculation. Tables 4 and 5 summarize the differences in test conditions and weighted average seasonal outdoor temperature used to calculate seasonal energy efficiency metrics for each country reviewed in this study.

Table 4: SEER Cooling Test Condition Summary

Country	Single Speed Test Points*	Variable Capacity Test Point*	Cooling Outdoor Test Temperatures (Dry Bulb)	SEER Hourly Temperature Range (°C)	SEER Weighted Average Outdoor Temperature (°C)
Australia/ New Zealand	2	2	29 °C, 35 °C	21 - 35	28.1
China	1	2	21°C**, 35 °C	24 – 37	27.7
EU	4	4	27°C, 35°C	17 – 39	23.0
Japan	2	2	29 °C, 35 °C	24 – 35	27.8
Korea	3	4	29 °C, 35 °C	24 – 37	27.1
US	2	5	19.4°C, 27.8 °C, 30.6 °C, 35 °C	19.4 – 38.9	29.3

* Test points reported represent the minimum allowable. Some countries allow additional optional test points that are not reported in this table.

** Or as recommended by manufacturer for minimum cooling operation condition.

Table 5: SCOP Heating Test Condition Summary

Country	Heating Outdoor Test Temperatures (Dry Bulb)	SCOP Hourly Temperature Range (°C)	SCOP Weighted Average Outdoor Temperature (°C, Tj)
Australia/ New Zealand	-7 °C, 2 °C, 7 °C	N/A	N/A
China	N/A	N/A	N/A
EU	-7 °C, 2 °C, 7 °C	-10 to 15	5.1
Japan	-7 °C*, 2 °C, 7 °C	0 to 16	9.2
Korea	-7 °C, 2 °C, 7 °C	-15 to 15	N/A
US**	-8.3 °C, 1.7°C, 8.3 °C	-16.7 to 11.1	-2.7

* -7⁰C is an optional test

** US HSPF calculation includes 6 different climate zone conditions. Climate zone III is shown in this table, which represents a mid-range heating load per Table 20 in CFR 430, Subpart B Appendix M1.

Note that all countries already include a 35°C test condition to define full load capacity. It is also interesting that while there are many test conditions are used for determining minimum cooling capacity efficiency, three of the countries calculate seasonal performance at temperatures that fall outside of the test temperature range. This approach requires extrapolation of cooling performance, rather than interpolation, which could lead to less accurate seasonal efficiency ratings.

3.3 Variable Capacity Testing

In all the established test procedures reviewed, variable capacity units are currently tested at fixed compressor speeds. This creates an issue because variable capacity units do not inherently operate this way in the field. When installed, the speed of the compressor increases/decreases dynamically to condition the space. To test these units in a fixed-speed mode (in accordance with the current test requirements), a lab/testing body must contact the manufacturer to upload specific software or connect specific equipment to force the unit into a testing mode. This leads to test results that are not representative of the field performance of variable capacity equipment, as the inherent dynamic compressor performance in response to variable loads is not captured. Specifically, variable speed compressors do not quickly find a steady state operation, but continuously modulate in response to changing space conditions. In a 2019 study on dynamic testing, results showed that variable speed units operating at low part load ratios had a lower coefficient of performance when allowed to modulate in response to room conditions as compared to operation with a fixed compressor speed, with the largest variation at over 50% at the lowest part load ratios. Initial studies indicate that units tested using this method demonstrate lower heating and cooling output capacity, thereby reducing rated energy efficiency levels (Palkowski, et al. 2019).

In addition, the necessity of manufacturer intervention when testing these units opens up the procedure to interference by allowing changes to be made to the unit that are not present when operating in the field. There is speculation that a manufacturer could bypass certain features that would decrease the efficiency of the unit. It is also not always possible for a testing facility to control a variable speed compressor to a fixed speed. None of the updates made to the test procedures listed above mitigate this issue.

To address these issues, both Canada and the EU are working to establish dynamic load-based test procedures for room air conditioners and heat pumps. These proposed test methods (CSA EXP07 and EN 14825) use an adaptation of the psychrometric approach to introduce sensible and latent heat loads to the indoor room and test the unit's control scheme for managing space temperature. The goal of developing these test procedures is to more closely reflect the operation of a unit in the field, which would better characterize unit operation at lower temperatures, better represent the efficiency gains associated with variable speed equipment and eliminate the ability to override controls.

These test procedures are in the process of being developed, and it is yet to be determined whether the increased testing burden associated with longer tests is offset by an increase in the accuracy of a unit's rating. In addition, some have raised concerns that the inherently dynamic nature of such test approaches may make them difficult to reproduce. Both of these concerns come from subjectivity of what constitutes steady-state operation in these dynamic load tests.

3.4 Secondary Energy Usage

Some of the test procedures established by these countries/organizations incorporate secondary energy measurements that are not directly tied to the energy consumption used to condition the space. All the governing bodies incorporate defrost cycle measurement into the testing. The EU and Australian test procedures measure the power consumed in off mode and standby mode (although Australia calls them Disconnected Mode and Inactive Mode). The US calculates the off-mode power consumption as well. The other jurisdictions do not include these power measurements.

While not included in the scope of this report, CSA EXP07 includes a completely separate term for non-space conditioning power, P_{CNA},

$$P_{CNA} = (H_{1c} * P_1 + H_{2C} * P_2 + H_{3C} * P_3) * \frac{3.412}{N}$$

where

P_1	=	Off Mode Power
P_2	=	Crankcase heater mode Power
P_3	=	Standby Mode Power

Establishing a separate term clearly identifies what aspects of unit operation (if any) are increasing power consumption. The research team was unable to find test data available to quantify the impact of various secondary energy use functions. Various testing resources noted that defrost energy can be significant, but this is also measured in most test procedures. The team was also told that crankcase heat is the largest consumer of off-mode power, and that this had a greater impact on AC units than heat pumps due to the fact that crankcase heat runs when the unit is off and heat pumps are typically operating at cold outside temperatures.

3.5 Recent Updates to Test Procedures

Since the last major review of Air Conditioner Test Procedures in 2011, Australia/New Zealand, Japan, the US, and the EU have published updates to their test procedures. Almost all the changes made to these test procedures do not impact the results of the test. For most updates, the changes either decrease the test burden or increase the reproducibility of the test procedure and are not expected to have an impact on the energy consumption reported. This section presents the changes made to each test procedure updated since 2011. No changes were made to the Chinese test procedure, so China is not covered in this section. Canada is also not covered due to not being specifically included in the scope of this investigation.

3.5.1 Australia/New Zealand

Although there have been many detailed changes to ISO 5151:2010 compared with ISO 5151:1994, many of these changes were anticipated in AS/NZS 3823.1.1:1998, Appendix ZZ, so there are few net technical changes in the new edition. The most significant changes are in the more detailed test procedures for cyclic heating tests to improve the reproducibility of testing, the addition of equations for calculating the discharge coefficient of nozzles, and the introduction of uncertainty of measurement requirements.

Australia also published *AU/NZS 3823.4.1:2014: Performance of electrical appliances—Air conditioners and heat pumps Part 4: Air-cooled air conditioners and air-to-air heat pumps—Testing and calculating methods for seasonal performance factors* 2014, which was new at that time. It has not been updated since.

3.5.2 European Union

In 2018 the EU adopted an updated version of BS 14511 that replaced the version previously required by the EU (2007). The new version of this standard covers the same scope of products as the old test procedure, except the 2018 version increases the scope to also allow for the testing of units using trans-critical cycles (e.g., units that use CO_2 as a refrigerant).

There were several methodological changes made in the new test procedure. Most of them increased specificity of the test procedure, reduced the ability for “gaming”, and reduced the test burden. The EU Standard did change the equation used in the Calorimeter Room method for calculating total cooling capacity; there was the addition of a term, heat removed from the indoor-side compartment, to the 2018 test procedure that compensates for heat leakage and allows smaller units (e.g., units that would not be able to overcome room enthalpy leakage) to be tested.

3.5.3 Japan

Japan’s test procedures, JIS B 8615 and JIS B 9612 (test method for non-ducted ACs/heat pumps and Room Air Conditioners, respectively) were updated in 2013 (from their 2005 edition). The new test procedure adopts ISO 5151:2010 as the testing procedure.

3.5.4 Korea

Korea’s current adopted test procedure is KS C 9306. While the research team was able to verify that Korea adopted a revision to this test method in 2017, the team was unable to establish specific changes due to not having an available translated copy of the prior version of the test method.

3.5.5 United States

The US updated the test procedure used for testing residential ACs and heat pumps in 2017. The US DOE published a final rule that updated the current test procedure for residential ACs and heat pumps (which is listed in the US Code of Federal Regulation 10 CFR 430 Subpart B Appendix M) and established a new test procedure, 10 CFR 430 Subpart B Appendix M1. The test procedure listed in Appendix M is currently used to determine the efficiency metrics used in the US Standard. In 2023 manufacturers will be required to meet standards that are based on metrics calculated in Appendix M1.

The changes to Appendix M test procedure include:

- Measurement of off mode power consumption
- Establishes a limit on the internal volume of the lines and devices connected to measure the pressure of the refrigerant circuit
- The method for calculating EER and COP for variable speed units was changed from a quadratic function to interpolation.
- The test burden for the outdoor air enthalpy method has been reduced from two 30-minute tests (one preliminary and one official) to one 30-minute test.
- Certification of fan delay for coil only units.
- Modifying the test procedure for variable speed heat pumps to incorporate testing at different speeds.
- Removing the 5% tolerance for part load operation when comparing the sum of nominal capacities of the indoor units and the intended system part load capacity for VRF multi-split units

These changes do not affect the measured energy consumption and only serve to improve the repeatability and accuracy of the test.

The changes to Appendix M1 include:

- Established minimum external static pressure values for different varieties of AC/heat pumps (variety referring to the type of mounting or system specific information).
- Established two separate default fan power values for coil only units: one for mobile home units and one for all other units.
- Updated the slope values used in the heating load line equation used in Appendix M1. These values are different for the calculation of HSPF2.
- Adopted an optional test to be run with the compressor at full speed at 5 degrees F to allow for interpolation of full speed operation between 5 degrees F (-15°C) and 17 degrees F (-8.3°C) instead of extrapolation.
- Established a delay time before the measurement of off mode power for systems that require the crankcase heating system to reach thermal equilibrium. For units without a compressor sound blanket, the delay time is 4 hours, and for units with a sound blanket, the delay time is 8 hours (units with sound blankets inherently need more time to come to thermal equilibrium).

These changes do have an impact on the reported energy consumption values in the US and were made to make the reported SEER2 and HSPF2 values more representative of the field performance of covered equipment.

4. Measuring Energy Efficiency

This portion of the report examines energy efficiency metrics in different economies and how the test methods identified in the previous sections impact the rated energy efficiency.

Each country reviewed as part of this study has a national energy efficiency program and corresponding standards and labeling (S&L) program. Economies vary in the metric chosen to define minimum efficiency performance standards (MEPS). Energy efficiency S&L programs, along with corresponding efficiency metrics are shown in Table 6. Section 4.1 explains the various metrics and defines acronyms and Section 4.2 describes the requirements in each country in more detail. Section 4.3 discusses past research into comparison and conversion factors of full load and seasonal efficiency metrics between countries. Section 4.4 discusses benefits and drawbacks of using full load and part load efficiency metrics to rate variable capacity equipment.

Table 6: National Energy Efficiency Programs – AC Units

Country	Implementing Organization	Energy Efficiency S&L Program	Energy Efficiency Metric	Efficiency Program Focus
Australia	Department of Environment and Energy	Equipment Energy Efficiency (E3) Program	SEER (Cooling) SCOP (Heating)	Reduce energy bills and greenhouse gas emissions
China	Administration of Quality Supervision, Inspection, and Quarantine	China Energy Label	EER (full load cooling) SEER (seasonal cooling) HSPF (seasonal heating)	Encourage customers to buy efficient products
EU	European Commission	Ecodesign / Energy Label	SEER (Cooling) SCOP (Heating)	Improving efficiency through informed customer choice
Japan	Ministry of Economy Trade and Industry (METI)	Top Runner Programme	APF (Combined cooling and heating) CSPF (Cooling) HSPF (Heating)	Sets weighted average efficiency targets for manufacturers
Korea	Korea Energy Agency	Energy Efficiency Standards and Labeling Program High-Efficiency Appliance Cert Program E-Standby Program	EER (Cooling) CSPF (Seasonal Cooling) HSPF (Seasonal Heating)	Uses both comparative and endorsement efficiency labels. Addresses standby power use

Country	Implementing Organization	Energy Efficiency S&L Program	Energy Efficiency Metric	Efficiency Program Focus
US	Department of Energy	Appliance Equipment Standards Program / Energy Star	EER (full load) SEER (Seasonal Cooling) HSPF (Seasonal Heating)	Implement and oversee MEPS; provide consumer resources and information

Source: https://clasp.ngo/economies

4.1 Energy Efficiency Metrics Overview

There are currently two main types of energy efficiency metrics used internationally to rate the energy efficiency of AC Units: full-load efficiencies (EER and COP) and seasonal efficiencies (SEER and SCOP, among others). Full-load ratings are used to assess performance at the highest rated compressor operating speed. Seasonal efficiency ratings aim to assess equipment efficiency over a range of operating conditions to represent the weighted average unit efficiency over a whole heating or cooling season. Seasonal efficiency ratings are a better measure of part-load performance and are increasingly being developed and applied in place of EER ratings to set MEPS and labeling requirements.

4.1.1 Full Load Efficiency Metrics: EER and COP

EER is the most established and most widely used efficiency metric for ACs. It is the ratio of the cooling capacity to the electricity consumption when measured at the maximum deliverable cooling capacity of the AC. This is determined in all countries studied for a single representative outdoor air temperature test condition (35°C dry bulb, 24°C wet bulb), as defined in ISO 5151, except the US.

The COP is the equivalent full load efficiency metric for AC units operating in the reverse cycle or heating mode.

4.1.2 Seasonal Efficiency Metrics

The EER metric only measures the efficiency of the unit at a sole designated design point, which is the maximum cooling capacity the device can deliver when measured under a single set of standardized temperature conditions. ACs typically only operate at full capacity for a small part of the cooling season and will run at part load the rest of the time (when not in the off mode). Thus, using energy efficiency metrics based on a single full-capacity design point ignores part-load performance and is not representative of real seasonal energy performance. In addition, performance metrics based solely on full-load conditions tend to encourage manufacturers to optimize full-load performance at the expense of part-load performance. Seasonal efficiency metrics have been created to provide an energy efficiency measure which is closer to the real energy efficiency performance of AC units throughout the cooling and heating seasons.

Seasonal efficiency metrics include the impact of variations in the outdoor air temperature in the cooling and heating load. These metrics typically require multiple test points to compute a seasonally weighted average efficiency and are intended to give results that represent how the AC unit would perform over a typical cooling season. For variable capacity units, seasonal efficiency includes operation at part load conditions. For single speed units, seasonal efficiency calculations assume that the unit cycles on and off to meet part load conditions.

Five economies have adopted specific seasonal energy performance test standards for ACs. The US was the first to develop a seasonal efficiency standard, followed by Korea and more recently Japan, China, and the EU.

Note that seasonal efficiency metrics vary by name in each country. While seasonal efficiency metrics more completely demonstrate part-load and seasonal efficiencies, the rating conditions are set by each country, with some adopting multiple sets of rating conditions for various climate zones within the country. This results in seasonal efficiency metric ratings that are not comparable between regions, even when they are called by the same name.

A definition of each seasonal efficiency metric included in this study can be found below.

4.1.1.1 Cooling Seasonal Performance Factor (CSPF)

CSPF is a seasonal performance metric, which is calculated by dividing the summed cooling capacity by the total power consumption over the entire annual cooling season.

4.1.1.2 Annual Performance Factor (APF)

In the residential sector, Japan uses an energy efficiency metric called the APF, which is an average of CSPF and HSPF. The APF, like SEER and EER, is a ratio of the total energy output over the total energy input, but accounts for both heating and cooling operation in one metric. APF is calculated as the average of the heating season and cooling season performance:

$$APF = \frac{(CSTL + HSTL)}{(CSTE + HSTE)}$$

Where

CSTL = Cooling Seasonal Total Load

HSTL = Heating Seasonal Total Load

CSTE = Cooling Seasonal Total Energy Consumption

HSTE = Heating Seasonal Total Energy Consumption

4.1.1.3 Cooling Energy Consumption Efficiency (CEER)

The Korean full load energy efficiency metric is the Standard Cooling Energy Consumption Efficiency, or CEER. The CEER is calculated by dividing total rated capacity in Watts by rated cooling power consumption in Watts. Heating Seasonal Performance Factor (HSPF)

HSPF is used to rate the seasonal heating efficiency of reverse cycle ACs (or heat pumps) and is determined by measuring electricity consumption at defined testing points and calculating the ratio of heating energy delivered to electric energy consumption. This metric is used to rate seasonal heating performance in four of the six countries included in this study.

4.1.1.4 Seasonal Coefficient of Performance (SCOP)

Seasonal Coefficient of Performance is used to calculate heating efficiency of reverse cycle ACs (or heat pumps) and is determined by measuring electricity consumption at defined testing points and calculating the ratio of heating energy delivered to electric energy consumption. This metric is used in the EU and Australia/New Zealand.

4.2 Energy Efficiency Metrics by Country

The following section examines the energy efficiency metric used by each country and how each metric is calculated. While many countries define multiple efficiency metrics, those used to establish minimum efficiency performance standards (MEPS) are listed in Table 7.

Energy Efficiency Metrics

Australia:	EER / SEER / SCOP
China:	EER / SEER
EU:	SEER / SCOP
Japan:	APF
Korea:	EER / CSPF / HSPF
US:	SEER / HSPF

4.2.1 Australia

Australia uses the fully load efficiency rating, EER, to establish MEPS levels. In 2019 Australia began transitioning to using SEER for energy efficiency labelling and is the only S&L initiative studied that includes reduction of greenhouse gases as an established program focus. SEER ratings in Australia also have the option to provide ratings for different climate zones, with equipment SEER ratings for cold, hot and mixed temperature zones. Temperature data for each climate zones varies based on historical data.

Due to the relatively new status of the SEER rating program, not all equipment is rated under the SEER standard. There is very little public data available regarding SEER performance of AC units in Australian product listing.

4.2.2 China

China has separate labeling requirements for single speed and variable capacity AC units, using the metrics of EER and SEER, respectively. SEER ratings were added for rating of variable speed compressor air conditioner products in 2010.

4.2.3 European Union

The EU uses the SEER and SCOP energy efficiency metrics (for cooling and heating, respectively) for rating air conditioner and heat pump efficiency and for establishing minimum efficiency performance standards. The EU also includes multiple temperature distributions for rating SEER in hot or cold dominant climate.

4.2.4 Japan

Japan uses an energy efficiency metric called the annual performance factor, or APF, which accounts for both heating and cooling performance in one metric. Interestingly, the Japanese standard includes both single speed and variable speed compressors but does not include two-speed or two-stage compressor units, as these are not available in the Japanese market.

From a standards and labeling standpoint, it is noteworthy that Japan is the only country studied that sets weighted average efficiency targets for manufacturers, rather than minimum efficiency performance standards. Because of this, there is no minimum level of acceptable efficiency for ACs in Japan, but efficiency targets across a manufacturer’s entire product line (CLASP 2018).

4.2.5 Korea

In Korea, mandatory MEPS regulations ban the production and sale of low energy efficiency products that fall below MEPS. Energy labeling is comparative and based on a one to five scale. In addition, Korea is the only country that has a labeling program specifically targeted at standby power consumption.

Seasonal period performance is rated using CSPF and HSPF metrics, which rate performance over a whole cooling or heating period. Full load heating and cooling efficiencies are rated using HCOP and CEER metrics, respectively.

4.2.6 United States

ACs and heat pumps are rated for SEER and HSPF metrics (for cooling and heating, respectively). The US also has a voluntary program, ENERGY STAR, aimed at identifying the most efficient equipment in each category. Since increasing SEER minimum thresholds is not a guarantee of improved peak power performance as it is mostly achieved via the use of inverters, the US ENERGY STAR optional efficiency program also requires a minimum EER for central ACs.

4.2.7 Current International Metrics and Levels

Current minimum efficiencies for cooling metrics (annual performance in the case of Japan) are shown in Table 7. Note, these metrics are not normalized, and are therefore not comparable between different countries.

Table 7: Current minimum efficiency (MEPS) levels

Country	Efficiency Metric	MEPS	Equipment Capacity
Australia/New Zealand	EER/AEER	3.66	<4 kW
China	SEER	4.30	<4.5 kW
EU (GWP>150)	SEER	4.60	<6 kW
EU (GWP<150)	SEER	4.14	<6 kW
Japan	APF	5.50	4-5 kW
Korea	EER	3.50	<4 kW
US	SEER	3.81	<19 kW

4.3 Energy Efficiency Metric Conversions

Previous work under a broad Room Air Conditioner benchmarking study in 2011 sought to create conversions between EER and seasonal energy efficiency metrics across international economies. As discussed in more detail below, EER values are fairly straight-forward and comparable among the countries studied. However, the more variable SEER values are more difficult to compare directly due, primarily, to the use of different test temperatures and inclusion of different energy consumption features for the different metrics.

4.3.1 EER Comparison

Test conditions for determination of EER were noted in Section 4.1.1 to be well-aligned internationally, with the US being the only country studied that did not completely align. The US uses a slight variation to indoor wet bulb temperature. This variation was shown in a previous study by Henderson (2001) to result in a 2.4% reduction when compared to EER calculated at ISO 5151 standard test conditions for central ACs using R-22 refrigerant. Subsequent research has shown that independent testing of split-packaged AC units using R-410A refrigerant produced consistent results to the established study (Pierrot and Conde 2011).

4.3.2 Seasonal Efficiency Metric Temperature Comparison

Comparison and conversion of seasonal efficiency metrics across international economies is less straightforward. This is due to several factors:

- Variation in regional temperature test conditions
- Inclusion of different variables in the calculation (i.e., fans, standby, etc.)
- Variable degradation coefficient in some economies

The primary factor affecting comparison of seasonal efficiency metrics in different economies is the variation in test temperatures, which is discussed in more detail in Section 4.1.2. The inclusion of different energy consumption variables has a smaller effect. However, despite these potentially significant differences in test temperatures, previous research performed as part of the 2011 CLASP benchmarking study has shown that normalized seasonal efficiencies match well with top performing equipment in Japan, China, and the US (Waide, Riviere and Watson 2011).

The 2011 CLASP study applied data from a 2010 study on Japanese variable speed non-ducted split system ACs supplied to the European market. The data consisted of the five test points required to compute CSPF, HSPF, and APF, and was used to characterize seasonal efficiency ratings for system products for each of the countries studied. However, the benchmarking study notes that the available data allowed for direct computation of Chinese SEER, Korean CSPF, and Japanese CSPF values. Computing the US and EU SEERs required assumptions because the available data did not provide enough information to directly compute the metrics. A summary table of the resulting APF conversion factors is shown in Table 8. Conversion factors were developed to and from each seasonal metric; only the conversion to APF is presented here, for brevity, and because it relates to the conversions shown in Table 9 below.

Note that the conversion table can be used to normalize one seasonal metric to another, using the formula $Y = C_{te} + Slope * X$.

Table 8: Seasonal Efficiency Metric Final Conversion Factors to APF

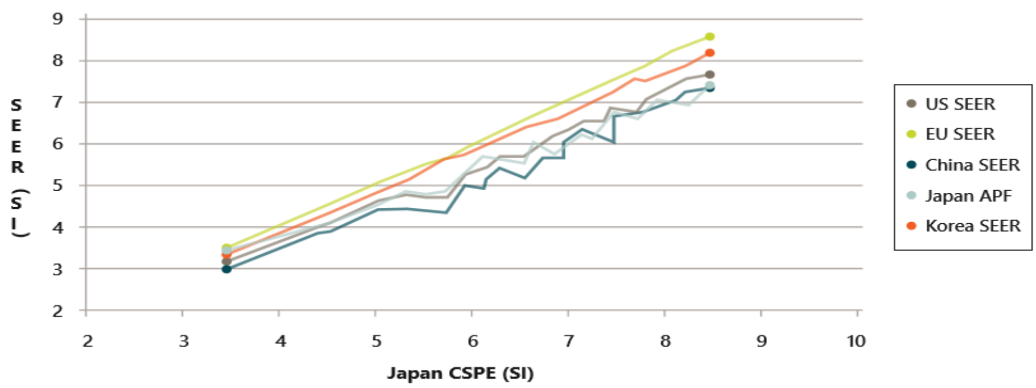
Y	X	Slope	C_{te}	R2	Std dev
Japan APF	US SEER	0.865	0.733	0.952	0.191
Japan APF	EU SEER	0.793	0.556	0.942	0.211
Japan APF	China SEER	0.861	0.987	0.949	0.197
Japan APF	Korea SEER	0.822	0.466	0.912	0.259

Source: (Baillargeon, et al. 2011)

Some simplifications were assumed in the development of the above conversion factors, which required additional calibration of the US and EU conversions. In the case of the US SEER ratings, a constant coefficient degradation of 0.1 was assumed, which is in line with typical reported levels. In addition, standby power and crankcase heater energy were not modeled, which means the EU SEER results only apply to the “on” condition and do not reflect the EU SEER as a whole.

Specifically, the study demonstrated that, while seasonal efficiency metrics differ across international economies, top-performing variable capacity AC equipment had efficiency levels that were well-correlated and within two units of one another when a conversion algorithm was applied to correct for regional differences. This comparison of top-performing seasonal metrics has been recreated below in Figure 10.

Figure 10: Re-creation of findings from comparison of normalized seasonal metrics



Source: (Waide, Riviere and Watson 2011)

This means that the specific test conditions used to measure the compressor performance may not have as large an effect on the computed seasonal efficiency as the theoretical temperature bins and weights used to compute the weighted average seasonal efficiency value. In addition, the study demonstrated that the various seasonal efficiency metrics maintain the ranking of more efficient equipment, which is an important attribute of a robust test procedure and metric, while the variation in absolute seasonal efficiency values may be necessary to capture regional climate-related performance differences.

4.3.3 Current MEPS with Normalization

Drawing from the MEPS in Table 7 above and applying the seasonal efficiency normalization calculations from the 2011 Benchmarking study, we can compare minimum efficiency levels internationally. Table 9 includes a normalization of each country's MEPS to the Japanese APF. Note that this comparison is only available for the countries that were included in the benchmarking study, so Australia/New Zealand and the US SEER2 metric are not included.

Table 9: Normalized Minimum Efficiencies

Country	Metric	MEPS	Equipment Capacity	Normalized to Japan APF
Australia/New Zealand	EER/AEER	3.66	<4 kW	N/A
China	SEER	4.30	<4.5 kW	4.69
EU (GWP>150)	SEER	4.60	<6 kW	4.20
EU (GWP<150)	SEER	4.14	<6 kW	3.84
Japan	APF	5.50	4-5 kW	5.50
Korea	EER	3.50	<4 kW	N/A
US	SEER	3.81	<19 kW	4.28
US	SEER2	3.93	<13 kW	N/A

Once normalized, we can see that Japan has the highest MEPS among the countries studied both in the 2011 benchmarking exercise and this study.

4.4 Representativeness of Energy Efficiency Metrics

As shown in sections 4.1 and 4.2 above, there are several different names for energy efficiency metrics, and each country uses a different test procedure and metric for representing seasonal energy efficiency of AC units. Previous research has shown that it is possible to normalize the seasonal efficiency metrics between countries. In addition to being able to compare metrics across countries, it is also important to compare how representative metrics are to actual field operation of these units.

The EER efficiency metric represents AC efficiency at full load, or 100% operation. However, peak cooling load conditions typically occur for less than 5% of annual AC operating hours. While this full load efficiency is an important consideration, a metric offering a broader view of efficiency over an entire heating or cooling season is more characteristic of actual performance.

The seasonal efficiency metrics aim to provide a more representative calculation of seasonal performance, taking efficiency at several part-load conditions into account. Seasonal efficiency calculations differ both by country and by compressor type, but all account for performance at multiple non-peak cooling load points.

As noted above, the current accepted test procedure for part load testing requires that the AC compressor speed be fixed at a given load condition in order to achieve steady state operation. This approach can be problematic, as the compressor speed varies by manufacturer and requires manufacturer input for test facilities to determine. Recent studies also indicate that compressor performance in fixed speed operation does not accurately represent how the compressor will operate in an everyday, non-laboratory situation (Palkowski, et al. 2019). A high-level comparison of current test methods and proposed dynamic load test methods is shown below in Table 10.

Table 10: Comparison of Current Test Methods and Dynamic Load Testing

Test Component	Current Test Methods	Proposed Dynamic Load Tests
Unit operation	Represents part load capacity using fixed speed operation	Allows compressor to respond to part load conditions in a variable manner
Test Temperature	Test conducted at discrete temperatures with performance interpolated between test points	Test conducted over a continuous range, with steady state performance measured at certain temperatures
Unit controls	Control requires manufacturer input to fix compressor speeds for testing of variable capacity units	Control by traditional means. Allows variable capacity unit to run as it would in field installation

One challenge in calculating seasonal efficiency metrics is how the degradation coefficient is applied. The degradation coefficient is the measure of efficiency loss due to equipment cycling. Some countries calculate seasonal efficiency assuming a fixed degradation coefficient (typically 0.25), while other countries allow equipment manufacturers to calculate a lower degradation coefficient by testing at additional operating points. While calculated degradation coefficients are more accurate and lead to more efficient seasonal efficiency metrics, the fact that not all countries apply them in the same manner introduces uncertainty and variability to seasonal efficiency ratings on an international scale. Standardization of degradation coefficient treatment in seasonal efficiency calculations would facilitate the harmonization of efficiency metrics.

Another challenge in measuring seasonal performance is factoring in dehumidification capacity. As noted in Section 3.2, the effect of uncontrolled outdoor air humidity levels on cooling efficiency is not well-defined. Quantifying dehumidification capacity is not possible when outdoor air humidity levels are not controlled in testing. In addition, variable capacity units quickly lose dehumidification capability as the load (and compressor speed) decreases. Control of outdoor air wet bulb temperature and measurement of latent cooling capacity are both potential avenues for improvement and harmonization, although setting required sensible heat ratios for testing has proven difficult.

The research team concludes that seasonal metrics are better at characterizing regional energy performance than full load metrics, but that there are still limitations to measuring seasonal metrics in variable capacity equipment. Limitations include how the degradation coefficient is calculated, the variation in dehumidification capacity, and fixed speed operation during testing.

The research team recommends measuring the degradation coefficient rather than assuming a fixed value as a best practice, though this may incur greater test burden in some countries due to more test points required. The team recommends requiring a minimum level sensible heat ratio during part load operation, though establishing these levels may be regionally specific based on local humidity levels. The team also recognizes that the traditional part load test at fixed compressor speeds is not representative of real-world operation for variable capacity equipment. While alternative test methods are being developed, the team believes the repeatability of these new dynamic load tests should be further investigated for repeatability between labs, possibly in a round robin testing arrangement.

5. Improvement and Harmonization

Test procedures are important in the evaluation of AC performance, and as we have seen they can vary between countries. This section discusses areas that test procedures can be harmonized and opportunities for future improvement.

5.1 Harmonization

Efforts to harmonize test procedures across economies, where practical, may yield several benefits. These benefits include being able to compare consistently across geographies, reduce test discrepancies, and independently corroborate results. In our review, we found several opportunities to further harmonization now and in the future, including test temperature conditions, test unit installation, efficiency metric calculation method, and standardized nomenclature.

5.1.1 Harmonization of Test Conditions

As shown in Tables 2, 4 and 5, there are different test temperatures that apply to full load versus seasonal energy efficiency metrics. There are also multiple temperatures used in testing and calculating seasonal efficiency performance. These temperatures impact efficiency metrics in different ways.

5.1.1.1 Full Load Capacity Testing

Test procedures for determining the full load efficiency (EER) of AC units are generally well-aligned across the countries studied in this report: each rates EER based on the T1 test condition defined in the international test standard ISO 5151. Furthermore, test methods and test temperature conditions are close enough to consider the EER ratings of different countries close to directly comparable. While the difference in temperature test conditions (of both the indoor and outdoor unit) are small, they do impact testing results. The control of the outdoor temperature humidity also impacts the operation. Standardizing on the ISO 5151 full load test temperature condition would improve comparability.

5.1.1.2 Seasonal Efficiency Metrics

There are two different types of temperatures that pertain to measuring and calculating seasonal efficiency metrics. One is the temperatures of the actual test procedure; the other is the seasonally representative weighted average temperature required to calculate the seasonal efficiency metric. These are both important in the evaluation of seasonal efficiency performance but impact the calculated metric in different ways.

Seasonal efficiency metrics are regionally specific. There is data that suggests that the specific test conditions may not have a significant impact on seasonal efficiency rating results, and that regionally identified heating and cooling temperature or load hours have a more significant impact on the final seasonal efficiency metric rating. This differentiation in heating and cooling temperatures and hours is important for countries and regions to be able to establish seasonal efficiency values that are representative of the performance of equipment in their particular climate and geography. As such, the team does not recommend standardization of climate-dependent seasonal efficiency metric calculations. Instead, we recommend standardizing the number and reporting of performance at different test temperatures, as well as interim energy variables (e.g., standby energy use), which would allow for easier and more transparent translation of one seasonal efficiency metric to another between various climates and economies. In addition, guidance on calculating season efficiency metrics based on region or climate zone for countries that do not have their own established test procedures would also advance international harmonization efforts.

The number of test points required to establish seasonal efficiency ratings also varies by country. Previous work in developing correlations between seasonal efficiency ratings among major countries has demonstrated the importance of the availability of standard data for the international comparison of these metrics. The research team recommends international standardization of a maximum and minimum capacity test temperature condition, with optional additional testing at interim test points. Most countries have already established 35°C as the maximum capacity test temperature, in line with ISO 5151 requirements. Based on current test standards and regional hourly temperature data, it appears that establishing a standard minimum capacity test temperature of 20°C would be representative of current test conditions. A 20°C low temperature test would eliminate extrapolation for seasonal efficiency calculation in 3 of the 6 countries studied (Australia/New Zealand, Japan, and Korea). While a 20°C low temperature condition would improve seasonal efficiency evaluation in the EU, extrapolation of performance would still be necessary at the lowest hourly temperature conditions. China and the US already have low temperature test conditions that do not require extrapolation of low temperature cooling performance, so would be minimally affected by this change.

5.1.2 Installation of the Unit

The length of refrigerant piping is not consistent between the countries. It varies from 5 meters to 7.5 meters, and the extra pressure drop in the piping could cause a change in EER of 1-3%. Alternatively, test methods could require verifying refrigerant charge prior to testing to alleviate the impact of varying piping length.

5.1.3 Calculation method

The method for calculating the energy efficiency metrics is fairly consistent, although there are several opportunities for greater harmonization.

First, standardizing which secondary energy uses are included in energy efficiency calculations would improve comparability across countries. These secondary energy uses impact efficiency and should be included in measured and calculated efficiency metrics.

Second, standardizing how the degradation coefficient is applied for variable capacity units would reduce variability in international energy efficiency metrics. Calculation of equipment-specific degradation coefficients would be the most accurate path forward but would also require additional test points in most countries.

Finally, standardization on the number to test points and reporting of performance at different test temperatures, in addition to the interim energy variables noted above (e.g., standby energy use), would allow for easier and more transparent translation of one seasonal efficiency metric to another between various climates and economies.

5.1.4 Equipment Naming Conventions

As established in this report, room air conditioners and associated metrics are referred to by many names across the globe, as well as in international test procedures. Establishing standard naming conventions would facilitate better understanding of the equipment under discussion, metric comparisons, and calculation methods.

5.2 Improvement of Realistic Assessment of Field Performance

Test procedures and associated energy efficiency metrics should accurately reflect how an AC unit will perform in a real-world installation. This section describes efforts to improve representativeness of AC test procedures, and also the associated limitations including the burden of transitioning to new testing and reporting requirements.

The 2011 Room Air Conditioner Benchmarking Study identified a key problem with testing variable capacity ACs in that the test lab requires input from the manufacturer. Often direct contact with the manufacturer is necessary to determine the correct operating mode. Currently, testing these units requires reliance on manufacturers providing accurate control set points for each load point along with a means to control the unit (e.g., a laptop or specific control sequence).

There are efforts to move to dynamic load testing for variable capacity air conditioners. Canada recently adopted CSA EXP07, which includes dynamic load testing for inverter driven air conditioners and heat pumps. There is also a current proposal to include dynamic testing in EN 14825, which is the European standard governing testing and rating of air conditioners and heat pumps at part load conditions. Dynamic load testing allows the units to operate in a manner closer to a field installation, thereby yielding efficiencies more representative of actual operation.

However, as mentioned previously, the reproducibility of these new dynamic tests is currently not well-characterized. In addition, these new proposed test methods may be more burdensome to conduct, will require time and resources to provision test facilities capable of performing the testing, and would nullify existing rating metrics and research knowledge of seasonal energy efficiency relationships. As this transition to new, dynamic load-based testing is likely to be long and burdensome, the research team recommends continued research on the benefits and repeatability of this test method. This will ensure that more accurately representing energy performance in an installed field condition does in fact offset the additional burden associated with transitioning to the new test approach.

6. Conclusions

Harmonization of AC test methods allows for international comparison and corroboration, both of equipment efficiencies and minimum energy performance levels. Ensuring that energy efficiency metrics accurately reflect real world use helps drive consumers to more efficient ACs. This study has provided a comparative review of AC test methods and efficiency rating metrics across six countries. The main findings of this review include:

1. **Globally, air conditioner test methods for non-ducted split system air conditioners are reasonably well aligned.** Recent progress has been made in several areas including: the greater adoption of seasonal efficiency metrics which aids end users in choosing efficient air conditioning equipment; the tightening and clarification of test procedures to prevent manufacturers from artificially inflating reported efficiencies; and the establishment of multiple climate zone distinctions for calculating seasonal energy efficiency metrics. Guidance on calculating season efficiency metrics based on region or climate zone for countries that do not have their own established test procedures would advance international harmonization efforts.

2. **The research team did identify several opportunities for harmonization of test procedures, including test temperature adjustments, standardized reporting, and nomenclature standardization.** Regional variations in temperature conditions required for testing and calculating seasonal efficiency metrics do affect calculated seasonal performance but are viewed as necessary to accurately represent usage in each climate. Standardizing on a low temperature test condition that allows for interpolation in calculating seasonal efficiency metrics (rather than extrapolation) would lead to more accurate results. Therefore, the research team recommends a standard low temperature test condition of 20°C. In addition, standardization on the number and reporting of performance at different test temperatures, as well as interim energy variables (e.g., standby energy use), would allow for easier and more transparent translation of one seasonal efficiency metric to another between various climates and economies. Measuring the degradation coefficient rather than using a constant value is a best practice but does require more test points. Guidance on calculating season efficiency metrics based on region or climate zone for countries that do not have their own established test procedures would also advance international harmonization efforts.

   Other opportunities for harmonization include standardizing installation procedures and nomenclature used in test procedures. Room air conditioners and associated metrics are referred to by many names across the globe, as well as in international test procedures. Establishing standard naming conventions would facilitate better understanding of the equipment under discussion, metric comparisons, and calculation methods.

3. **In addition to near term harmonization opportunities, there are opportunities to improve representativeness of test procedures in the future, especially for variable capacity equipment.** Testing of variable capacity ACs at part load conditions has proven to be problematic, from the perspective of both the test procedure and the accuracy of results. Current proposed changes to test methods for variable capacity units in some economies to introduce load-based testing may help alleviate testing issues requiring manufacturer input and control and improve the accuracy and representativeness of the results. However,

additional work is required to refine the proposed test methods to ensure the results are repeatable and benefits of the improved test procedure are effectively balanced with the additional burden associated with transitioning and implementing the new approach. Efforts to improve test procedures and transition to calorimetric testing should be balanced against existing harmonization efforts and infrastructure based on current testing approaches and product ratings. While alternative test methods are being developed, the repeatability of these new dynamic load tests should be further investigated for repeatability between labs, possibly in a round robin testing arrangement.

7. References

Appendix M to Subpart B of Part 430. n.d. "Uniform Test Method for Measuring the Energy Consumption of Central Air Conditioners and Heat Pumps."

Appendix M1 to Subpart B of Part 430. n.d. "Uniform Test Method for Measuring the Energy Consumption of Central Air Conditioners and Heat Pumps."

AS/NZ 3823.4.2:2014. n.d. "Performance of electrical appliances - Air conditioners and heat pumps."

AS/NZS 3823.1.1:2012. n.d. "Performance of electrical appliances - Air conditioners and heat pumps (Part 1.1)."

AS/NZS 3823.4.1:2014. n.d. "Performance of electircal appliances - Air conditioners and heat pumps (Part 4.1)."

Baillargeon, Pierre, Normand Michaud, Luc Tossou, and Paul Waide. 2011. *Cooling Benchmarking Study. Part 1: Mapping Coponent Report.* CLASP.

BS EN 14511-1:2018. n.d. "Air Conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors (Part 1)."

BS EN 14511-2:2018. n.d. "Air Conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors (Part 2)."

BS EN 14511-3:2018. n.d. "Air Conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors (Part 3)."

BS EN 14511-4:2018. n.d. "Air Conditioners, liquid chilling packages and heat pumps for space heating and cooling and process chillers, with electrically driven compressors (Part 4)."

2018. *CLASP.* Accessed 10 2019. https://clasp.ngo/.

Econoler, Navigant, CEIS and ACEEE. 2011. "Cooling Benchmarking Study Report."

GB T 7725-2004. n.d. "Room Air Conditioners."

Harley, Bruce. 2017. "CSA Heat Pump Test Procedure Update." *https://neep.org/sites/default/files/NEEPCSAHarley2017-06-28.pdf.* April 25. Accessed 2019. https://neep.org/sites/default/files/NEEPCSAHarley2017-06-28.pdf.

Horie, Hayato, and Eiji Hihara. 2012. "Study On Anuual Performance of Room Air Conditioners Under Partial Load Conditions." *International Refrigeration and Air Conditioning Conference.* Accessed 10 2019. http://docs.lib.purdue.edu/iracc/1336.

IEA. 2018. *The Future of Cooling; Opportunities for energy-efficiency air conditioning.* International Energy Agency.

ISO 5151:2017. n.d. "Non-ducted air conditioners and heat pumps - Testing and rating for performance."

JIS C 9312 2015. n.d. "Room Air Conditioners."

KS C 9306. 2017. "Air Conditioners."

Mavuri, Dr Satya Prasad. 2015. *Field Behaviour of Inverter Air Conditioners Effect on Seasonal Performance.* Victoria, Australia: International Journal of Application or Innovation in Engineering & Management.

Palkowski, Carsten, Andreas Zottl, Ivan Malenkovic, and Anne Simo. 2019. *Fixing Efficiency Values by Unfixing Compressor Speed: Dynamic Test Method for Heat Pumps.* Energies.

Pierrot, Andre, and Julio Conde. 2011. *Cooling Benchmarking Study. Part 3: Testing Component Report.* CLASP.

Rice, C. Keith, Jeffrey D. Munk, and Som S. Shrestha. 2015. *Review of Test Procedure For Determining HSPF's of Residential Variable-Speed Heat Pumps.* Oak Ridge National Laboratory.

Shah, Nihar; Phadke, Amol; Lawrence Berkely National Laboratory; Waide, Paul; Navigant Consulting, Inc. 2013. "Cooling the Planet: Opportunities for Deployment of Superefficient Room Air Conditioners."

Simo, Anne; Palkowski, Carsten; Wachau, Andre; Federal Institute for Materials Research and Testing (BAM). 2018. *Proposal for the revision of the harmonized test standard EN 14825:2016, for the testing and rating of air conditioners and heat pumps at part load conditions and calculation of seasonal performance.* Federal Institute for Materials Research and Testing (BAM).

The World Bank. 2014. *Electric power consumption (kWh per Capita).* https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC.

Waide, Paul, Phillippe Riviere, and Rowan Watson. 2011. *Cooling Benchmarking Study. Part 2: Benchmarking Component Report.* CLASP.