COOLING BENCHMARKING STUDY

Part 2: Benchmarking Component Report

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BY

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in Partnership with
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ABBREVIATIONS AND ACRONYMS

°C	Degrees Celsius
°F	Degrees Fahrenheit
AC	Air Conditioner
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
APF	Annual Performance Factor
Btu	British thermal unit
Btu/h	Btu per hour
CC	Cooling Capacity
Cd	Degradation Coefficient
CEIS	Centre for Testing, Innovation and Services
COP	Coefficient of Performance
CSPF	Cooling Seasonal Performance Factor
CSTE	Cooling Seasonal Total Electricity Consumption
CSTL	Cooling Seasonal Total Load
EER	Energy Efficiency Ratio
EU	European Union
Fint	Intermediate Frequency
FL	Full Load
Fmin	Minimum Frequency
Frat	Rated Frequency
HSPF	Heating Seasonal Performance Factor
HSTE	Heating Seasonal Total Electricity Consumption
HSTL	Heating Seasonal Total Load
ISO	International Organization of Standardization
kW	Kilowatts
MEPS	Minimum Energy Performance Standard
NAFTA	North American Free Trade Agreement
NOPR	Notice of Proposed Rulemaking

OAT	**Outdoor Air Temperature**
P	**Power**
Pck	**Crankcase Heater Power**
Poff	**Off mode Power**
Psb	**Standby Power**
Pto	**Thermostat Off Power**
RAC	**Room Air Conditioner**
SCOP	**Seasonal Coefficient of Performance**
SEER	**Seasonal Energy Efficiency Ratio**
SI	**The International System of Units / Système international d'unités**
TEWI	**Total Equivalent Warming Impact**
TSD	**Technical Support Document**
TXV	**Thermostatic Expansion Valve**
US DOE	**United States Department of Energy**
US	**United States**
VSD	**Variable Speed Drive**
W	**Watt**

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EXECUTIVE SUMMARY

This report presents the findings of an air conditioner benchmarking exercise which has successfully produced viable energy efficiency (EER and SEER) conversion factors. These can be used to convert among room air conditioner energy efficiency requirements in place in the major economies of the world. The conversion factors allow the comparison of metrics addressing full and part-load performance and thus can be used to compare the stringency and impact of policy requirements on peak power demand (EER metrics) and on annual energy use and CO_2 emissions (SEER metrics). The conversion factors are applicable to non-ducted split-type room air conditioners of either fixed speed or variable-speed/frequency type and also to ducted split-AC units.

In addition to the above, the impact of differences in the permitted tolerances is assessed and suitable adjustment factors are proposed.

The overall uncertainty from applying the resulting energy efficiency conversion factors is assessed and documented through comparison with detailed test results from the Testing Component of the Cooling Benchmarking Study. It is found that the conversion factors are suitable for normalized comparison of regulatory policy settings, which was the primary purpose of this exercise. In some cases (depending on the explicit test results being compared), the formulae will also provide a reasonably accurate conversion of individual unit test results; however, in some cases the accuracy is not high enough to use the conversion formulae for this purpose.

The conversion coefficients are applied to compare the minimum energy performance requirements in the world's major economies for the most common types of split room air conditioners. The results show that the Japanese Top Runner requirements are appreciably more stringent than those applying in other economies for split AC units; these are between 17% (for more than 6 kW units) and 68% (for less than 3.2 kW units) more demanding than any current or proposed requirements in other economies.

This is the first time that SEER conversion factors have been successfully developed and validated. Thus, policy makers and other practitioners will now be able to compare the energy performance of different air conditioner markets on a common footing.

INTRODUCTION

Context of the Study

As part of its efforts to support transitioning to a world in which appliances, equipment and lighting are built for maximum Energy Efficiency (EE) and minimal contribution to global climate change, the Collaborative Labeling and Appliance Standards Program (CLASP) funded a study to provide tools and procedures allowing an international comparison of the EE performance and policy measures for air conditioners with a cooling capacity of 19 kW or less used in the residential and commercial sectors. CLASP is an international organization that promotes EE Standards and Labeling (S&L) in commonly used appliances and equipment.

Air Conditioning (AC) systems represent a major energy end-use in several countries, and contribute to the growth of energy consumption and peak load in the commercial and residential sectors. This trend is recently increasing due to rising living standards in several countries combined with a cost reduction of AC products. This tendency is contributing to an increase in greenhouse gas emissions across the world.

This study covered AC products offered in the global market as well as testing procedures and regulatory or voluntary initiatives introduced in different economies. In support of this study, information was collected for Australia, China, the European Union (EU), Japan, India, Korea, Taiwan and the United States (US). The main objective was to provide a meaningful comparison of the effectiveness of air conditioner models sold in major economies. This has been done through an analysis of the market characteristics, Minimum Energy Performance Standards (MEPS) levels and EE classes used for labeling schemes. In addition, conversion functions were developed allowing comparison of different efficiency metrics used across the world.

The project team included Econoler acting as team leader and experts from Navigant, CEIS and ACEEE. CLASP experts were also closely involved in work supervision and provided direction and advice to the project team. Several external experts and country representatives provided market information, advice and views on different issues related to the international comparison of AC equipment efficiencies.

This report is the second of three reports prepared as part of this global study on air conditioner energy efficiency. It presents analysis and the development of a series of conversion functions for metrics used in different economies, as well as a comparison of the relative stringencies of different MEPS and labeling schemes. This report is structured to:

1. Discuss the main AC energy efficiency metrics;
2. Set out the general characteristics of the seasonal energy efficiency metrics;
3. Develop conversion formulae for full capacity EER energy efficiency metrics;
4. Develop conversion formulae for part-load SEER energy efficiency metrics;
5. Describe current policy settings applying to ACs and apply the conversion factors developed in the fourth point to compare their ambition (stringency); and

6. Present the main conclusions.

Other reports prepared as part of this project include:

- Report 1: Mapping component. This report presents a review of AC products offered in different economies and some market characteristics.

- Report 3: Testing component. This report presents the conclusions from a comparison of various economies' AC test procedures, and the actual testing of a limited sample of products under different test procedures.

Scope of the Study

In this study, the term Room Air Conditioner (RAC) includes:

- RAC products with a cooling capacity of up to 19 kW;
- Electrically driven vapor compression units. Absorption units are excluded;
- Cooling only units and the cooling function of reverse cycle (heating and cooling) units.

The scope of the study includes the following RAC sub-categories:

- Non-ducted single split units (mobile or fixed split units);
- Non-ducted single split unit heat pumps;
- Ducted single split units;
- Multi-split units;
- Single-packaged AC units;
- Single and double duct units (portable air conditioners);
- Central AC units (rooftop units).

Purpose of the Benchmarking Component

Currently the energy performance of RACs is measured in each economy using a designated test procedure and energy efficiency metric. As these are not identical across economies, it is not possible to directly compare energy efficiency metrics and policy settings. The benchmarking component of this study aims to overcome this comparability barrier by deriving conversion metrics that can be applied to translate RAC energy performance measurements made in one economy into the values that would be recorded for the same products were they to be tested and rated in other economies. The resulting analysis produces formulae that can be used to convert between each of the more important energy efficiency metrics currently in use for RACs around the world. These formulae are developed for the most common types of AC products sold in international markets: both non-ducted and ducted split ACs, and fixed speed and variable speed (inverter driven) units. The scope of applicability and resulting margin of error from the use of these formulae is also assessed.

This is the first time that such a comprehensive exercise to develop conversion formulae for both full capacity and seasonally averaged energy efficiency metrics has been attempted. The results, while not perfect, are found to be sufficiently robust to allow meaningful comparison of energy efficiency policy settings across the selected economies despite their current use of different energy performance test procedures. The conversion formulae are applied to current energy efficiency policy settings to enable the comparison of their relative ambition on an equal basis, thereby assisting policy makers to compare the stringency of requirements for RACs in different economies.

1 Air conditioner energy efficiency metrics

There are presently two main types of metrics used internationally to rate the energy efficiency of RACs: energy efficiency ratios (EERs) and seasonal energy efficiency ratios (SEERs). EER ratings are used to assess full load performance and are used in many S&L schemes around the world. However, SEER 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. This report sets out a basis for comparing the EERs measured in different economies and also for comparing SEERs measured in different economies, as explained in section 1.1.

1.1 Energy efficiency ratio (EER)

The EER is the oldest and most widely used RAC efficiency metric. It is the ratio of the cooling capacity to the electricity consumption when measured at full load, i.e., at the maximum deliverable cooling capacity of the RAC. This is determined in all economies for a single representative test condition, which specifies a single set of indoor and outdoor dry and wet-bulb air temperatures that have to be maintained during the test. In practice, the T1 test conditions specified in the international standard ISO 5151:1994 have been widely adopted. Among economies that have conditions aligned to this standard, the principal adjustment needed to convert between different EER test results is to take account of differences in the permitted test tolerances. All the economies addressed in this study have EER test conditions fully aligned with ISO 5151:1994 except for the US. The test procedure used in the US (and all North American Free Trade Agreement (NAFTA) economies) also has considerable alignment with the ISO 5151 T1 test condition but with some slight deviations, which introduce a degree of non-comparability in the full-load EER results. Thus, a correction factor needs to be applied to enhance the comparability of the EER test results produced using the ISO T1 test condition and the NAFTA test conditions, as well as any policy settings based upon them.

There could be a number of factors which produce differences in EER test results for the same unit, including variations in test conditions, standard operating conditions, and the tolerances applied in different jurisdictions. The objective of this study with respect to EER conversions is to develop conversion formulae that allow the EER recorded under the prevailing test procedure requirements in one specific region to be compared directly with the EER measured under the prevailing test procedure requirements used in another region. In practice, it is found that this can be done via a straightforward relationship of the type:

$EER_{ZONE1} = \alpha_{12} * EER_{ZONE2}$ and vice versa as: $EER_{ZONE2} = \alpha_{21} * EER_{ZONE1}$

1.2 Seasonal energy efficiency ratios (SEER)[1]

The EER metric only measures the efficiency of the unit at a sole designated design point, which is the maximum cooling capacity the device is capable of delivering when measured under a single set of standardized temperature conditions. In practice, however, RACs 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, reliance on energy efficiency metrics based on a single full-capacity design point ignores part-load performance and will tend to give efficiency performance rankings that are not representative of real seasonal energy performance. This is compounded because performance metrics based solely on full load conditions will tend to encourage manufacturers to optimize full load performance at the expense of part-load performance. To obviate this problem, SEERs have been created in order to provide an energy efficiency measure which is closer to the real energy efficiency performance of RAC units in situ over the cooling season. SEERs include the impact of variations in the outdoor air temperature and in the cooling load, which is also sensitive to building and user behavioral norms. These metrics typically require several test points to compute a seasonally weighted average efficiency (the SEER), and are intended to give results that are representative of how the air conditioner would perform over a typical cooling season within a representative building type having typical operating characteristics.

Four economies have already adopted specific seasonal energy performance test standards for RACs. The US was the first to develop a SEER standard, followed by Korea and more recently Japan and China. The EU is poised to adopt a SEER metric which is expected to come into effect in 2012. Therefore, the SEER benchmarking work conducted in this report examines methods for converting between seasonal energy efficiency test results produced in China, the EU, Japan, Korea, and the US (and by implication the other NAFTA economies that operate regionally harmonized test procedures).

The objective of this study with respect to seasonal energy efficiency metrics is to establish relationships that allow SEERs to be converted between the five specific SEER metrics that are in common use. As the SEER requirements have more test points and are designed to be representative of local climates, building types, and user behavior, they have more degrees of freedom than the EER metrics and it is more complicated to derive formulae to convert between them. Nonetheless, the generic conversion formulae between SEER metric 1 and SEER metric 2 can be expressed as:

$SEER_1 = f_{1->2}(SEER_2)$ and vice and versa: $SEER_2 = f_{2->1}(SEER_1)$

These functions are dependent on the technical features of the products being considered, and in particular on the means used to adapt the capacity of the unit to the required building load.

The capacity of the unit can be adapted by means of several technologies:

- AC units with single speed compressor units (fixed-speed units), which cycle the compressor on and off to adapt their capacity to the load variations over a period of time;

[1] The term SEER is used generically in this section to apply to any energy efficiency metric that uses a weighted-average of multiple test points.

- Tandem units, which have two compressors in parallel and can meet varying loads by operating combinations of the compressors in on and off modes; and
- Units equipped with variable speed drive (VSD) compressors, which vary the rotational speed of the compressor motor.

In this document, we focus on small split packaged AC units (mini-splits) as these are the most common type of residential AC units used around the world. These products are dominated by two control techniques: single speed compressors and VSD compressors.

The next section discusses SEER characteristics, and the subsequent section discusses the development of conversion formulae.

2 Characteristics of the seasonal energy efficiency metrics

To be able to explain the energy efficiency metric conversion formulae and how they were developed, it is first necessary to understand the characteristics of the metrics themselves. This section describes the test specifications used in the seasonal metrics and the related algorithms that are used to derive the SEER metrics. The general principle used to establish the different SEERs is similar in the five economies. The US AHRI 210/240 test standard, which sets out the specifications used to establish the US SEER, is presented as an example, followed by a discussion of variations in the methods used in the other economies.

The objective of this section is to describe:

- the main methods used to classify the seasonal energy efficiency of air conditioners that are applied in different economies;
- the required inputs, testing points, and technical characteristics of the seasonal performance metrics; and
- the modeling hypotheses that enable a single seasonal performance figure to be computed from a temperature bin distribution (which is characteristic of the local climate).

ACs adapt their capacity to the load according to the required cooling and/or heating needs.[2] The ratio between the energy needed at any given set of operating conditions and the nominal capacity of the AC is called the load ratio.

The annual energy consumption of air-to-air type ACs will depend on the combined energy use in each of the following operating modes:

- Cooling mode;
- Heating mode; and
- Standby mode.

The annual energy consumption of each operating mode varies as well:

- In cooling mode, variations are a function of outdoor air temperature, inside air temperature and humidity, indoor and outdoor air flows, cooling load, and stand-by energy consumption.
- In heating mode, variations are a function of outdoor air temperature and humidity, indoor air temperature, indoor and outdoor air flows, heating load, and stand-by energy consumption
- In standby mode, variations are a function of hours spent and power drawn in standby mode.[3]

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[2] Some economies, such as Japan, include the heating mode in their seasonal energy efficiency metric; thus, both cooling and heating modes need to be considered when making seasonal energy efficiency conversions.

[3] Power management can be used to lower standby loads.

Standby energy consumption is currently only taken into account in the pending European SEER metric. For all the other standards, test measurements are only made during the period when the compressor is operational and hence standby loads are not considered.

2.1 The US SEER metric

2.1.1 Introduction

In US regulations, the US DOE has defined a SEER index in Btu/Wh for central ACs with a cooling capacity lower than 19 kW (typical of residential use in the US). A separate heating factor, called the heating seasonal performance factor (HSPF), is also used but is outside the scope of the present study. For ACs with cooling capacity greater than 19 kW, another seasonal performance indicator is used called the Integrated Energy Efficiency Ratio (IEER) (see ASHRAE 90.1 2010), which is a weighted part load index, similar to the one used for chillers in the AHRI 550 590 standard (the Integrated Part Load Value (IPLV)). Both ducted and non-ducted split system ACs, including the non-ducted mini-split AC systems which are commonly classified as room ACs outside of North America, are considered to be central ACs in US regulations provided their cooling capacity is less than 19 kW.

2.1.2 Scope of application of the US SEER

In the US standards, a central AC or heat pump is defined as a "product other than a packaged terminal air conditioner, which is powered by single phase electrical current, air cooled, rated below 65000 Btu/h (19.05 kW), not contained within the same cabinet as a furnace, the rated capacity of which is above 225000 Btu/h and is a heat pump or cooling only unit." This definition includes split-packaged (single and multi-split) non-ducted RACs and applies to both cooling-only and reversible models. The official US test procedure for central ACs is contained in the Code of Federal Regulations 430 Appendix M. For split systems, this test procedure refers to the AHRI 210/240-2006 test procedure. The cooling and heating capacities, power input, and energy efficiency ratio(s) are measured according to the method in ASHRAE-37-1988 *Methods of testing for rating unitary air conditioning and heat pump equipment*.

2.1.3 Temperature and load conditions

A single cooling load curve, intended to be representative of a typical US building in a single nationally representative climate, is used to represent the cooling period climate for the whole US and to compute the SEER. The building cooling load, BL, is assumed to be a linear function of outdoor air temperature as follows.

$$BL(T_j) = \frac{T_j - 65}{95 - 65} \frac{P_c(FL, Rating)}{1.1}$$

Where:

- T_j: is the outdoor air temperature axis divided into discrete intervals (or bins) of 5 °F (about 2.8 °C) represented by the subscript j;
- $BL(T_j)$ is the building cooling load for a temperature in bin j, in units of kW;

- P_c(FL, rating) is the rated cooling capacity at full load (FL) as measured at the full load test condition[4] in units of kW;
- 65 °F: is the assumed indoor temperature (18.3 °C); and
- 95 °F: is the assumed maximum outside temperature at full load (35 °C).

In order to be able to average the efficiency at different pairs of load and temperature conditions, the hours of occurrence of each outdoor temperature during the cooling season are tallied for each of the bin intervals. The median temperature of the interval bounds is taken to be representative for the bin as a whole. The fraction of the time spent at each outdoor temperature interval is shown in Table 1.

Table 1: Distribution of fractional hours within cooling season temperature bins, AHRI 210/240

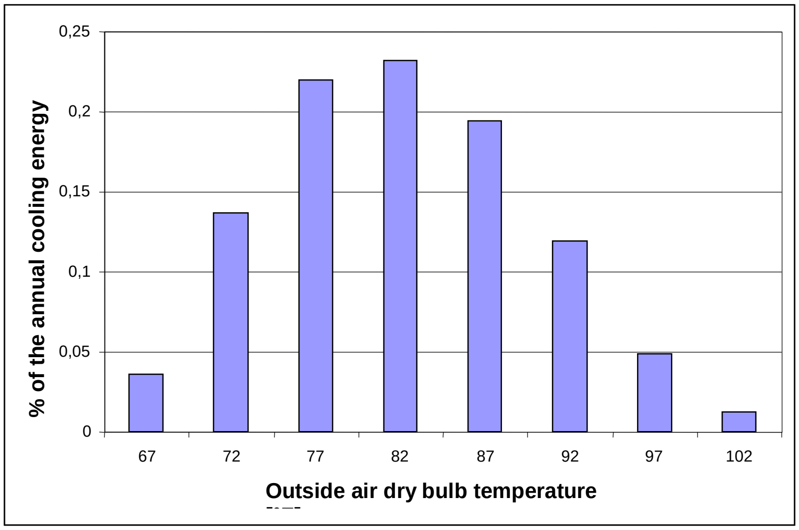
Bin Temperature Range [°F]	65-69	70-74	75-79	80-84	85-89	90-94	95-99	100-104
Representative temperature for bin °F	67	72	77	82	87	92	97	102
Representative temperature for bin °C	19.4	22.2	25.0	27.8	30.6	33.3	36.1	38.9
Fraction of total temperature bin hours	0.214	0.231	0.216	0.161	0.104	0.052	0.018	0.004

By multiplying the cooling load (kW) by the fractional hours of operation in each bin ($\frac{n_j}{N}$, where N is the number of hours of cooling operation and n_j is the number of hours of cooling operation in temperature bin j), an approximation of the energy spent at each temperature level (or equivalently, each load ratio) is derived.

Figure 1 shows how in AHRI 210/240, the proportion of total annual cooling energy needs is assumed to vary with outdoor air temperature. For the standard SEER rating, the energy-weighted average operating conditions correspond to an outdoor air temperature of about 82 °F (27.8 °C) and 52% load.

[4] This full load test condition is also used to produce the power and cooling capacity measurements in the EER ratings, and hence is very close to the ISO T1 condition.

Figure 1: Cooling energy needs as a function of outdoor air temperature (°F) for AHRI 210/240



2.1.4 Computing the US SEER

For each temperature (median temperature of each bin), a given load ratio is associated with a given temperature via the linear formula for building cooling load given in section 2.1.3. The electricity consumption of the unit is computed from measurements taken at a few testing points[5] (via simple modeling[6]) for a given load ratio and outdoor air temperature along the building load curve. Then, the SEER is calculated by calculating the ratio of the cooling energy delivered to the electric energy consumption, as follows:

$$\mathrm{SEER} = \frac{\sum_{j=1}^{8} \frac{q(T_j)}{N}}{\sum_{j=1}^{8} \frac{e(T_j)}{N}}$$

Where T_j represents the eight temperature bins defined in AHRI 210/240 (section 2.1.3) and N is the total number of hours in the cooling season.

For each temperature bin, two terms must be calculated.

The first term is $\frac{q(T_j)}{N}$ which is the bin-weighted net cooling load where:

$$\frac{q_c(T_j)}{N} = BL(T_j).\frac{n_j}{N}$$

[5] Two to seven testing points are used; see section 2.1.7 for additional information.

[6] The test points and modeling process are further detailed below.

Where q_c (Tj) = the cooling load in temperature bin j, n_j is the number of hours of cooling in bin j, and BL(Tj) is the building cooling load at bin temperature Tj. This term is "the ratio of the total space cooling provided during periods of the space cooling season when the outdoor temperature fell within the range represented by bin temperature Tj to the total number of hours in the cooling season (N)" expressed in units of Btu/h.

The second term is $\frac{e(T_j)}{N}$ which is the bin-weighted energy consumption where:

$$\frac{q_e(T_j)}{N} = \dot{Q}_e(T_j, X(T_j)).\frac{n_j}{N}$$

Where $\dot{Q}_e$ is the electric power of the unit, X(Tj) is the cooling load ratio at temperature T in bin j, i.e., is the ratio of the required building load to the cooling capacity of the air conditioner. This is "the electrical energy consumed by the test unit during periods of the space cooling season when the outdoor temperature falls within the range represented by bin temperature Tj to the total number of hours in the cooling season (N)" expressed in units of W. The introduction of this factor enables the effect of part load to be treated when computing the seasonal performance.

2.1.5 Testing and theoretical modeling to compute the performance at different load and outdoor temperature pairs

The modeling methods used to calculate the performance of an AC unit for each one of the temperature bins depend on the capacity control technology used by the AC unit. Each temperature bin corresponds to specific outdoor air temperature/humidity conditions and a specific load ratio (the indoor air temperature and humidity conditions are fixed). The general principle applied is to derive the performance curves of the specific AC units from performance values measured at a few test points. These performance curves give the cooling (or heating) capacity and electricity consumption as a function of outdoor air conditions for different AC capacity control technologies. In consequence, the following discussion treats the modeling approach applied to an AC unit differently in accordance with its capacity control technology.

Units with a fixed-speed compressor

Fixed-speed units are only required to be tested at two test points, A and B (see Table 2). The C and D points are optional and are used to compute the coefficient of degradation of energy efficiency as a function of decreasing load ratio. This is intended to express compressor cycling losses at lower loads and is assumed to vary linearly such that the gradient is equal to the degradation coefficient C_D^c. Equipment suppliers have the option to conduct supplementary tests to calculate the actual C_D^c value, or to avoid the testing costs and adopt a default value of 0.25; however, as the default value is quite high, its use is likely to lower the rated SEER of the unit compared to the case where additional tests are done.

Table 2: Fixed-speed compressor test conditions in cooling mode, AHRI 210/240

Test description	Air Entering Indoor Unit Temperature (°F)		Air Entering Outdoor Unit Temperature (°F)	
	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb
A Test—required (steady, wet coil)....	80	67	95	75 [1]
B Test—required (steady, wet coil)	80	67	82	65 [1]
C Test—optional (steady, dry coil)....	80	(3)	82	....
D Test—optional (cyclic, dry coil)	80	(3)	82	....

Notes:

(1) The specified test condition only applies if the unit rejects condensate to the outdoor coil.

The following simplified formula is used to compute the SEER, where, as previously reported, the peak of the cooling needs distribution occurs at an outdoor temperature of 82 °F corresponding to 50% of full load.

NB: For the SEER simplified formula, only the AHRI B rating point is required. The testing point A is required to rate the EER as required in the AHRI standard.

$$SEER = EER_B.PLF(0.5)$$

$$PLF(0.5) = \left(1 - 0.5.C_D{}^c\right)$$

Where:

EER_B = net steady-state efficiency (Btu/Wh) at the AHRI B rating point

PLF(0.5) = degradation of EER at 50% load ratio

Units with two capacity steps

Four test points are required in the case of units with two capacity steps, although the C and D test points are still optional, as shown below in Table 3:. Tests are required at full capacity for two different outdoor air temperatures. More tests are required at the smaller of the two capacity levels for the same two sets of outdoor air temperature conditions.

Figure 2, below, shows how the load curve and the capacity of the two stages of the AC vary as a function of outdoor air temperature. Linear fits of the cooling capacity and electric power consumption are computed via the two testing points at different outdoor air temperature for each capacity stage. Hence the capacity and electric power at each stage may be computed for different temperatures than the ones actually tested by using the following formula (capacity stages are indicated with k =1 or 2).

$$\dot{Q}_c^{k=1}(T_j) = \dot{Q}_c^{k=1}(82) + \frac{\dot{Q}_c^{k=1}(95) - \dot{Q}_c^{k=1}(82)}{95 - 82}(T_j - 82)$$

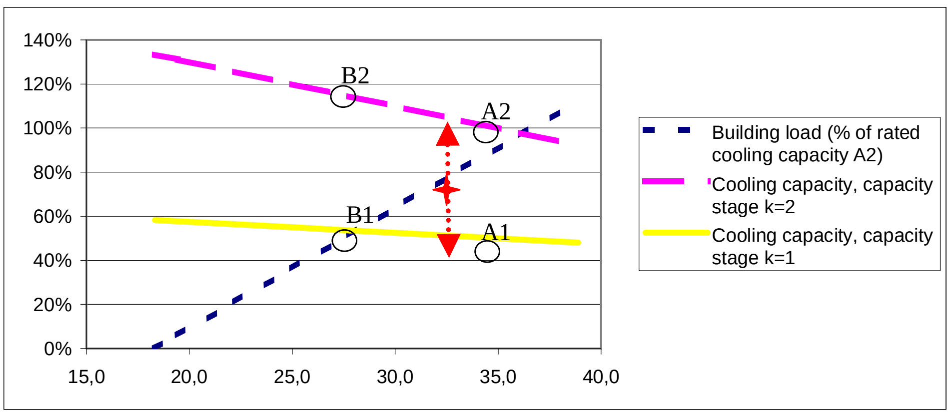
Table 3: Two-capacity step AC unit test conditions in cooling mode, AHRI 210/240

Test description	Air Entering Indoor Unit Temperature (°F)		Air Entering Outdoor Unit Temperature (°F)		Compressor Capacity
	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb	
A_2 Test—required (steady, wet coil)........	80	67	95	75 (1)	High
A_1 Test—required (steady, wet coil)........	80	67	95	75 (1)	Low
B_2 Test—required (steady, wet coil)........	80	67	82	65 (1)	High
B_1 Test—required (steady, wet coil)........	80	67	82	65 (1)	Low
C_1 Test (4)—optional (steady, dry coil).....	80	(4)	82	....	Low
D_1 Test (4)—optional (cyclic, dry coil)	80	(4)	82	....	Low

Notes:

(1) The specified test condition only applies if the unit rejects condensate to the outdoor coil.

Figure 2: Illustration of the procedure to compute the SEER of a two stage AC, AHRI 210/240



There are two cases that can occur when computing the electric power at a specific pair of temperature and building load (Tj, BL(Tj)):

- The building load $BL(T_j)$ is lower than the steady state capacity at low speed $\dot{Q}_c^{k=1}(T_j)$
- The building load $BL(T_j)$ lies between the steady state capacity of the lower and higher stages

In the first case the cooling load factor for the given temperature bin is defined as:

$$X^{k=1}(T_j) = \frac{BLT(T_j)}{\dot{Q}_c^{k=1}(T_j)}$$

In the case of fixed-speed air conditioners, the cycling loss is modeled by the PLF and C_D^c coefficient. The cooling capacity supplied is assumed to equal the building load while the electric power consumption is increased by the cyclic degradation equation as follows:

$$\frac{q_c(T_j)}{N} = X^{k=1}(T_j).\dot{Q}_c^{k=1}(T_j).\frac{n_j}{N} \quad \text{and} \quad \frac{e_c(T_j)}{N} = \frac{X^{k=1}(T_j).\dot{E}_c^{k=1}(T_j)}{PLF_j}.\frac{n_j}{N}$$

In the second case, the appliance is assumed to cycle between the two stages to supply the required cooling capacity. The cooling capacity supplied by each stage can be computed as a simple barycenter:

$$X^{k=1}(T_j) = \frac{\dot{Q}_c^{k=2}(T_j) - BLT(T_j)}{\dot{Q}_c^{k=2}(T_j) - \dot{Q}_c^{k=1}(T_j)} \quad \text{and} \quad X^{k=2}(T_j) = 1 - X^{k=1}(T_j)$$

Electric power is then calculated as:

$$\frac{e_c(T_j)}{N} = \left[X^{k=1}(T_j).\dot{E}_c^{k=1}(T_j) + X^{k=2}(T_j).\dot{E}_c^{k=2}(T_j) \right] \frac{n_j}{N}$$

Variable Speed Drive (Inverter) units

Units with variable speed drives (VSDs) can vary their capacity and are required to be tested at five test points, as set out below in Table 4. These tests enable the variation of cooling capacity and electric power at low speed (B1, F1) and high speed (A2, B2) to be calculated. An intermediate frequency (compressor speed), test E_v is defined as:

Intermediate speed = Low speed + (High speed – Low speed)/3.

For this point, the evolution of performance at fixed frequency and variable outdoor air temperature is interpolated from the two preceding performance curves.

The only difference with the calculation method for the two-capacity step units is when the building load $BL(T_j)$ lies between the steady state capacity of the lower and higher stages (minimum and maximum compressor speed). The EER of the cooling capacity that matches the building load in that interval is fitted as a second order polynomial equation as follows:

$$EER^{k=i}(T_j) = A + B.T_j + C.T_j^2$$

In order to compute coefficients A, B, and C, it is first necessary to identify the three points of interpolation between the cooling capacity lines and the building load curve for the three frequencies tested.

Table 4: Inverter compressor test conditions in cooling mode, AHRI 210/240

Test Description	Air Entering Indoor Unit Temperature				Air Entering Outdoor Unit Temperature				Compressor Speed
	Dry-Bulb		Wet-Bulb		Dry-Bulb		Wet-Bulb		
	°F	°C	°F	°C	°F	°C	°F	°C	
A_2 Test - required (steady, wet coil)	80.0	26.7	67.0	19.4	95.0	35.0	75.0(1)	23.9(1)	Maximum
B_2 Test - required (steady, wet coil)	80.0	26.7	67.0	19.4	82.0	27.8	65.0(1)	18.3(1)	Maximum
E_V Test - required (steady, wet coil)	80.0	26.7	67.0	19.4	87.0	30.6	69.0(1)	20.6(1)	Intermediate
B_1 Test - required (steady, wet coil)	80.0	26.7	67.0	19.4	82.0	27.8	65.0(1)	18.3(1)	Minimum
F_1 Test - required (steady, wet coil)	80.0	26.7	67.0	19.4	67.0	19.4	53.5(1)	11.9(1)	Minimum
G_1 Test(5) - optional (steady, dry coil)	80.0	26.7	(5)		67.0	19.4	—		Minimum
I_1 Test(5) - optional (cyclic, dry coil)	80.0	26.7	(5)		67.0	19.4	—		Minimum

Notes:

(1) The specified test condition only applies if the unit rejects condensate to the outdoor coil.

2.1.6 Tolerances

No tolerance is permitted for the declared US SEER values. Thus, it is incumbent on the product supplier to take account of any actual product and test variability before making their product performance declaration.

2.1.7 How data demanding is the US SEER procedure?

Table 5 presents a summary of the minimum number of test points that are required to rate the SEER of an AC according to the US test procedure.

Table 5: Number of test points (required and optional) for AHRI 210/240

ARI 210/240	SEER	
Number of testing points	Min	Max
Fixed speed compressor	2	4
Two capacity stages	4	6
VSD	5	7

2.1.8 Supplementary information regarding the US SEER

Although it gives a better index of comparison than the full load ratings that are used in many parts of the world, several criticisms of the AHRI 210/240 standard have been raised in the last few years as are reported in

Kavanaugh (2002), Fairey (2004), SEC (2004), and Dougherty (2002). Some of the criticisms that pertain to the cooling mode are summarized as follows:

- Since the standard offers only one climatic representation and the part load performances of the units are not published, calculation of the SEER for a specific climate zone cannot be done; anyway, the SEER should not be used to compute the energy consumption of a specific house.
- Placing the minimum requirements only in terms of the SEER allows units with poor EER (as low 2.0 W/W in SI units in some cases) to remain on the market; this raises peak power issues for electric utilities.
- The choice of indoor air temperature is too high and does not reflect actual US habits.
- To increase EER at low loads, manufacturers increase the evaporating temperature and decrease the air flow rates, leading to lower dehumidification capability. Since individual performance ratings are not published, it is not possible for installers to design the AC to ensure proper dehumidification.
- In real use, US central ACs may also provide ventilation, but this is not taken into account in the AHRI procedure (SEC, 2004). This issue is specific to the US, where heating and cooling is ensured through an air based system; for other regions, cooling in residences is generally ensured by a mini-split AC and ventilation via a dedicated mechanical ventilation system (if any). It would be better if the energy consumption of the ventilation fan (which does not only operate when cooling is required) was included in the test procedure and product performance rating, along with the potential benefits from enabling free-cooling.
- Manufacturers have questioned the applicability of the default degradation (cycling) coefficient of 0.25 in the case of units with high cycling default values.

In practice, most of these criticisms do not apply only to the US SEER, but rather are applicable to all the seasonal performance indices considered in this study.

2.2 Japanese CSPF and APF

2.2.1 Introduction

Variable speed split ACs (inverters) were introduced in the early 1990s in Japan, and a seasonal performance metric was adopted in 2004 for residential ACs[7] (JRA-4046) and in 2006 for commercial ACs. The standards are similar, except for different load and temperature conditions to take into account the usage characteristics of commercial equipment.

According to the JRA-4046 standard, residential AC units have a thermal cooling capacity of up to 10 kW. The energy performance metric reported to the consumer is the Annual Performance Factor (APF), which is defined

[7] Previous Japanese Top Runner targets expressed in COP still apply to new products; they have simply been complemented with the more recent APF requirements. See section 2.2.6 for more information.

as the weighted average of the Cooling Seasonal Performance Factor (CSPF) and of the Heating Seasonal Performance Factor (HSPF).[8] Although used to produce the APF, the CSPF and the HSPF are not generally reported to consumers. For cooling-only split ACs, the APF equals the CSPF, thus simplifying the calculation. However, most dwellings in Japan use reversible VSD mini-split units as their primary heating means, and hence virtually all ACs on the Japanese market are reversible. This means that to usefully benchmark the seasonal cooling performance requirements in Japan, it is necessary to benchmark the APF value of reversible units, and thus to also consider the heating mode. This point is discussed in more detail when establishing the energy efficiency conversion coefficients in sections 3 and 4.

2.2.2 Scope of the residential standard JRA-4046

This standard classifies "room air conditioners" sold on the Japanese market as single-package type or split-system type with a rated cooling capacity not exceeding 10 kW and rated electric power consumption not exceeding 3 kW. Moreover, only ACs with a single fixed-speed compressor or variable speed compressor are in the scope of this standard; units with two speed compressors or two capacity stages are not sold on the Japanese market.

2.2.3 Scope of the commercial standard JRA-4048

This standard applies to "packaged air conditioners" (cooling capacity < 28 kW), which are primarily intended for commercial use. It includes multi-split units which are not classified as "room air conditioners" in Japan, as well as two step and variable capacity units. Specific conditions are detailed for different buildings and climates. We do not consider this standard in the analysis that follows as this study focuses on residential AC units.

2.2.4 Temperature and load conditions

The standard APF value is computed for the "Tokyo mild climate", even though 17 other Japanese climates are also specified in the standard.

The cooling and heating building load curves are straight lines, defined by the formulae set out below, in cooling and heating mode respectively.

Cooling mode

The rated cooling capacity Φ_{BL} is assumed to be equal to the building load for an outdoor air temperature of 33 °C, and the load is assumed to be zero for an outdoor air temperature of 23 °C. Thus, the AC capacity is intentionally undersized by a few percentage points at the ISO 5151 T1 test condition that has an outdoor air temperature of 35 °C.

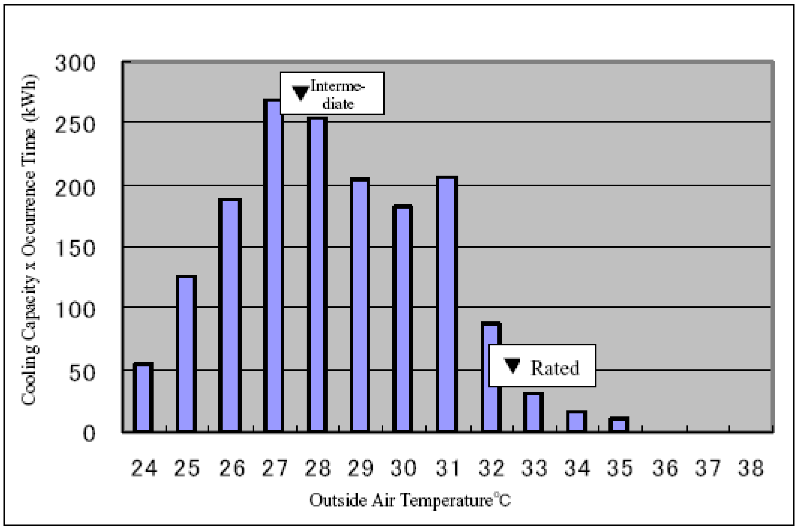
$$BL_c(T_j) = \frac{T_j - 23}{33 - 23}.\Phi_{BL}$$

---

[8] The HSPF used in Japan is distinct from the US HSPF referred to earlier.

To compute the number of hours of use, the cooling season is defined as running from June to September in Tokyo, and the number of hours in the season when the outdoor temperature exceeds 24 °C are binned as a function of the outdoor air temperature. The product of the number of hours and the cooling capacity by temperature bin is represented in Figure 3 for the cooling season. The weighted average point of the distribution occurs at 54% of full load and 28.4 °C.

Figure 3: Distribution of cooling energy as a function of outdoor air temperature (ECCJ, 2006)



Heating mode

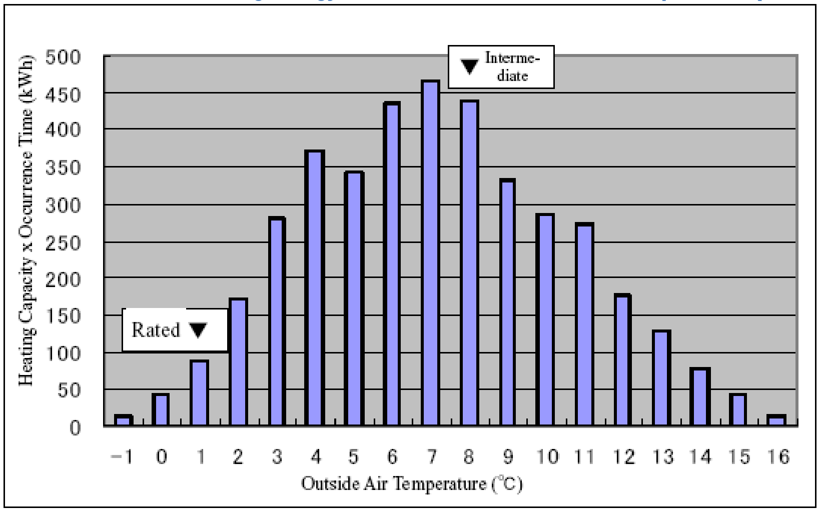
The heating load is assumed to be zero at 17 °C outdoor temperature and to be equal to 1.025 (= 1.25 * 0.82) times the rated cooling capacity at 0 °C outdoor temperature (where 1.025 is the average ratio between the heating capacity at 0 °C and the rated cooling capacity[9]). Hence, the heat pump is supposed to be sized to cover 100 % of the heating needs for an outdoor temperature of 0°C.

$$BL_h(T_j) = 1.25.\Phi_{BL}.0.82\frac{17 - T_j}{17}$$

Where BL_h is the building heat load for the bin temperature T_j. To compute the number of hours of use, the heating season is defined as running from November to mid-April for the climate of Tokyo, and the hours when the outdoor temperature falls below 17 °C for heating are binned as a function of the outdoor air temperature. The product of the number of hours and the heating capacity by temperature bin is shown in Figure 4 for the heating season. The weighted average point of the heating distribution occurs at 60% of full load and 7 °C.

9 This ratio is reported in the documents used to develop the APF concept and is presumably based upon a statistical analysis of Japanese air conditioners at the time the APF concept was elaborated.

Figure 4: Distribution of heating energy as a function of outdoor air temperature (ECCJ, 2006)



2.2.5 Computing the APF

The APF is defined as the ratio of the total thermal energy supplied by the equipment to the total electricity consumption of the unit over the year for the default Tokyo climate.

$$APF = (CSTL + HSTL) / (CSTE + HSTE)$$

Where:

- CSTL = cooling seasonal total load in kWh
- HSTL = heating seasonal total load in kWh
- CSTE = cooling seasonal total electricity consumption in kWh
- HSTE = heating seasonal total electricity consumption in kWh

Two additional performance ratios are defined as follows:

- the CSPF, the cooling seasonal performance factor where CSPF = CSTL / CSTE
- and the HSPF, the heating seasonal performance factor where HSPF = HSTL / HSTE

CSTL is the sum of the cooling energy delivered in each temperature bin. It is a linear function of the rated cooling capacity of the unit (under the ISO 5151 T1 test conditions) for an equivalent number of full load hours. HSTL is the equivalent metric for heating. As the maximum heating load is computed as a function of the rated cooling capacity, the HSTL is also proportional to the rated cooling capacity.

The total number of equivalent full load hours to be used is 583 hours for cooling and 1421 hours for heating. Table 6 shows the resulting values for CSTL and HSTL for variable rated cooling capacities.

Table 6: CSTL and HSTL variations with the rated cooling capacity, JRA 4046 – Annual total load (both heating and cooling loads) for Tokyo

Rated cooling capacity		kW	1.0	1.1	1.2	1.4	1.6	1.8	2.0
Tokyo	Total	kWh	2004	2204	2405	2805	3206	3607	4008
	Cooling season	kWh	583	641	700	816	933	1050	1166
	Heating season	kWh	1421	1563	1705	1989	2273	2557	2842

Rated cooling capacity		kW	2.2	2.5	2.8	3.2	3.6	4.0	4.5
Tokyo	Total	kWh	4408	5010	5611	6412	7214	8015	9017
	Cooling season	kWh	1283	1458	1633	1866	2099	2332	2624
	Heating season	kWh	3125	3552	3978	4546	5115	5683	6393

Rated cooling capacity		kW	5.0	5.6	6.3	7.1	8.0	9.0	10.0
Tokyo	Total	kWh	10019	11222	12624	14227	16031	18035	20038
	Cooling season	kWh	2915	3265	3673	4140	4665	5248	5831
	Heating season	kWh	7104	7957	8951	10087	11366	12787	14207

2.2.6 Testing and theoretical modeling to compute performance for different load and outdoor temperature pairs

The number of test points required is less than in the US AHRI 210/240 test standard. In addition, and in contrast to the US standard, the exact ISO 5151 T1 indoor and outdoor temperature conditions are used.

Cooling mode

In cooling mode, for fixed speed units, the default degradation C_D^C coefficient is set to 0.25 for all units; it is not permitted to override this value through additional testing as is permitted in the US SEER procedure. The performance curve of the full load cooling capacity and its power variation with outdoor air temperature is standardized by the following two relationships, which produce an increase in EER of approximately 18% when the outdoor air temperature decreases from 35 °C to 29 °C. This amounts to a 3% increase in EER for each °C of outdoor temperature decrease.

$P_c(29\ °C) / P_c(35\ °C) = 1.077$ P_c: cooling capacity

$P_e(29\ °C) / P_e(35\ °C) = 0.914$ P_e: cooling electric power

Only two tests are required for variable speed units: the ISO T1 test and the "intermediary cooling capacity" test, where the product manufacturer has the freedom to decide what percentage of full load capacity the latter test will be conducted at. Nevertheless, in practice, this degree of freedom is not used, and manufacturers declare the efficiency at 50% of rated capacity.

As in the AHRI 210/240 standard, performance curves are drawn by capacity stage (intermediate and full capacity). In both cases, the cooling capacity and electric power variation with outdoor air temperature are straight lines, with the same gradients as for the fixed-speed units. Thus the EER increases by about 3% for each 1 °C decrease in the outdoor dry bulb temperature, between 35 °C and 29 °C.

Heating mode

In heating mode, the frost operation zone is considered to occur between -7 °C and 5.5 °C.[10] Outside this interval, performance curves are modeled using the assumption that the average variation in heating capacity and electric power are the same for all appliances. The slopes of these variations are given by the following relationships within the outdoor temperature range of -7 °C to 7 °C:

$P_H(-7\ °C) / P_H(7\ °C) = 0.64$ P_H: heating capacity

$P_e(-7\ °C) / P_e(7\ °C) = 0.82$ P_e: heating power

The COP decreases by about 1.6% for each 1 °C decrease in the outdoor dry bulb temperature.

Only two tests are performed for fixed-speed heat pumps: the ISO 5151 H1 (7°C) and H2 (2°C) tests. Full load performance curves in the outdoor temperature range of -7°C to 5.5°C are linear interpolations/extrapolations based on the H3 and H2 points, where the H3 point is deduced from the H1 point using the equations above. The default degradation coefficient C_D^H is set to 0.25 for all units, and challenge testing to establish the actual unit value is not permitted.

In the case of variable speed heat pumps, there is only one supplementary test point at reduced capacity ("intermediate standard heating capacity") for H1 conditions. The full capacity performance curves are defined in the same manner as for single speed units. At reduced speed, the same coefficients of evolution of performance are used as at full load. The performance at reduced speed under frost conditions H2 are computed using the following relationship:

$P_{H.intermediate}(2\ °C) / P_{H\ intermediate}(7\ °C) = 0.78$ $P_{H\ intermediate}$: heating capacity at reduced speed

$P_{e\ intermediate}(2\ °C) / P_{e\ intermediate}(7\ °C) = 0.88$ $P_{e\ intermediate}$: heating power at reduced speed

This relationship equates to a COP decrease of 8% for the corresponding outdoor temperature decrease and a COP decrease of 4% to take into account the impact of frost and defrost cycles.

In addition, variable speed reversible ACs are assumed to be able to operate at higher than rated speed to be able to manage peak heating requirements at low outdoor air temperature. Hence, a third high capacity stage is defined, above the rated and intermediate stages. It is defined by two default coefficients that translate heating capacity and power of this stage at -7 °C and 2 °C. The degradation of COP with outdoor air temperature is a bit higher than for the other stages (1.8% versus 1.6 %). The performance at 2 °C for this stage is defined as a function of the performance of the full load test at H2 conditions as follows:

---

[10] As noted previously, the minimum temperature for the default Tokyo climate is 0 °C. Nevertheless, the methodology can be used for other climates. This is why temperature conditions of less than 0 °C are quoted in the standard.

$P_{H\ high\ speed}(2\ °C) / P_{H\ rated\ speed}(H2) = 1.12$ $P_{H\ high\ speed}$: heating capacity at highest speed

$P_{e\ high\ speed}\ (2\ °C) / P_{e\ rated\ speed}(H2) = 1.06$ $P_{e\ high\ speed}$: heating power at highest speed

This third stage favors VSD (inverter) units compared to fixed-speed units since it enables the balance point to be lowered and then the impact of resistive heating (if any) to be decreased.

2.2.7 Tolerances

The permitted tolerances for declared APF value, given in the JRA-4046 and JRA-4048 standards, are set at 10% for residential AC units. This means that the tested value should be 90% or more of the declared value for a unit not to fail a performance verification test.

2.2.8 How data demanding is the APF procedure?

Table 7 presents a summary of the minimum number of test points that are required to rate the APF of an AC according to the Japanese test procedure.

Table 7: Number of test points (required and optional), JRA-4046 and JRA-4048

JRA-4046 and JRA-4048	CSPF	HSPF	APF
Single speed compressor	1	2	3
Two capacity stages (JRA-4048 only)	2	3	5
Inverter	2	3	5

2.2.9 Implications of the Japanese methodology regarding the CSPF and HSPF values

In cooling mode, the CSPF of fixed-speed units is directly proportional to the ISO 5151 T1 EER for fixed-speed units, with SEER = 1.135 EER. For VSD units, the rated performance differences between models depends on the efficiency at T1 conditions and the efficiency at 50% reduced capacity, such that the CSPF can be defined as a function of these two efficiency values.

In heating mode, the HSPF calculated with this method does not compare the units with respect to the effect of outdoor air temperature. Moreover, since the average weighted outdoor air temperature for Tokyo is about 7 °C (7.14 °C), the HSPF does not vary from the standard H1 COP value for reasons related to differences in the outdoor air temperature. The HSPF of variable speed units varies because of the H1 COP, the part load performance (intermediate heating capacity is also fixed around 50% of the H1 heating capacity), and the performance and heating capacity at 2 °C.

2.3 Korean SEER

2.3.1 Introduction

Korea introduced a seasonal performance metric in 1992. It was updated in 2010 (described in standard KSC 9306-2010) and covers most residential and commercial ACs with a cooling capacity up to 35 kW. The Korean SEER standard is similar to the JRA-4046 standard.

According to Choi (2009), the national energy efficiency legislation includes CSPF requirements for split ACs from 2010 onwards in addition to the existing EER requirements. For reversible ACs, the regulatory requirements are set in terms of the average full-load cooling and heating performance (the same index as was previously used in Japan, (EER + COP) / 2; however, there are no plans to use the HSPF as yet).

2.3.2 Temperature and load conditions

The hours per bin specified in the test standard are shown in Table 8 below.

The rated cooling capacity φ_{cr2a} is assumed to be equal to the load *BL* for an outdoor air temperature of 35 °C and the load is anticipated to be zero for an outdoor air temperature of 23 °C.

$$BLc(Tj) = \frac{Tj - 23}{35 - 23} \cdot \varphi_{cr2a}$$

Table 8: Number of hours per bin for KS 9306-2010

j	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tj	°C	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
hj	hours	54	96	97	113	98	96	110	107	105	94	76	61	22	5	2

2.3.3 Testing and modeling in cooling mode: variation from the JRA-4046 standard

Although the method applied in Korea was previously the same as in Japan, modifications have been introduced for variable speed units that concern the evolution of unit performance with outdoor air temperature.

For single speed units, the same parametric values as reported in the Japanese standard are used, as follows:

$P_c(29\ °C) / P_c(35\ °C) = 1.077$ P_c: cooling capacity

$P_e(29\ °C) / P_e(35\ °C) = 0.914$ P_e: cooling electric power

However, for variable speed units, these should be modified as follows:

$P_c(29\ °C) / P_c(35\ °C) = 1.077$ P_c: cooling capacity

$P_e(29\ °C) / P_e(35\ °C) = \mathbf{0.864}$ P_e: cooling electric power

Hence, the EER increases by about 4% for each 1 °C decrease in the outdoor dry bulb temperature. This compares with a comparable value of 3% for the Japanese standard.

2.3.4 Tolerances

The permitted tolerance in measured versus declared seasonal performance metrics was lowered from 10% to 8% in the 2010 version of the KSC9306 standard. This means that the tested value should be 92% or more of the declared value for a unit not to fail a performance verification test.

2.4 Chinese SEER

2.4.1 Introduction

China introduced a seasonal performance metric in 2008 (described in standard GB21455-2008) for VSD (inverter) mini-splits with a cooling power up to 14 kW. This does not apply to multi-split ACs which use an IPLV metric close to the IPLV described in the AHRI 210/240 standard (2008 edition). Note that the standard GB21455-2008 does not apply to fixed-speed split units.

The Chinese SEER standard is similar to the JRA-4046 standard but is only used for the cooling mode at present. Jianhong (2009) suggests that it might be extended in the coming years to the heating mode and that an APF, as applied in Japan, could then replace or complete the SEER metric. The Chinese SEER uses the same method and testing points as are applied in the Japanese method; however, the allocation of hours by temperature bin and the typical building load curve are modified to better represent typical Chinese usage conditions.

2.4.2 Temperature and load conditions

The hours per bin specified in the test standard are shown in Table 9.

Table 9: Number of hours per bin for GB 21455-2008

J	#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Tj	°C	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
Hj	hrs	54	96	97	113	98	96	110	107	105	94	76	61	22	5	2

The rated cooling capacity φ_{cr2a} is supposed to be equal to the load for an outdoor air temperature of 35 °C and the load is anticipated to be zero for an outdoor air temperature of 23 °C.

$$BLc(Tj) = \frac{Tj - 23}{35 - 23} . \varphi_{cr2a}$$

2.4.3 Tolerances

The permitted tolerance for the Chinese SEER is 10%. This means that the tested value should be 90% or more of the declared value for a unit not to fail a performance verification test.

2.5 EU SEER

2.5.1 Introduction

Europe does not currently have a SEER metric; however, a method has been developed to support the ongoing Ecodesign rulemaking process. As of June 2011, this EU SEER calculation method is close to being finalized and is unlikely to change from the current draft test procedure prEN14825:2010. The SEER is the efficiency metric that will be reported to the end-user via the revised energy label. The ISO 5151 T1 EER should be reported in the technical documentation.

2.5.2 Scope

If the prEN14825 draft standard is adopted by EU Member States, the metrics applied should be the same for all electric vapor compression AC and heat pump units. Nevertheless, the most advanced draft energy efficiency regulation only pertains to ACs with a cooling power below 12 kW and to water based heat pumps.

2.5.3 Temperature and load conditions

The climate data applied in the draft test standard is derived from a weighted average of EU air conditioning climates. The bin distribution of hours per temperature is shown below.

Table 10: EU bin distribution to compute SEER, prEN14825:2010

J	**#**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Tj	**°C**	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Hj	**Hrs**	205	227	225	225	216	215	218	197	178	158	137	109	88	63	39	31	24	17	13	9	4	3	1	0

The part load ratio curve equation is: $pl(Tj) = (Tj-16) / (35 - 16)$. This should be multiplied by the rated capacity of the unit to get the cooling capacity in kW. Tj is the temperature of bin j.

2.5.4 Low power mode electricity consumption

In addition to the cooling mode, the low-power mode energy consumption of ACs of less than 12 kW cooling capacity is addressed via a nominal annual duty cycle, which specifies an assumed number of hours of low power mode operation per annum. This number of hours is then multiplied by the magnitude of the low power mode to calculate the associated energy use, which may then be used to adjust the SEER. The $SEER_{on}$ is the metric obtained when low power modes are not taken into account, while the SEER figure does take them into account.

2.5.5 Computing the EU SEER

Calculation principle

The SEER (for cooling) is calculated as:

$$SEER = Q_C / Q_{CE}$$

where:

Q_C is the reference seasonal cooling demand [kWh/year], calculated as:

$$Q_C = Pdesignc * H_{CE}$$

where:

Pdesignc is the design load for cooling [kW], equal to the declared capacity for cooling *Pdc(Tj)* at *Tj* = *Tdesignc* outdoor temperature;

H_{CE} = the equivalent full load on-mode hours for cooling [hrs.]

Q_{CE} is the seasonal electricity consumption for cooling [kWh/year], calculated as:

$$Q_{CE} = (Q_c / SEER_{on}) + H_{TO} \cdot P_{TO} + H_{CK} \cdot P_{CK} + H_{OFF} \cdot P_{OFF} + H_{SB} \cdot P_{SB}$$

where:

H_{TO}, H_{CK}, H_{OFF}, H_{SB} are the number of seasonal operating hours for cooling in respectively the thermostat-off, crankcase heater operation, off- and stand-by modes;

P_{TO}, P_{CK}, P_{OFF}, P_{SB} are the electric power input [kW] in respectively the thermostat-off, crankcase heater operation, off- and stand-by modes.

$SEER_{on}$ is the average seasonal energy efficiency ratio [-], constructed from bin-specific energy efficiency ratios, and weighted by the number of seasonal hours at which the bin condition occurs:

$$SEER_{on} = \frac{\sum_{j=1}^{n} hj * Pc(Tj)}{\sum_{j=1}^{n} hj * \frac{Pc(Tj)}{EERbin(Tj)}}$$

where:

Tj is the bin temperature assigned to bin with index *j*;

j is the bin number;

n is the number of bins;

hj is the number of hours assigned to bin with index *j*;

Pc(Tj) is the part load demand for cooling at bin *j*, calculated as:

$$Pc(Tj) = Pdesignc * pl(Tj)$$

where:

pl(Tj) is the part load ratio, calculated as (and concluding: pl(Tj) = 1.00 at Tj=Tdesignc):

$$pl(Tj) = (Tj\text{-}16) / (35 - 16)$$

EERbin(Tj) is the bin-specific energy efficiency ratio that applies to bin *j*, calculated for either fixed speed, staged, or variable capacity units.

Operating hours by mode

The hours to be used for the different modes of operation are shown in Table 11 below. It should be noted that the values for cooling only and reversible units are likely to change. Nevertheless, European split ACs of less than 12 kW cooling capacity are almost exclusively reversible, so the hours to be used are more likely to be the ones that apply to the reversible product.

Table 11: EU hours[11] of operation in the different modes to compute the SEER, prEN14825

Type of air conditioner / function		Unit	Heating season	On mode cooling: H_{CE} heating: H_{HE}	Thermostat-off mode H_{TO}	Standby mode H_{SB}	Off mode H_{OFF}	Crankcase heater mode H_{CK}
Air conditioners, except double ducts and single duct								
Cooling mode, if appliance offers cooling only		hrs./a		350	221	2142	5088	7760
Cooling and heating modes, if appliance offers both modes	Cooling mode	hrs./a		350	221	2142	0	2672
	Heating mode	hrs./a	Average	1400	179	0	0	179
			Warmer	1400	755	0	0	755
			Colder	2100	131	0	0	131

[11] Note that the hours in the table do not sum up to 8760 hours (one year) as, for instance, the crankcase heater is likely to remain on while the unit is plugged in. More details on the computation of these hours can be found in the EuP Lot 10 study (2009).

2.5.6 Testing and theoretical modeling to compute the performance for different (load, outdoor temperature) couples

The EU SEER is based upon the determination of four part load EERs for different load and temperature conditions used to compute the $SEER_{on}$ metrics. The four part load conditions are presented in Table 12 below for air-to-air AC units. The other bin efficiencies are interpolated from these four test conditions. For part load ratios lower than 21%, the efficiency remains equal to the one for point D.

Table 12: Part load conditions required to compute the EU $SEER_{on}$, prEN14825

	Part load ratio	Part load ratio (%)	Outdoor air dry bulb temperature (°C)	Indoor air dry bulb (wet bulb) temperatures (°C)
A	(35-16)/(TDesignc -16)	100%	35	27(19)
B	(30-16)/(TDesignc -16)	74%	30	27(19)
C	(25-16)/(TDesignc -16)	47%	25	27(19)
D	(20-16)/(TDesignc -16)	21%	20	27(19)

The tests performed to determine these four points depend on the means used to reduce capacity, and beyond that, upon the individual unit control technology as follows:

- Fixed-speed units (ON-OFF control): four full load tests are performed with varying outdoor air temperature according to conditions A, B, C, and D. The part load degradation factor is based on the same C_D^c low as is used in the US test procedure and is calculated in the same manner. The default value is 0.25 (as in the US and Japan); however, as in the US procedure, manufacturers have the right to do additional testing to verify the actual value and to substitute the default value for the measured one.

- Staged capacity units: only two steps are envisaged, although the procedure can be applied to units with more steps by only characterizing the highest and lowest capacity stages. The procedure is essentially the same as the approach used in the AHRI and JRA test procedures; however, for a given outdoor air temperature, if the load lies between the cooling power of the two stages, the interpolation requires the testing of these two stages at this outdoor air temperature to make the interpolation. The interpolation is linear in electric power but nonlinear in EER, as is the case for the AHRI standard.

- VSD (inverter) units: the test point conditions can be attained directly by the control of the AC; thus only 4 test points are required for the $SEER_{on}$.

2.5.7 Tolerances

Although the legislation has not yet been approved, the permitted tolerance regarding seasonal performance metrics has been set to 8% in the draft legislation. If this is adopted in legislation, the tested value should be 92% or more of the declared value for the unit to pass a verification test.

2.5.8 How data demanding is the EU SEER procedure?

In this evaluation, only the required testing points to compute the $SEER_{on}$ are considered; supplementary tests to compute low power mode are not considered. For staged capacity units, the number of testing points depends on the capacity ratio of the lower capacity stage. If it is a two stage (twin compressor) unit, where the minimum capacity of the first stage is, for instance, 55% of full capacity, the unit should be tested at the following conditions for a total of five test points:

- A35/Stage 1 or 100% (or the ISO T1 condition);
- A30/Stage 1 and A30/Stage 2, as the 100% and 55% of full load conditions fall above and below the target 75% load;
- A25/Stage 2, as the target 50% load is lower than the smallest available capacity stage of 55% of full load; and
- A25/Stage 2, as the target 25% load is lower than the smallest available capacity stage of 55% of full load).

Table 13 summarizes this for each of the technology capacity control cases.

Table 13: Number of test points (required and optional), EU SEER

prEN14825	SEER
Fixed-speed compressor	4
Two capacity stages	5
VSD (inverter)	4

2.5.9 Supplementary information about the EU SEER

Because there is presently no data reported by manufacturers with this metric, low power modes values for ACs on the market are not known and have to be assessed by other means for the analysis presented in this study. This is done via the use of information supplied in the existing EU Ecodesign preparatory study.

2.6 Summary of specific characteristics of the Asian SEER metrics

In the derivation of national load curves, the Chinese, Japanese, and Korean standards each have one climate condition that differs from the US standard. In addition, the method they use to compute AC electricity consumption is simplified in order to decrease the number of required test points and thereby reduce the associated testing costs. To this end, several default assumptions are made to enable the AC performance at other design conditions to be modeled. In addition, while the US SEER only addresses the cooling mode, the principal Japanese metric addresses both the cooling and heating modes. In Japan, the metric reported to the consumer is the APF (Annual Performance Factor), which is defined as the weighted average of the CSPF (Cooling Seasonal Performance Factor) and the HSPF (Heating Seasonal Performance Factor). The term CSPF, which is equivalent to the SEER, is common to the Chinese, Japanese, and Korean test standards, and the HSPF is like the SEER but for the heating mode. Although they are measured and used to produce the APF, the CSPF and HSPF are generally not reported directly to the consumer. For cooling-only split ACs, the APF equals the CSPF. However, most residences in Japan use reversible variable speed drive (VSD) mini-split AC units as the primary heating means; hence, almost all ACs sold on the Japanese market are reversible. This means that to usefully benchmark the seasonal cooling performance requirements in Japan, it is necessary to benchmark the APF value of reversible units, and thus to consider the heating mode as well as the cooling mode.

2.7 Specific characteristics of the EU SEER metric

The draft EU SEER test standard is similar to the US SEER test standard, except it uses different climatic conditions. In addition, the method used to compute AC electricity consumption is not identical and requires the use of a different number of test points. Lastly, unlike its older US counterpart, the draft European SEER does not just account for power consumed during active operation for cooling, but also includes the impact of standby and other low power modes (such as the energy used to heat the crank case to prevent freezing in the winter). It is thus a slightly more comprehensive energy performance metric.

2.8 Comparison of the number of test conditions for the SEER metrics

Across the different SEER test standards, the number of test points (required or optional) varies depending on the calculation method applied and the permitted options. The number of testing points is summarized in Table 14.

Table 14: Number of test points (required and optional) in the different SEER test standards depending on the capacity control characteristics of the air conditioner under test

USA	Fixed-speed	Two stages	VSD
Min	2	4	5
Max	4	6	7
China, Korea, Japan	**Single speed**	**Two stages**	**VSD**
CSPF	1	2	2
Europe	**Single speed**	**Two stages**	**VSD**
SEER	4	5	4

2.9 Differences in permitted test tolerances

Every test standard has its own permitted tolerance in the declared EER, which is used in the event of verification testing. Under a verification test, a unit is deemed to have an accurate rating if its manufacturer declared energy performance is within the permitted tolerance of the independently measured energy performance. Different tolerances introduce an extra layer of complexity when comparing declared energy efficiency ratings and energy efficiency policy settings across economies; due to the commercial advantage from having better energy efficiency, there can be a tendency for producers to declare their product performance as close as possible to the highest reasonably justifiable value without there being a legal basis for a challenge. There is no firm data to establish to what extent producers make use of this possibility. However, as there is no systematic reason to believe producers supplying different economies have different abilities to manage their production tolerances (i.e., the degree to which there is variation in the performance of each produced unit of a product), it is reasonable to take these tolerances into account when comparing efficiency levels across economies. The permitted tolerances in EER declarations are shown in Table 15. The same tolerances apply for the associated national SEER metrics.

Table 15: Maximum permitted tolerances in declared EER values in the different economies

	US	EU	China	Korea	Japan
Tolerances	0%	8%	10%	8%	10%

Depending on how well they know the performance of their unit, different manufacturers may declare performance closer to the tolerance limit. In principle, however, the average of all declarations should be above the indicated target by the same percentage X for every country, so that the difference in declared values should on average be the difference in the tolerances (i.e., 100% + X % in the USA, 92% + X % in Europe, and so on, where the first value chosen is 100% minus the permitted tolerance). Therefore, to take into account systematic differences in permitted tolerances across the five economies considered in the EER and SEER benchmarking analysis, the calculated value is corrected by the permitted tolerance of the specific economy, as shown here for the case of Korea:

Korea EER declared = Korea EER measured / 0.92

3 Benchmarking conversion formulae - EER

As the world's AC markets are dominated by non-ducted split-packaged units, called mini-splits in North America, these are the primary focus of the AC benchmarking efforts discussed in this report. These are far and away the most common type of residential AC used around the world and are also in widespread use in non-residential buildings. In principle, the conversion functions are dependent on the means of capacity control used by the AC unit; AC units having fixed speed compressors are expected to behave quite differently from those that have compressors controlled with a variable speed drive (VSD). Thus the two cases are treated separately when developing the conversion formulae in the analysis presented below. The resulting EER and SEER conversion formulae developed within this study are then applied to benchmark the stringency of the existing MEPS schemes in major economies using SEER metrics, namely China, the EU, Japan, Korea, and the US, in order to compare their respective levels of ambition.

3.1 Overview

A study by Henderson (2001) conducted within the rubric of a previous benchmarking project for the Asia-Pacific Economic Cooperation (APEC) forum assessed EER test differences. The goal of the APEC project was similar to this project, i.e., to propose simple conversion algorithms to convert between efficiency metrics used in different economies, but the scope was limited to EER metrics.

After stating the differences in EER test conditions that apply in each economy, the modeling hypotheses which are applied to take those effects into account are described and discussed. This enables conversion coefficients between the EER applied in North America, Korea, and the ISO 5151 T1 EER to be computed. For all other economies under consideration in this study, the EER at full load is measured in line with ISO 5151.

3.2 Regional EER test condition variations

There are minor variations in the standard test rating conditions applied in some economies to determine the EER, and these lead to slight variations in the EER recorded whenever national test standards are not fully aligned with ISO 5151. The previous work reported by Henderson (2001) synthesized these differences, summarized in Table 1. The main differences in testing conditions occur for economies in North America and Korea. The other economies considered in this study all measure the EER using the ISO 5151 T1 test condition, and the only differences that occur are due to the application of different tolerances, rather than differences in the test conditions. Thus, the remainder of this section simply addresses the question of how to convert between EERs measured under the ISO 5151 T1 condition and those measured under the test conditions applied in North America and Korea.

Table 16: Summary of full-load efficiency test conditions used in different national test standards (from Table 59, Append B, EES Report, Nov. 99 as reported by Henderson, 2001)

Economy	Test procedure name	Test point name	Similarity to ISO 5151 point T1	Stated climate type	Air temperature entering the indoor side		Air temperature entering the outdoor side		Condenser water temperature	
					Dry-bulb	Wet-bulb	Dry-bulb	Wet-bulb	Inlet	Outlet
Australia	AS/NZS 3823.1.1-98	T1	T1 except wet-bulb tolerances	Moderate	27±1(0.3)	19±0.6(0.2)	35±1(0.3)	24±0.6(0.2)	30±0.2(0.1)	35±0.2(0.1)
Canada	CAN/CSA-C368.1-M90	None	close to T1 excluding water cooled units	Not stated	26.7±0.56 (0.28)	19.4±0.34 (0.17)	35±0.56 (0.28)	23.9±0.34 (0.17)	NA	NA
	CAN/CSA-C273.3-M91	A	T1 excluding water cooled units	Stead State Wet Coil Test A	27±1(0.3)	19±0.5(0.2)	35±1(0.3)	28±0.5(0.2)	NA	NA
	CAN/CSA-C744-93	None	close to T1 excluding water cooled units	Not stated	26.7±0.56 (0.28)	19.4±0.34 (0.17)	35±0.56 (0.28)	23.9±0.34 (0.17)	NA	NA
China	GB 7725-96	T1	T1	Moderate	27±1(0.3)	19±0.5(0.2)	35±1(0.3)	24±0.5(0.2)	30±0.2 (0.1)	35±0.2 (0.1)
Hong Kong	ISO 5151-94(E)	T1	T1	Moderate	27±1(0.3)	19±0.5(0.2)	35±1(0.3)	24±0.5(0.2)	30±0.2 (0.1)	35±0.2 (0.1)
Japan	JIS C9612-94	None	T1 (except water temperature tolerances)	Not stated	27±1(0.3)	19±0.5(0.2)	35±1(0.3)	24±0.5(0.2)	30±0.3	35±0.3
	JIS B8616-93									
Korea	KS C 9306-97	NA	T1		27±1	19.5±1	35±1	24±0.5	30±0.5	35±0.5
	KS B 6369-95	NA	T1		27±1	19.5±1	35±1	24±0.5	30±0.5	35±0.5
Mexico	NOM-073-SCFI-94	None	close to T1 except for water condenser units	Not stated	26.6±0.55 (0.28)	19.4±0.33 (0.17)	34.9±0.55 (0.28)	23.8±0.33 (0.17)	NA	NA

Economy	Test procedure name	Test point name	Similarity to ISO 5151 point T1	Stated climate type	Air temperature entering the indoor side		Air temperature entering the outdoor side		Condenser water temperature	
					Dry-bulb	Wet-bulb	Dry-bulb	Wet-bulb	Inlet	Outlet
International	ISO 5151-94(E)	T1	T1	Moderate	27±1(0.3)	19±0.5(0.2)	35±1(0.3)	24±0.5(0.2)	30±0.2(0.1)	35±0.2(0.1)
Philippines	PNS 240-89	D	close to T1 except outdoor wet-bulb and differences for water condenser units	Philippines	27±0.5(0.3)	19±0.3(0.2)	35±0.5(0.3)	27±0.3(0.2)	31±0.2(0.1)	37±0.2(0.1)
Chinese Taipei	CNS 3615–95	Cooling condition	very close to T1	Not stated	27±1	19.5±0.5	35±1	24±1	30±0.5	35±0.5
	CNS 2725-95	Cooling condition	close to T1 except for water condenser units	Not stated	27±1	19.5±0.5	35±1	24±0.5	30±0.5	30±0.6
Thailand	TIS 1155-2536 (1993)		T1 except for exclusion of arithmetic mean tolerances	Not stated	27±1	19.±0.5	35±1	24±0.5	NA	NA
USA	10 CFR 430 Subpart B, Appendix F, ANSI/AHAM RAC-1-82 & ASHRAE 16-83-RA88	None	close to T1 except for water condenser units	Not stated	26.7±0.56 (0.28)	19.4±0.34(0.17)	35±0.56(0.28)	23.9±0.34(0.17)	23.9±0.22(0.11)	35±0.22 (0.11)
	10 CFR 430 Subpart B, Appendix M &ARI 210/240-94	A	T1 excluding water cooled units	Steady state Wet Coil Test A	26.7±1.1(0.28)	19.4[2] ±0.56(0.17)	35±1.1(0.28)	23.9±0.56(0.17)	29.4±0.28 (0.11)	35±0.28 (0.11)
	ARI 310/380-93	None	close to T1 excluding water cooled units	Not stated	26.7±0.56 (0.28)	19.4±0.34(0.17)	35±0.56(0.28)	23.9±0.34(0.17)	NA	NA
International	ISO 5151-94(E)	T1	T1	Moderate	27±1(0.3)	19±0.5(0.2)	35±1(0.3)	24±0.5(0.2)	30±0.2(0.1)	35±0.2(0.1)

The differences in testing conditions for the US, Korea, and ISO 5151 T1 tests are summarized in Table 17. The main differences occur for the indoor dry bulb and wet bulb temperatures.

Table 17: Standard rating efficiency test conditions for the ISO 5151 standard, NAFTA and Korea, extract from (Henderson, 2001)

	Outdoor DB (°C / °F)	Indoor DB (°C / °F)	Indoor WB (°C / °F)	Indoor RH (%)	Indoor Dew Pt. (°C / °F)
ISO T1	**35** / 95	**27** / 80.6	**19** / 66.2	46.9%	14.6 / 58.2
Test A (NAFTA)	35 / **95**	26.7 / **80**	19.4 / **67**	51.1%	15.6 / 60.0
Korea	**35** / 95	**27** / 80.6	**19.5** / 67.1	49.5%	15.5 / 59.9

3.3 Impact of variations in outdoor and indoor conditions on the EER

Table 18 and Table 19 below report the EER and maximum capacity correction factors that are recommended by Henderson (2001) to take into consideration the slight variations around the standard rating conditions for outdoor and indoor air temperatures. The adjustment factors depend on the type of compressor being used and the type of thermostatic control (in Table 19 TXV stands for thermostatic expansion valve).

Table 18: Recommended factors to adjust for outdoor conditions variations (% change per °C increase in outdoor air temperature: dry bulb) (Henderson, 2001)

	Efficiency	Capacity
Reciprocating Compressor	-2.0%	-1.2%
Scroll Compressor	-2.4%	-0.8%

Table 19: Recommended factors to adjust for indoor conditions variations (% change per °C increase in indoor air temperature) (Henderson, 2001)

	Efficiency		Capacity	
	WB	DB	WB	DB
TXV	2.4%	0.16%	3.2%	0.14%
Short Orifice	1.6%	0.14%	2.4%	0.14%

As explained by Henderson, the impact of the indoor dry bulb variation on both efficiency and capacity is small and can be neglected when comparing EERs measured under NAFTA or Korea and ISO 5151 T1. However, the impact of the variations in the indoor wet bulb temperatures is important and needs to be considered. In general the adjustment factors found for thermostatic expansion valve (TXV) units should be considered as default, as these are much more common on modern mini-split products than are the older short orifice devices. Applying the findings of Henderson to typical current AC unit configurations, we would conclude that the 2.4%/°C factor of correction applicable on wet bulb indoor temperature variation on units with TXV should be the most appropriate one.

3.4 EER conversions: NAFTA and Korea to ISO

Following the correction formulae set out above and noting the difference in wet bulb temperature of 0.4 °C, the conversion between EER values measured under ISO 5151, point T1 and EERs recorded under the NAFTA point A condition can be expressed as simply:

$$EER_{NAFTA} = EER_{T1} * 1.0096$$

To convert an EER expressed in Btu/Wh to SI W/W values, the EER_{NAFTA} should be multiplied by 0.2931.

Thus an appliance with an EER of 3.0 W/W measured under ISO 5151 would have an EER of 3.03 (W/W) under NAFTA, i.e. of 10.33 Btu/Wh, if differences in the testing tolerances are not taken into account.

For the cooling capacity, the conversion factor can be expressed as:

$$CC_{NAFTA} = CC_{T1} * 1.013, \text{ where the cooling capacity, CC, is expressed in SI units.}$$

For Korea, the wet bulb temperature difference is slightly more important, at 0.5 °C instead of 0.4 °C. However, there is no inlet temperature correction and the same correction coefficient as for NAFTA can be used.

Following the hypotheses set out above and noting the difference in wet bulb temperature of 0.5 °C, the conversion between EER values measured under ISO 5151, point T1 and EERs recorded under the Korean condition can be expressed as simply:

$$EER_{Korea} = EER_{T1} * 1.012$$

3.5 EER conversions: summary

The analysis presented previously has shown there are two factors that need to be considered when making EER conversions: differences in test temperatures and differences in permitted tolerances. In practice the impact of different tolerances can be much higher than the impact of the nominal differences in test temperature applied in the national test standards.

The APEC assessment showed that all the economies under consideration within the current study are aligned with the ISO 5151 test condition except for Korea and the US. The NAFTA test conditions are very similar to the ISO 5151 test conditions except for a significant but modest variation in the indoor wet bulb temperature. Henderson demonstrated that it is viable to correct for this by applying the following conversion formulae for the EER and cooling capacity (CC):

$$EER_{NAFTA} = EER_{T1} * 1.0096$$

$$CC_{NAFTA} = CC_{T1} * 1.013$$

where SI units are used[12] and T1 refers to the ISO 5151:1994 T1 test condition. This enables conversion coefficients between the EER applied in North America and the ISO 5151 T1 EER to be computed. In the case of Korea the following conversion should be used:

$$EER_{Korea} = EER_{T1} * 1.012$$

While applying these correction factors improves the comparability of the EERs produced under the principal sets of test conditions, the magnitude of the correction is actually very small and there is a bigger effect from

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[12] To convert from Btu/Wh to SI W/W values, the EER_{NAFTA} should be multiplied by 0.2931.

applying the tolerance corrections in line with the method described in section 2.9 (these are not included in the above formulae).

Although the conversion coefficients between the NAFTA and ISO EER were established for central ACs sold on the US market using R22 refrigerant, the testing of split-packaged AC units using R410A refrigerant conducted within the current study produced results that are consistent with Henderson's formulation. Combined with the lack of obvious physical reasons for believing the conversion coefficients should be different for split-packaged units using R410A, we conclude that the EER conversions proposed by Henderson will be applicable for these units too. We therefore propose that the formulae above be used to convert between NAFTA or Korea EER and ISO EER test results. All other economies of interest for this study use EER metrics that are harmonized with the ISO 5151 EER metric and hence are already aligned. The impact of differences in tolerances can then be taken into account by applying the formulation set out in section 2.9.

4 Benchmarking conversion formulae - SEER

This section explains the methodology used to convert between the various national SEER metrics for non-ducted and ducted split AC units. The methodology is elaborated separately for fixed-speed and variable speed units. Provisional SEER conversion formulae are developed in each technology case for each economy, the results are tested, and in some cases the formulae are refined in light of the additional evidence. Finally, our best estimates for each SEER conversion formulae are presented and the errors associated with their use described. The formulae are also presented taking into account an adjustment for the impact of different test tolerances. These formulae are then applied in subsequent sections to compare the ambition of current energy efficiency policy settings.

4.1 SEER conversions for fixed-speed mini-split AC units

This section presents a methodology to convert between the various national SEER metrics for fixed-speed (on-off) mini-split units and presents the associated conversion formulae for each economy of interest.

4.1.1 US: AHRI 210/240 standard

Indirect method

A simplified formula, with an excellent level of accuracy (Henderson 2001) compared to the other equivalent SEER cases, is used to compute the SEER from the EER as follows:

$$SEER = EER(82\ °F) * (1 – Cd * (1 – 0.5))$$

Where EER(82 °F) is the full load efficiency of the AC for an outdoor air temperature of 82 °F (or 27.8 °C); Cd is the cycling coefficient, and 0.5 is the load ratio.

This can be rewritten as a function of the standard rating condition EER(95 °F) by characterizing the ratio EER(82°F) / EER(95°F), which, a priori, may vary with the product. Henderson (2001) studied the potential default values for this ratio for different compressor types (reciprocating and scroll), with different design points (high optimal compression ratio and medium optimal compression ratio) and different thermostatic valves. All values were established for the R22 refrigerant. The final median recommended values are -2.0% EER/°C for scroll compressors and -2.4 %EER/°C for reciprocating compressors with R22 refrigerant. However, this is intended for small deviations around the design point (assumed to match a 50 °C refrigerant condensing temperature). Still according to Henderson, the average ratio for lower indoor temperatures derived from an analysis using a detailed simulation model of an AC lies between -3.05% and -2.8%. In addition, the ratio tends to decrease with lower outdoor air temperature, with -3.05% EER/°C corresponding to a 45 °C condensing temperature.

Computing this same slope for ACs working with R410A refrigerant tested under JRA-4046 (2004) and JRA-4048 (2006) standards gives a default slope of -2.97% EER/°C. Thus -3.0% EER/°C seems a reasonable candidate to be used as a default value. An interval could be established analyzing current scroll compressors working with R22 and R410A refrigerants and considering different refrigerant condensing temperatures at standard rating conditions. Complementary testing performed by CEIS within this study for a non-ducted and a ducted unit, tested with the AHRI 210/240 standard testing conditions, led to an exact slope of -3.0% EER/°C in both cases.[13]

Cd can be taken as a default value, but it can also be established through testing. In practice it can vary between 0.24 (0.25 being the default value) and 0.04 (Dougherty, 2002). Cd varies because of indoor fan power and control during the off cycle, and with the type and bleeding properties of the thermostatic expansion valve when cycling. As it is not public data, it is not possible to know the Cd value for a given unit.

Keeping the following values:

- 0.04 ≤ Cd ≤ 0.25; and
- EER(82 °F) / EER(95 °F) = 1.217 (-3% EER/°C)

Would result in the ratio of the SEER to EER being:

- 1.07 ≤ SEER / EER ≤ 1.19, with the simplified formula; and
- 1.10 ≤ SEER / EER ≤ 1.20, with the complete formula.

However, larger variations of the SEER to EER ratio could be seen due to variations of:

- the ratio EER(82 °F) / EER(95 °F) (or of the average EER variation slope with ambient temperature); and
- the control of the outdoor air flow rate at low ambient and possibly variable indoor flow rates.

Direct method

Figure 5 below maps the relationship between SEER and EER using data supplied by the US AC industry to the US DOE. The results presented in the figure below show:

- It is possible to clearly separate single speed units from capacity modulating units based on the SEER/EER ratio;
- However, supplementary technical information regarding the indoor and outdoor air flow control is needed in order to be able to precisely map the relationship of SEER/EER. Even with this detailed technical information, there remains a relatively large degree of variation in the SEER/EER ratio for individual units.
- Overall, the SEER/EER ratio for single speed units lies between 1.01 and 1.22, which is a slightly larger interval than we induced from the off design performance parameters [1.07; 1.20]. To reach the wider interval of SEER/EER ratios observed, and using our simple parameters, the average slope EER variation should vary between -2.4% EER/°C and -3.2% EER/°C.

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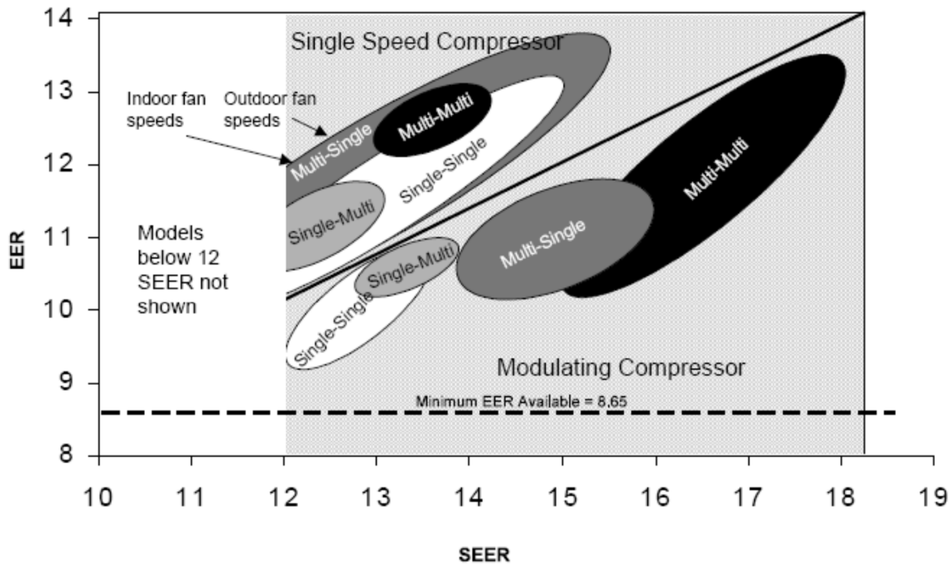
13 Values computed on the basis of the test reports by CEIS in the frame of this study.

Figure 5: Effects of Compressor and Fan Modulation on the EER-SEER Relationship in Existing 3-ton Split Air Conditioning Systems



Source: *ARI Unitary Directory*, February-July 1998

The next step is to update the figure above by analyzing the US AHRI directory for central ACs. This would require a large amount of work, as the types of compressor controls (and possibly of fan controls) are not entered in the directory and must therefore be retrieved from manufacturers' catalogues.

The more recent update in 2005[14] gives a similar figure from the AHRI database of central ACs, shown in Figure 6 below. This data, however, predates the enforcement of the SEER 13 legislation (see Section 5).

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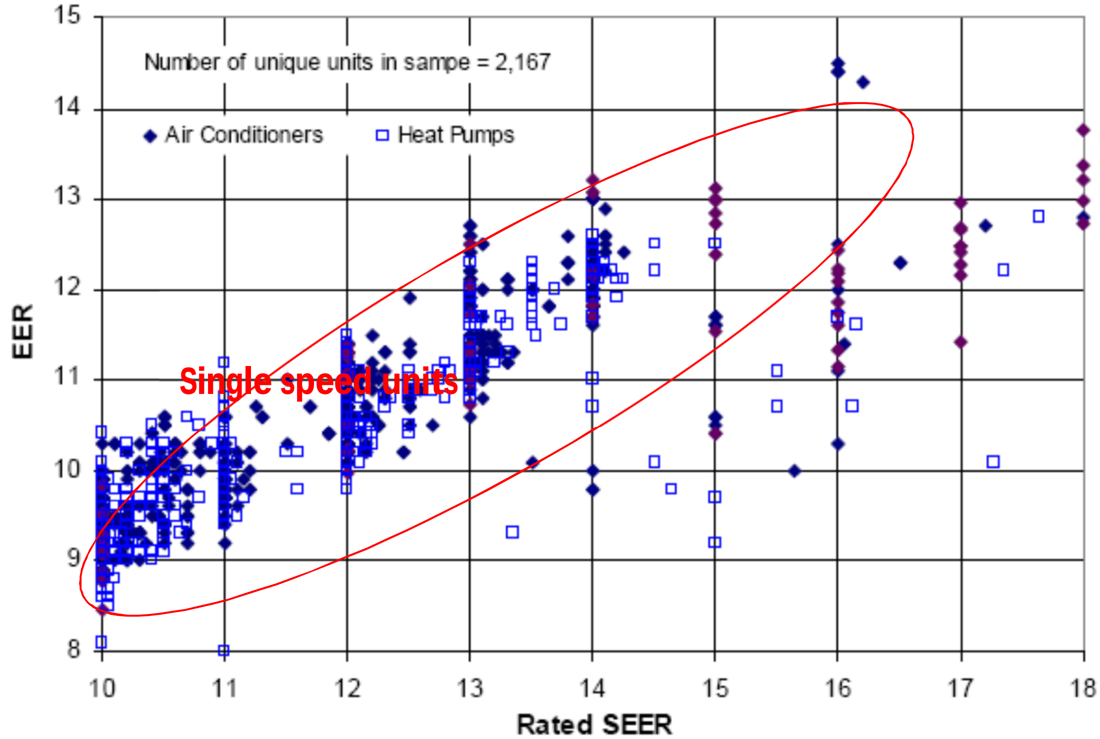
14 EER & SEER as Predictors of Residential Seasonal Cooling Performance. Updated Report of Residential Research. Developed by Southern California Edison, Design & Engineering Services, 6042 N. Irwindale Avenue, Suite B Irwindale, California 91702. December 15, 2005.

Figure 6: Performance characteristics of SEER-rated cooling systems: Rated SEER(82°F) versus Rated EER(95°F)



All in all, the SEER/EER ratio for single speed units lies between 1.00 and 1.25, thus a slightly larger interval than in Figure 5 above [1.01; 1.22]. To reach the wider interval of SEER/EER ratios observed, and using our simple parameters, the average slope EER should vary between -1.9% EER/°C and -3.9% EER/°C.

Correction for ducted units

Most units on the US market are ducted, and so consume supplementary energy to power the fan that delivers the required network static pressure. In ISO 5151, and in all other seasonal performance standards addressed in this study, a correction is applied to take this into account. For the two units tested by CEIS, this EER correction was 1.5% for the ducted inverter and 3.5% for the ducted single speed unit. In the absence of more data, we assume that 2.5% should be used as the average value, with 1% and 4% respectively as the minimum and maximum values.

4.1.2 Single speed units in Japan tested via the JRA-4046 and -4048 standards

As explained before in the description of the JRA standard, the off design parameters for single speed units are fixed to:

- Cd = 0.25; and
- EER(29°C) / EER(35°C) = 1.18 (-2.97% EER/°C).

This can be compared to the testing by CEIS, where the SEER/EER ratio for the AHRI 210/240 standard test conditions gave an exact slope of -3.0% EER/°C; indeed, the results are different with the test results of the EER(29°C) / EER(35°C) obtained with the Japanese standard. In the latter case the slope was found to be -2.7% EER/°C for the ducted unit and -4.1% EER/°C for the non-ducted unit.

The use of the default values leads to a single value of the CSPF/EER ratio:

- CSPF / EER(35°C) = 1.06

This is comparable with the lower end of the interval established for the AHRI 210/240 standard, for the same EER slope and Cd value of 0.25.

The CSPF index is not published by manufacturers in Japan; only the EER, COP, and APF ratings are published. We should then try to link the EER to the APF for single speed units; this would enable broad comparison of reversible on-off units to Japanese inverter units. However, it is believed the added value would be low as it would be necessary to guess the heating capacity, the COP at full load, and the variation of COP with outdoor air temperature while we have no detailed data in heating mode for on-off products. Furthermore, the data that is available, such as that in the EuP Lot 10 study, exhibit very large variations. Consequently, we only consider the CSPF figure in this report for single speed units.

4.1.3 Single speed units in Korea

With the KSC9306-2010 standard, it is possible to compute the CSPF for on-off mini-split ACs. The calculation is done with the same default coefficient as described in the Chinese standard:

- Cd = 0.25; and
- EER(29°C) / EER(35°C) = 1.18

The use of the default values leads to a single value of the SEER/EER ratio as follows:

- SEER / EER(35°C) = 1.03

4.1.4 Single speed units in China

With the GB/T 7725-2004 standard, it is possible to compute the CSPF for on-off mini-split ACs. The calculation is done with the same default coefficient as described in the Chinese standard for the climatic conditions specified in section 2.4:

- Cd = 0.25; and
- EER(29°C) / EER(35°C) = 1.18

The use of the default values leads to a single value of the SEER/EER ratio as follows:

- SEER / EER(35°C) = 1.02

4.1.5 Single speed units in Europe

The situation for single speed units tested under the European standard is similar to the case for the US, except there are no simplified metrics and the Cd default value of 0.25 can be challenged (i.e., manufacturers are not required to use the default value if they do additional tests to demonstrate what the actual degradation coefficients are for their products). In addition, the prEN14825:2010 standard requires different low power mode values to be associated with an annual duty cycle expressed in terms of hours spent in that mode per year.

There is still no catalogue data available that reports these low power mode values as the legislation is not yet in force as of July 2011. We therefore base our default values on those used in the EuP Lot 10 study and information obtained in the tests conducted by CEIS in the course of this study.

The average, minimum, and maximum values to be used are presented in the table below. All values are presented as a percentage of the nominal power input.

Table 20: Default values of low power modes for EU SEER, in % of rated input power or in W

	Non ducted			Ducted			
	Min	Ave	Max	Min	Ave	Max	
Thermostat Off Power (Pto)	2%	3%	4%	4.5%	6.0%	7.5%	in % of T1 input power
Standby Power (Psb)	2	5	12	2	5	12	in W
Off mode Power (Poff)	-	-	-	-	-	-	
Crankcase Heater Power (Pck)	0%	0%	1%	0%	0%	1%	in % of T1 input power

The thermostat off power, Pto, is mainly caused by the indoor fan power that remains on when the unit is not cooling (for hours without cooling load) but when the end-user leaves the AC in cooling mode. This is much higher for ducted units because of the energy consumption required to maintain the available static pressure to serve the ductwork. For all tested units, the fan did work all the time when the compressor was off and the unit was in cooling mode.

Standby power lies typically between 1 W and 10 to 15 W.

A crankcase heater was used in only one of the 4 units tested by CEIS and was found to have a power demand of 35 W, which is close to what was previously identified in EuP Lot 10 study. It was found to work continuously, as soon as the compressor is off. This is equivalent to 1% of the rated input power. The average product is not assumed to be fitted with a crankcase.

Finally, most units have a remote control and consequently do not have an off mode.

4.1.6 SEER conversion factors for single speed units

Correction for tolerances

Every standard has its own permitted tolerance, as presented in Table 21 below.

Table 21: Maximum permitted tolerances in the declared seasonal performance values in the different economies

	US	EU	China	Korea	Japan
Tolerances	0%	8%	10%	8%	10%

Different manufacturers, depending on how well they know the performance of their unit, may declare performance closer to the tolerance limit. But in principle, the average of all declarations should be above the indicated target by the same percentage X for every country so that the difference in declared values should on average be the difference in the tolerances (100% + X% in the USA, 92% + X% in Europe, and so on). Then, to take into account different tolerances in different countries, the calculated value is simply corrected by the tolerance of the specific country as follows (here for Korea):

Korea SEER declared = Korea SEER measured / 0.92

China, Korea, Japan

These countries have very similar test standards, with only slightly different climates and a smaller permitted tolerance in Korea. Deriving the SEER conversion factors between those values is thus straightforward and has very low uncertainty, as all parameters are fixed.

Table 22: Conversion coefficients for single speed units in cooling mode, China, Korea, Japan

	China	Korea	Japan
China	100%	99%	104%
Korea	101%	100%	105%
Japan	96%	95%	100%

Table 22 is to be read as [column SEER] = [X%] * [row SEER], so China SEER = 101% * Korea SEER.

US

The US SEER conversion factors are computed against the China SEER and then can be converted into the Korea or Japan SEERs via the conversion coefficients in Table 22. The US conversion factor includes the NAFTA-to-ISO correction discussed previously. For ducted units, when converting the US SEER to any other metrics, the SEER should be multiplied by a correction factor of 2.5% on average (the minimum correction being 1% and the maximum 4%). This leads to the corrected table below.

Table 23: SEER conversion coefficients for single speed units in cooling mode, US versus China

US versus China		Min	Average	Max
Parameters	Cd	0.04	0.1	0.25
	EER vs. OAT slope	-4.0%	-3.0%	-2.0%
Results	US SEER = Y * China SEER (non-ducted)	Y=91%	Y=99%	Y=115%
	US SEER = Y * China SEER (ducted)	Y=90%	Y=97%	Y=110%
	China SEER = X * US SEER (non-ducted)	X=110%	X=101%	X=87%
	China SEER = X * US SEER (ducted)	X=111%	X=103%	X=91%
Note: OAT = Outdoor air temperature				

For the average case above, the lower average ambient temperature in the US standard and the lower Cd value, both of which lead to higher SEER values, are almost compensated by the difference in the permitted tolerance.

These results have translated the variation in single speed US SEER/EER ratios observed on the US market, which may not be representative of the mini-split type product segment; however, given that further data is not available, we assume that this variation is also applicable for mini-split units.

EU

In addition to the variation in slope and Cd, the EU SEER conversion factors take into account the low power modes. For the US SEER, this leads to the need for separate treatment of ducted units, because of their higher thermostat off-mode power. The SEER conversion coefficients derived for non-ducted units are presented in Table 24 below.

Table 24: SEER conversion coefficients for single speed units in cooling mode, EU versus China

		Non-ducted			Ducted		
EU versus China		Min	Ave	Max	Min	Ave	Max
Parameters	Cd	0.04	0.1	0.25	0.04	0.1	0.25
	EER Vs OAT slope	-4.0%	-3.0%	-2.0%	-4.0%	-3.0%	-2.0%
	Pto, in % of rated input	2%	3%	4%	4.5%	6.0%	7.5%
	Psb, in W	2	5	12	2	5	12
	Poff, in % of rated input	-	-	-	-	-	-
	Pck, in % of rated input	0%	0%	1%	0%	0%	1%
Results	EU SEER = Y * China SEER	128%	112%	86%	125%	109%	84%
	China SEER = X * EU SEER	78%	90%	117%	80%	91%	119%

Conclusions

The conversion coefficients are straightforward for the SEERs computed with the Chinese, Japanese and Korean indexes, for which the only input is the EER. However, for US and EU standards, more consumption parameters from the products are taken into account in the SEER calculation.

With more degrees of freedom and a poor knowledge of the distribution of these parameters, the study tried to give a meaningful average and robust uncertainty limits to the resulting SEER conversion figures. These are summarized in Table 25 below for non-ducted units. The table is to be read as Y = α * X, with α_min, α_ave, and α_max respectively representing the minimum, average, and maximum conversion coefficients.

Table 25: Conversion coefficients for single speed mini-splits between EU, US non-ducted, China, Korea, and Japan SEERs

Y	X	α_min	α_ave	α_max
Korea	China	NA	99%	NA
Japan CSPF	China	NA	104%	NA
US SEER non-ducted	China	91%	99%	115%
EU SEER non-ducted	China	86%	112%	128%
China	Korea	NA	101%	NA
Japan CSPF	Korea	NA	105%	NA
US SEER non-ducted	Korea	92%	100%	116%
EU SEER non-ducted	Korea	87%	113%	129%
China	Japan CSPF	NA	96%	NA
Korea	Japan CSPF	NA	95%	NA
US SEER non-ducted	Japan CSPF	87%	95%	111%
EU SEER non-ducted	Japan CSPF	82%	107%	123%
Korea	US SEER non-ducted	86%	100%	109%
Japan CSPF	US SEER non-ducted	90%	105%	114%
China	US SEER non-ducted	87%	101%	110%
EU SEER non-ducted	US SEER non-ducted	75%	113%	141%
Korea	EU SEER non-ducted	77%	89%	116%
Japan CSPF	EU SEER non-ducted	81%	93%	121%
US SEER non-ducted	EU SEER non-ducted	71%	89%	134%
China	EU SEER non-ducted	78%	90%	117%

Ideally, these results should be further refined with more detailed energy consumption and product parameter information per product category taken from large or statistically representative product databases in order to be most useful for both the ducted and non-ducted single-speed products.

4.2 SEER conversions for VSD mini-splits

This section presents a methodology to convert between the various national SEER metrics for variable-speed mini-split units, and presents the associated conversion formulae for each economy of interest.

4.2.1 Product database

In order to compute the SEER for a unit, it is necessary to compute the part load efficiency and reduced outdoor temperature efficiency for the load curves of the different metrics. As the only public information available in Japan is the APF (which is an annualized compound of the cooling and heating seasonal performance factors), it is not possible to make use of the publicly published performance data. The same issue occurs in the US and China where only the SEER, EER, and cooling capacity data is available. In Europe, the SEER values which will be applicable in the near future have not yet been tested and reported. Consequently, we need to base the analysis on other sources of data.

In 2005, the utility Southern California Edison led some work in order to assess whether the US SEER metrics should be refined by US climatic zone (SCE, 2005). In this study they used a database of US central ACs for which they could access the detailed model information required to compute the yearly hourly performances of these units under any climate (parameters of the DOE2 model for central ACs). This database could enable similar calculations to be made for the EU and Japanese SEERs for a representative set of US units. However, this data is not representative of our main VSD mini-split target product.

Within the scope of the EU Lot 10 Preparatory Study, Japanese manufacturers supplying the European market sent anonymous information for average and best mini-split VSD single split products sold from 1996 to 2006, with cooling power rated between 2.8 and 4 kW in Japan and three single split units between 10 and 12.5 kW. All these products are non-ducted. For these products, the five testing points required to compute the CSPF, the HSPF, and thus the APF were made available. We use this database of 52 models to represent and characterize VSD mini-split products.

The representativeness of these products compared to the Japanese and other markets is discussed below.

4.2.2 Japanese CSPF, Korean CSPF, and Chinese SEER

The cooling mode information available in the database enables direct computation of the Chinese SEER, the Korean CSPF and the Japanese CSPF. The cooling mode performance model defined in the JRA-4046 standard (which is also used in the Chinese and Korean standards) is presented below. It is considered to have two capacity stages – the rated capacity stage and the intermediate cooling capacity stage – with their respective cooling and electric power displaying the same variation with outdoor air temperature.

Outdoor air temperature (OAT) impact in the cooling mode in the JRA-4046 standard can be shown as:

$$P_{c_{rated}} = P_{c_{rated(35)}} . (1 + C_{Pc} . (OAT - 35))$$

$P_{e_{rated}} = P_{e_{rated(35)}} . (1 + C_{Pe} . (OAT - 35))$

And

$P_{c_{int}} = P_{c_{int(35)}} . (1 + C_{Pc} . (OAT - 35))$

$P_{e_{int}} = P_{e_{int(35)}} . (1 + C_{Pe} . (OAT - 35))$

With:

$P_{c_{rated}}$: Cooling capacity at the rated frequency, varies with the OAT

$P_{c_{rated(35)}}$: Rated cooling capacity (OAT = 35 °C)

$P_{e_{rated}}$: Cooling electric power input at the rated frequency, varies with the OAT

$P_{e_{rated(35)}}$: Rated cooling electric power input (OAT = 35 °C)

$P_{c_{int}}$: Cooling capacity at the "intermediate" frequency, varies with the OAT

$P_{c_{int(35)}}$: Rated "intermediate" cooling capacity (OAT = 35 °C)

$P_{e_{int}}$: Cooling electric power input at the "intermediate" frequency, varies with the OAT

$P_{e_{int(35)}}$: Rated "intermediate" cooling electric power input (OAT = 35 °C)

C_{p_c}: the slope of variation of the cooling capacity with the outdoor air temperature

C_{Pc} = - 0.0128

C_{p_e}: the slope of variation of the electric consumption with the outdoor air temperature

C_{Pe} = + 0.0143

As mentioned previously in section 2, there is only a slight variation between this and the approach used to compute the Korean CSPF for variable speed units. The coefficient Cpe should be taken as:

C_{Pe} = + 0.0227

Part load performance in cooling mode in the JRA-4046 standard:

The part load impact is measured through a single test at 50% capacity ratio (as compared to the unit rated output) with an OAT of 35 °C, the same as for the rated capacity. Between 50% capacity and 100% capacity, EER is interpolated between both values as a function of outdoor air temperature.

When the building load is lower than the intermediate capacity of the AC, the performance degrades with a Cd default coefficient of 0.25.

Thus to compute the Japanese and Korean CSPFs and the Chinese SEER, it is not necessary to make any additional modeling hypotheses.

4.2.3 Japanese APF

In order to compute the APF, it is necessary to compute the HSPF in addition to the calculation of the CSPF. All the required information is available for the 52 models in the database.

In the case of the cooling mode, no hypothesis is required to be able to compute the CSPF and its contribution to the APF.

4.2.4 US SEER

Some hypothesis have to be made to compute the US SEER, as this metric requires more testing points than are available under the JRA-4046 test standard.

Three frequency levels are tested in the AHRI 210/240 standard:

- At rated frequency (Frat), there are two test points, @ OAT = 35 °C and @ OAT = 27.8 °C; these two test points enable the computation of the cooling capacity and electric power consumption variation (straight lines) as a function of outdoor air temperature. Hence, these slopes may differ from the default values used in the JRA-4046 standard.

- At minimum frequency (Fmin), two tests are performed, @ OAT = 27.8 °C and @ OAT = 19.4 °C; these two test points are used to compute the cooling capacity and electric power consumption variation (straight lines) as a function of outdoor air temperature. Hence, these slopes may differ from the default values used in the JRA-4046 standard and from the values obtained at rated frequency.

- At intermediate frequency (Fint), one single test point is performed, @OAT = 30.6 °C; the intermediate frequency (Fint) is defined as a function of the minimum (Fmin) and rated (Frat) frequencies as follows: Fint = Fmin + (Frated – Fmin) / 3. The efficiency varies along the building load curve as a second order polynomial.

For frequencies ranging between Frat and Fmin, the cooling capacity and electric power variations versus the OAT are interpolated from the slopes at the rated and minimum frequencies; hence, there are no supplementary variables to be defined for these slopes' parameters.

The complete procedure used in the US standard to compute the SEER metrics has been adapted.

In the first step, the following inputs are used:

- The linear slopes of the variation of Pc and Pe with outdoor air temperature are assumed to be the same regardless of the frequency, and equal to the ones adopted in the Japanese and Chinese standards;

- The unit is assumed to have as a minimum capacity step the 50% capacity step declared by Japanese manufacturers;
- The intermediate frequency EER is computed by linear interpolation of EER with frequency between the minimum and maximum frequencies at the same temperature conditions; and
- Cd is assumed to be equal to 0.1, as manufacturers are permitted to do a supplementary test and units are generally equipped with electronic or at least thermostatic expansion valves. In the model, as the minimum capacity is 50%, this value suggests the peak performance is reached at 50% capacity and then the performance decreases slowly. The Cd is thus not just the Cd value of the AHRI standard but gives the inverter shape of the unit, with performance improvement under part load conditions peaking at 50% capacity and then decreasing.

4.2.5 EU SEER

The same hypotheses are used as in the Japanese and Chinese models, with Cd = 0.1 as was assumed for the US SEER. In this first step, parasitic losses are not modeled so that results are obtained only for EU $SEER_{on}$ and not for EU SEER.

4.2.6 Representativeness of the database used

Comparison of the database with Japanese 2011 market data

To support this work, more recent AC performance data was downloaded from Japanese manufacturer websites for VSD mini-split units available for sale in 2011. The product information is listed in Annex 1.

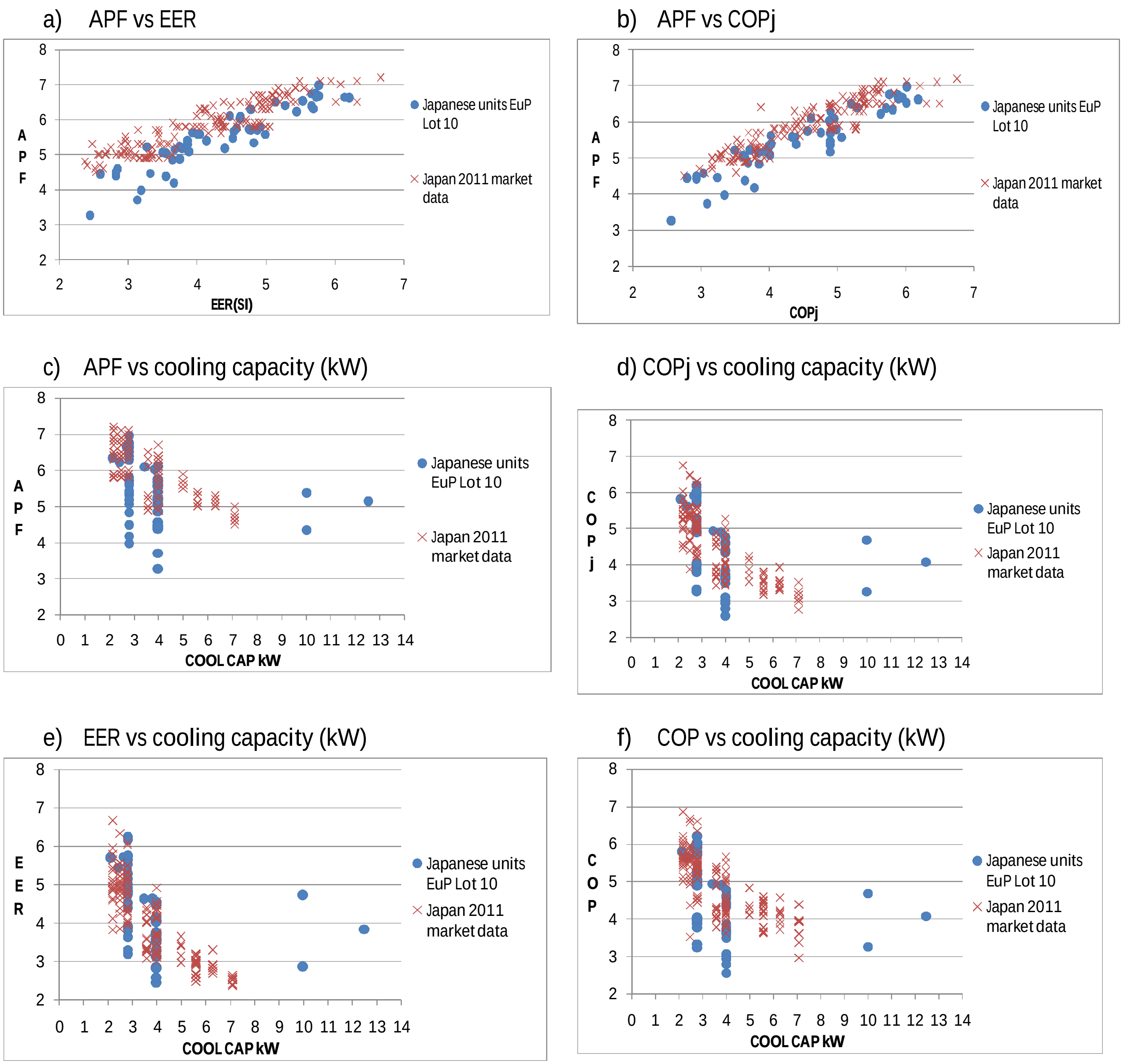
The following characteristics are available for these products:

- Cooling and heating capacities;
- EER;
- COP; and
- APF.

It is thus also possible to compute the Japanese COPj = (EER + COP) / 2 for these products.

The graphs in Figure 7 below illustrate the comparison of products in the EuP Lot 10 database and the more recent 2011 market data.

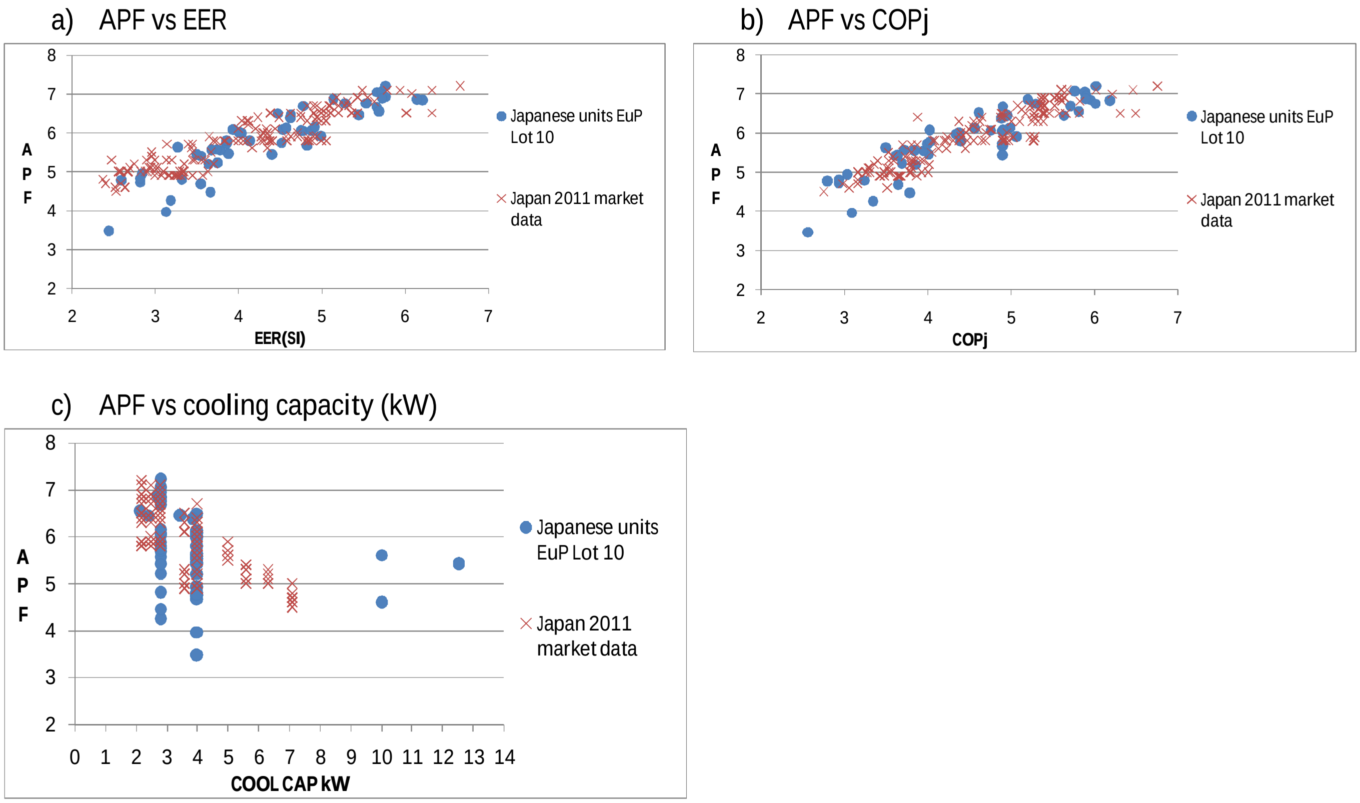
Figure 7: Comparison of the EuP Lot 10 database and 2011 Japanese market data



It clearly appears in Figure 7a that the APF value of the products in the EuP database is now well below the APF of units on the market; lower EER products now have better APF indexes. Figure 7b and Figure 7e show that the main difference is not the full load performance, either EER or COPj, but rather the part load performance.

In order to derive results that are applicable with the units presently available for sale, a correction has been made to the EU Lot 10 database. All units' part load performance in cooling and in heating mode are adjusted by the same regression so that both distributions fit better on Figure 8a below. The results are shown in the same figure as above with the corrected input in Figure 8.

Figure 8: Comparison of the EuP Lot 10 database and 2011 Japanese market data, after EuP Lot 10 correction



In Figure 8a, the distribution of APF vs EER now presents a satisfactory picture, i.e., the corrected EuP Lot 10 database behaves similarly to the distribution identified on the Japanese market. After correcting the database, only some products clearly appear to be below the minimum requirements in force today, and if these products were in the market they should be removed. The same conclusion can be drawn from Figure 8b regarding the relationship between the APF and the COPj ((EER+COP)/2).

In Figure 8c, Figure 7d, Figure 7e, and Figure 7f, it can be clearly seen that today's products do not have such a large spread in performance for the same cooling capacity, which is presumably attributable to the impacts of recent MEPS schemes. The impact of these MEPS is clearly more significant for the APF than for the full load performance values.

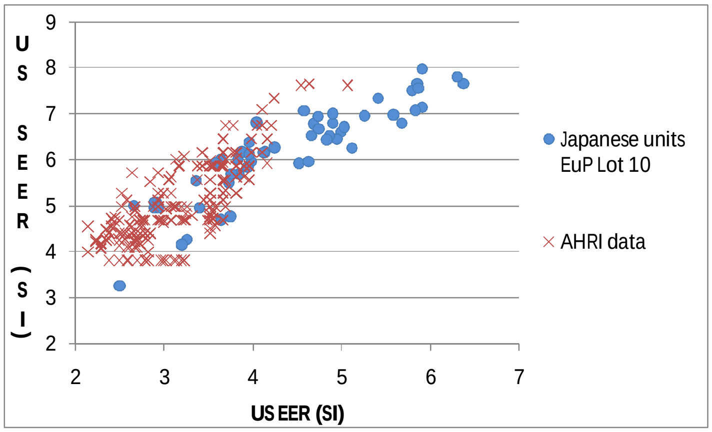
The latter four graphs – Figure 8c, Figure 7d, Figure 7e, and Figure 7f – also show that our product database is not representative of the full capacity range and, strictly speaking, the correlations between metrics should be limited to units with cooling power of 4 kW and below. Nevertheless, in the upper range, of between 4 and 7 kW, market products do have efficiency indicators that are not so different to some of the values seen for the 4 kW products: the EER and COP may be a bit lower with higher cooling capacities, but APF values are comparable. Thus, it was decided to make use of the databases as presented above to derive the SEER conversions.

Comparison of the corrected database with the USA 2011 market data

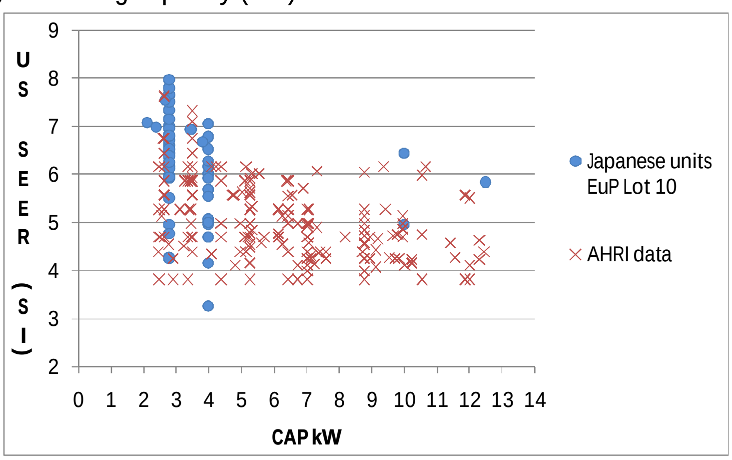
The AHRI database of VSD mini-split heat pump products was used for this analysis. It was filtered to only include market active products (as of February 2011) within the HRCU-A-CB-O[15] category. This amounts to 306 products.

Figure 9: Comparison of the EuP Lot 10 database vs 2011 US AHRI data

a) US SEER (SI) vs US EER (SI)

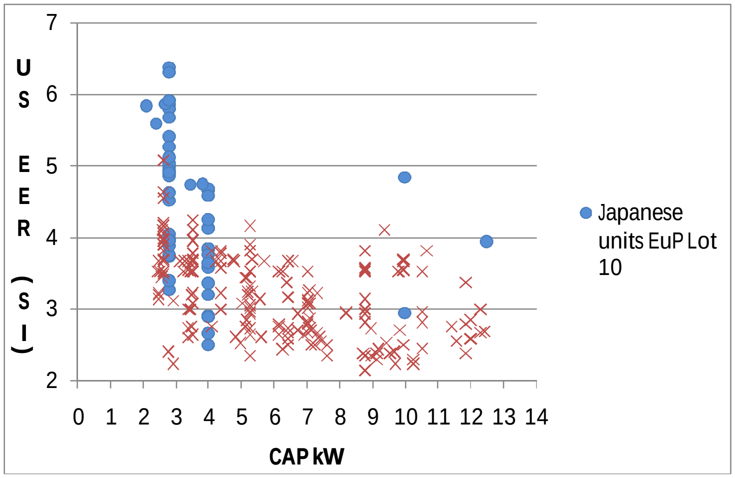


b) US SEER (SI) vs cooling capacity (kW)



15 HRCU-A-CB-O: split system: heat pump with remote outdoor unit, air source, free delivery.

c) US EER (SI) vs cooling capacity (kW) (CAP kW)



Despite the cooling capacity coverage of products in our database mainly addressing smaller capacity units, as can be seen in Figure 9b, the SEER range covers most of the products in the AHRI database. However, by comparison with the Japanese market, it appears that the US products can reach almost as high SEER values but without such high EER values at standard rating conditions. This is best shown on Figure 9a and Figure 9c, in which the best units on the Japanese market find no counterpart on the US market. This is certainly partly driven by the double legislative requirements in Japan, which set Top Runner performance requirements both in terms of COPj and APF (see Section 5). This mainly affects units of less than 2.8 kW, which are also the more efficient ones in Japan.

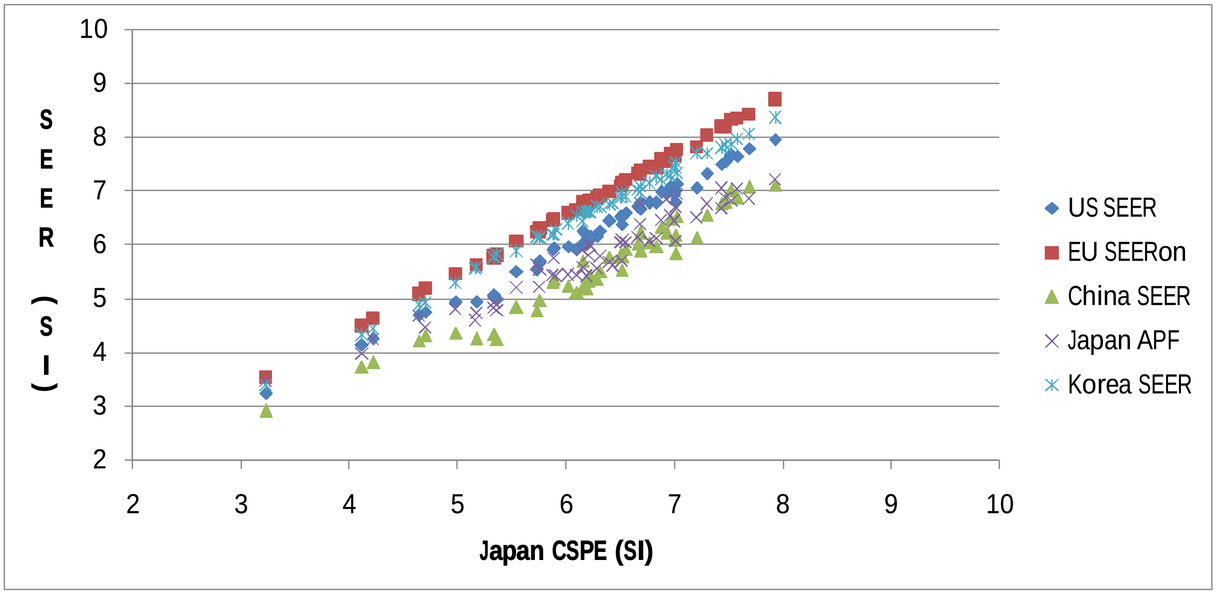
These differences show that manufacturers do use the degrees of freedom offered in order to reach the US SEER MEPS levels, and that units on the US market are not designed as they are in Japan despite the same major manufacturers competing on both markets. This is a limit of the study that cannot be addressed here because there is no equivalent data set available for US units as was made available for the Japanese market.

4.2.7 Test of provisional SEER conversion factors against tested units

Provisional SEER conversion factors

The results of the computation of the different SEERs with the simplified methods described above in sections 4.2.2 to 4.2.5 and the data available for the Japanese models are presented in the graph below. The US SEER, EU $SEER_{on}$, Chinese SEER and Korean SEER are plotted as a function of the Japanese CSPF coefficient.

Figure 10: Comparison of different SEERs for EuP Lot 10 database of Japanese models



This preliminary analysis enables us to identify linear relationships between the different SEERs. They are summarized in the table below. They should be read using the following equation, derived below for the EU, US, Korean, Japanese, and Chinese SEERs (CSPF for Japan):

Y = Cte + Slope * X

Table 26: Provisional SEER conversion factors between the cooling seasonal performance indicators of the US, Japan, Korea, China and Europe

Y	X	Slope	Cte	R2	Std dev	Dev min	Quartile 25 %	Median	Quartile 75%	Dev max
EU $SEER_{on}$	US SEER	1.058	0.261	0.993	0.090	-4.4%	-0.6%	0.1%	0.9%	4.5%
China SEER	US SEER	0.931	-0.273	0.989	0.100	-5.7%	-1.1%	0.2%	1.6%	3.5%
Korea SEER	US SEER	0.983	0.503	0.972	0.170	-7.0%	-1.5%	0.3%	1.6%	9.1%
US SEER	EU $SEER_{on}$	0.938	-0.202	0.993	0.085	-4.0%	-0.9%	-0.1%	0.6%	5.0%
China SEER	EU $SEER_{on}$	0.867	-0.415	0.967	0.174	-9.1%	-2.5%	0.1%	2.1%	8.7%
Korea SEER	EU $SEER_{on}$	0.935	0.219	0.992	0.093	-3.0%	-1.1%	-0.1%	1.0%	4.2%
US SEER	China SEER	1.062	0.359	0.989	0.107	-3.3%	-1.4%	-0.2%	0.9%	6.5%
EU $SEER_{on}$	China SEER	1.115	0.689	0.967	0.197	-6.5%	-2.1%	-0.2%	2.0%	11.5%
Korea SEER	China SEER	1.026	0.954	0.929	0.272	-8.7%	-2.9%	0.0%	2.6%	16.6%
US SEER	Korea SEER	0.989	-0.324	0.972	0.171	-6.9%	-1.8%	-0.4%	1.5%	8.8%
EU $SEER_{on}$	Korea SEER	1.061	-0.175	0.992	0.099	-3.4%	-1.1%	0.0%	1.1%	3.4%
China SEER	Korea SEER	0.905	-0.470	0.929	0.255	-11.1%	-3.1%	-0.4%	3.0%	12.9%
Japan CSPF	China SEER	1.003	0.717	0.956	0.205	-7.1%	-2.4%	0.0%	2.1%	13.2%
China SEER	Japan CSPF	0.954	-0.443	0.956	0.200	-10.0%	-2.3%	-0.2%	2.5%	9.8%
Japan CSPF	US SEER	0.954	0.314	0.988	0.106	-5.2%	-0.9%	0.3%	1.1%	6.0%
US SEER	Japan CSPF	1.036	-0.253	0.988	0.110	-5.1%	-1.1%	-0.3%	0.9%	6.0%
Japan CSPF	EU $SEER_{on}$	0.903	0.067	0.999	0.034	-1.3%	-0.4%	0.0%	0.4%	1.4%
EU $SEER_{on}$	Japan CSPF	1.106	-0.066	0.999	0.038	-1.3%	-0.4%	0.0%	0.4%	1.4%
Japan CSPF	Korea SEER	0.961	-0.110	0.996	0.059	-2.3%	-0.6%	-0.1%	0.6%	2.4%
Korea SEER	Japan CSPF	1.037	0.137	0.996	0.061	-2.2%	-0.6%	0.1%	0.6%	2.6%

While the R^2 coefficients are rather satisfactory, it can be seen that the maximum difference between the modeled SEERs and the reference SEERs may reach -11% and +17%.

The highest bias occurs in two cases: first, for correlations with the Japanese APF, for which the HSPF carries an important weight and may not be directly correlated to the cooling performance; second, for the China and Korea conversions, for which the higher difference occurs around Japan CSPF ranging between 5 and 5.5 on

Figure 10, where the Korea and China SEER trends differ for a set of units. This latter difference is likely to arise from the different EER vs. OAT slopes and hours of operation per bin.

It should also be noted that, despite having similar modeling and calculation hypotheses, the Japanese and Chinese cooling indices correlations also deviate substantially from the modeled Japanese/Chinese SEER just because of the different hours by bin.

Comparison of the preliminary conversion coefficients with the test results for the non-ducted inverter carried out at CEIS

This section takes the test data measured by CEIS on a non-ducted inverter unit of 3.5 kW and compares the computed SEERs from the tests with the values obtained by using the regressions that were explained previously.

A Cd value of 0.1 is used for the EU and the US and 0.25 for Japan and China. The APF calculation cannot be checked as heating mode tests were not conducted; hence, only the SEERs are tested.

A comparison of the predicted SEER relationships and those measured by CEIS is shown in Table 27 below where Test X is the tested result for the X SEER, Test Y is the tested result for the Y SEER, and Model Y is the predicted (modeled from the correlations) value of the Y SEER from the tested X SEER value. The values Dev min and Dev max show the maximum expected variation in the real Y value from the Test Y value due to experimental uncertainty; thus, if the Model Y value falls within these confidence intervals it can be considered to be reliable.

Table 27: Comparison between computed conversions and test results of the non-ducted inverter

Y	X	Dev min	Dev max	TEST Y	TEST X	Model Y	BIAS
EU $SEER_{on}$	US SEER	-4.4%	4.5%	6.23	5.12	5.68	-9%
China SEER	US SEER	-5.7%	3.5%	4.31	5.12	4.49	4%
Korea SEER	US SEER	-7.0%	9.1%	5.28	5.12	5.53	5%
US SEER	EU $SEER_{on}$	-4.0%	5.0%	5.12	6.23	5.64	10%
China SEER	EU $SEER_{on}$	-9.1%	8.7%	4.31	6.23	4.98	16%
Korea SEER	EU $SEER_{on}$	-3.0%	4.2%	5.28	6.23	6.04	14%
US SEER	China SEER	-3.3%	6.5%	5.12	4.31	4.94	-4%
EU $SEER_{on}$	China SEER	-6.5%	11.5%	6.23	4.31	5.50	-12%
Korea SEER	China SEER	-8.7%	16.6%	5.28	4.31	5.38	2%
US SEER	Korea SEER	-6.9%	8.8%	5.12	5.28	4.90	-4%
EU $SEER_{on}$	Korea SEER	-3.4%	3.4%	6.23	5.28	5.43	-13%

Y	X	Dev min	Dev max	TEST Y	TEST X	Model Y	BIAS
China SEER	Korea SEER	-11.1%	12.9%	4.31	5.28	4.31	0%
Japan CSPF	China SEER	-7.1%	13.2%	4.97	4.31	5.04	1%
China SEER	Japan CSPF	-10.0%	9.8%	4.31	4.97	4.29	0%
Japan CSPF	US SEER	-5.2%	6.0%	4.97	5.12	5.20	5%
US SEER	Japan CSPF	-5.1%	6.0%	5.12	4.97	4.89	-4%
Japan CSPF	EU $SEER_{on}$	-1.3%	1.4%	4.97	6.23	5.69	15%
EU $SEER_{on}$	Japan CSPF	-1.3%	1.4%	6.23	4.97	5.43	-13%
Japan CSPF	Korea SEER	-2.3%	2.4%	4.97	5.28	4.97	0%
Korea SEER	Japan CSPF	-2.2%	2.6%	5.28	4.97	5.29	0%

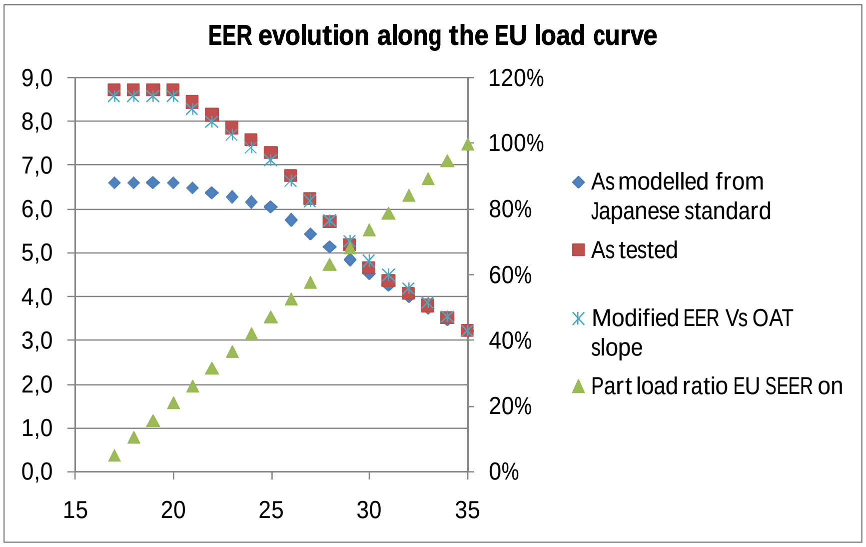
Several observations can be made regarding these results:

- The results predicted by the SEER correlations for Korea, China, and Japan fall between 0% and 2% of the measured values (colored black in Table 27 above);
- The results for US SEER correlations, but excluding the EU $SEER_{on}$, exhibit a systematic bias of 4% to 5%. This is positive if the predicted value is derived from the US value, and negative when another economy's SEER is used to predict the US SEER (colored green in Table 27 above); and
- In the case of the correlations related to the EU $SEER_{on}$, the bias is much higher and is between 6% and 16% (colored red in Table 27 above).

These findings suggest that one or several of the modeling hypotheses in the modeling of the US SEER and of the EU $SEER_{on}$ needs to be modified, but the other correlations are quite accurate.

The figure below shows the expected evolution of the EER with outdoor temperature and load as produced with the model used to establish the correlations (model of the Japanese standard) and as tested.

Figure 11: EER – left Y axis - and Part Load Ratio – right Y axis - as a function of OAT; as modeled, tested and corrected



The measured EER values at 20 °C and 25 °C are much higher than the expected values which could occur for two main reasons:

- First, that the model assumes the unit cycles below 50% of full load while it may still be able to operate without cycling at 20°C and 21% of full load; thus, the part load performance continues to improve below 50% of full load.
- Second, that there may be a larger than expected increase in EER with reduced outdoor air temperature.

It is possible from the US test data to establish the average slope at maximum speed between 35 °C and 27.8 °C; there, the average slope of the increase in EER is -2.77% EER/OAT °C. At minimum speed and between an outdoor air temperature of 18 °C and 27 °C, this slope increases to reach -4.48% EER/OAT °C. This difference in the slope seems to explain two thirds of the difference between the EU $SEER_{on}$ value measured (6.23) and the one computed from the Korean SEER (5.42), referring to Table 27 above. The simplified modeling part-load assumption of a minimum capacity stage at 50% load before cycling sets in would account for the remainder.

Consequently, the EER slope versus OAT has been modified as follows:

- The rated EER slope versus OAT is unchanged, and is about -3.0% (as computed between 29 °C and 35 °C),
- The intermediate capacity stage EER slope versus OAT is decreased to -5.0% (as computed between 29 °C and 35 °C).

Applying these revised EER versus OAT slopes to correct the values presented in Table 25 produces the values shown in Table 28.

Table 28: Comparison of the corrected computed SEER conversions and the CEIS test results for the non-ducted inverter unit

Y	X	Dev min	Dev max	TEST Y	TEST X	Model Y	BIAS
EU $SEER_{on}$	US SEER	-4.6%	5.1%	6.23	5.12	5.91	-5%
China SEER	US SEER	-5.1%	3.4%	4.31	5.12	4.03	-6%
Korea SEER	US SEER	-7.4%	10.0%	5.28	5.12	5.05	-4%
US SEER	EU $SEER_{on}$	-4.5%	5.2%	5.12	6.23	5.41	6%
China SEER	EU $SEER_{on}$	-9.0%	8.3%	4.31	6.23	4.29	0%
Korea SEER	EU $SEER_{on}$	-3.3%	4.3%	5.28	6.23	5.29	0%
US SEER	China SEER	-3.2%	5.7%	5.12	4.31	5.46	7%
EU $SEER_{on}$	China SEER	-6.2%	11.3%	6.23	4.31	6.30	1%
Korea SEER	China SEER	-8.7%	16.6%	5.28	4.31	5.38	2%
US SEER	Korea SEER	-7.4%	9.5%	5.12	5.28	5.43	6%
EU $SEER_{on}$	Korea SEER	-3.6%	3.7%	6.23	5.28	6.23	0%
China SEER	Korea SEER	-11.1%	12.9%	4.31	5.28	4.31	0%
Japan CSPF	China SEER	-7.1%	13.2%	4.97	4.31	5.04	1%
China SEER	Japan CSPF	-10.0%	9.8%	4.31	4.97	4.29	0%
Japan CSPF	US SEER	-5.6%	6.8%	4.97	5.12	4.73	-5%
US SEER	Japan CSPF	-5.7%	6.7%	5.12	4.97	5.42	6%
Japan CSPF	EU $SEER_{on}$	-1.2%	1.5%	4.97	6.23	4.97	0%
EU $SEER_{on}$	Japan CSPF	-1.4%	1.3%	6.23	4.97	6.22	0%
Japan CSPF	Korea SEER	-2.3%	2.4%	4.97	5.28	4.97	0%
Korea SEER	Japan CSPF	-2.2%	2.6%	5.28	4.97	5.29	0%

After this correction, the observed bias lies outside the planned confidence interval for only three cases. The conversion involves the US SEER for all three cases, and results in a prediction that is higher than the test results. This means the confidence interval should be increased in these cases. The predictions are satisfactory for all other cases.

Comparison of the preliminary conversion coefficients with the test results for the ducted inverter carried out at CEIS

In practice CEIS could only perform tests to confirm conversion coefficients for ducted inverters for Europe and Japan. The Korean and Chinese SEERs can also be computed as they require the same input required for the Japan SEER. The heating mode could not be tested so the Japanese APF is not considered.

The comparison between the predicted values and the tested values is shown in the table below.

Table 29: Comparison between corrected computed conversions and test results of the ducted inverter

Y	X	Dev min	Dev max	TEST Y	TEST X	Model Y	BIAS
China SEER	EU $SEER_{on}$	-9.1%	8.3%	3.29	4.69	3.42	4%
Korea SEER	EU $SEER_{on}$	-3.4%	4.5%	4.31	4.69	4.23	-2%
EU $SEER_{on}$	China SEER	-6.2%	11.3%	4.69	3.29	4.63	-1%
Korea SEER	China SEER	-8.8%	16.9%	4.31	3.29	4.22	-2%
EU $SEER_{on}$	Korea SEER	-3.7%	3.8%	4.69	4.31	4.81	2%
China SEER	Korea SEER	-11.2%	13.1%	3.29	4.31	3.55	8%
Japan CSPF	China SEER	-7.1%	13.3%	3.90	3.29	4.17	7%
China SEER	Japan CSPF	-10.1%	9.9%	3.29	3.90	3.15	-4%
Japan CSPF	EU $SEER_{on}$	-1.2%	1.6%	3.90	4.69	4.20	8%
EU $SEER_{on}$	Japan CSPF	-1.5%	1.3%	4.69	3.90	4.35	-7%
Japan CSPF	Korea SEER	-2.4%	2.5%	3.90	4.31	4.30	10%
Korea SEER	Japan CSPF	-2.3%	2.7%	4.31	3.90	3.93	-9%

In four cases, shown in red above, the prediction does not lie within the dispersion identified in the original database. This is thought to be the result of the very low EER of the unit being tested, as no such low-EER model was available in the database used to derive the correlations. Hence, the precision for any unit is not likely to be better than [-10%, +10%], even in the case of the very similar Korea and Japan SEER metrics. It would be necessary to extend the database in order to produce better predictive correlations.

4.2.8 Derivation of final SEER conversion factors

Correction for tolerances

The corrections for tolerances have been previously described in the part on seasonal performance metrics on section 2.9. The EuP Lot 10 database is compatible with products sold on the Japanese market whose declaration may be only 90% of their tested value. Hence, the conversion coefficients are corrected to enable comparison with the Japanese market. For instance, the US SEER is assumed to be 10% lower than would be the case for the conversion coefficients previously described, due to the fact that there is no permitted tolerance for the US SEER, but a 10% permitted tolerance for the Japanese market.

China, Korea, Japan

These countries have very similar test procedures and only slight differences in climate, although the permitted tolerance in the Korean standard is less than for the others. Nonetheless, there can be significant variations between the predictions and the tested values. Hence, even if the results in Table 30, below, suggest a good correlation between the Korean and Japanese cooling index, it should not be forgotten that the conversion coefficients have been established from a limited set of products. Using these coefficients for products that are dissimilar to the ones used in this study could therefore lead to greater bias than reported here. For example, an inverter unit with a relatively low EER was tested within this study and the conversion correlations were found to be off by about 10%, while the dispersion in the database used to derived the correlations only had a maximum deviation of 2.5% (when converting from the Japanese CSPF to the Korean SEER).

Table 30: Conversion coefficients for VSD mini-split units for China, Korea, and Japan

Y	X	Slope	Cte	R2	Std dev	Dev min	Quartile 25 %	Median	Quartile 75%	Dev max
China SEER	Japan APF	1.102	-0.798	0.949	0.223	-7.8%	-2.0%	-0.1%	2.5%	11.5%
China SEER	Japan CSPF	0.926	-0.464	0.956	0.208	-10.1%	-2.4%	-0.2%	2.5%	9.9%
China SEER	Korea SEER	0.937	-0.491	0.927	0.267	-11.2%	-3.2%	-0.3%	3.1%	13.1%
Japan APF	China SEER	0.861	0.987	0.949	0.197	-8.4%	-1.9%	0.2%	1.8%	7.1%
Japan APF	Korea SEER	0.822	0.466	0.912	0.259	-10.1%	-3.1%	-0.2%	3.6%	8.3%
Japan CSPF	China SEER	1.032	0.773	0.956	0.220	-7.1%	-2.4%	0.0%	2.1%	13.3%
Japan CSPF	Korea SEER	1.025	-0.119	0.996	0.065	-2.4%	-0.7%	-0.1%	0.6%	2.5%
Korea SEER	China SEER	0.989	0.969	0.927	0.275	-8.8%	-3.0%	0.0%	2.6%	16.9%
Korea SEER	Japan APF	1.111	0.062	0.912	0.301	-8.2%	-3.3%	-0.1%	3.2%	17.9%
Korea SEER	Japan CSPF	0.972	0.141	0.996	0.063	-2.3%	-0.6%	0.1%	0.6%	2.7%

The US

The US conversion factors are computed against all the other country SEERs below. They include the NAFTA-ISO correction discussed previously. A separate set of conversion factors is required for ducted units. As mentioned previously, for ducted units, when converting US SEER to any other metrics, the SEER should be multiplied by a correction factor in order to take into account that the AHRI 210/240 standard does not correct the cooling capacity and power consumption for the static pressure of the indoor fan.

Non-ducted units

For non-ducted units, the conversion factors can be computed as for the other metrics. They are presented in the table below for conversions to the Chinese, Korean, and Japanese indices.

Table 31: Conversion coefficients for VSD non-ducted mini-split for US versus China, Korea, and Japan

Y	X	Slope	Cte	R2	Std dev	Dev min	Quartile 25 %	Median	Quartile 75%	Dev max
China SEER	US SEER	0.998	-0.258	0.991	0.094	-5.2%	-1.1%	0.2%	1.4%	3.2%
Japan APF	US SEER	0.865	0.733	0.952	0.191	-7.1%	-1.7%	0.2%	2.7%	6.7%
Japan CSPF	US SEER	1.051	0.384	0.986	0.126	-5.6%	-1.0%	0.3%	1.3%	6.8%
Korea SEER	US SEER	1.014	0.559	0.967	0.184	-7.5%	-1.7%	0.3%	1.8%	10.1%
US SEER	Japan CSPF	0.938	-0.273	0.986	0.119	-5.7%	-1.2%	-0.4%	1.0%	6.7%
US SEER	China SEER	0.993	0.310	0.991	0.094	-3.1%	-1.3%	-0.2%	0.9%	5.8%
US SEER	Japan APF	1.101	-0.521	0.952	0.216	-7.0%	-2.4%	-0.2%	2.7%	9.0%
US SEER	Korea SEER	0.954	-0.338	0.967	0.178	-7.5%	-2.0%	-0.5%	1.7%	9.5%

Ducted units

We base our analysis of ducted units on the very limited information we have, which suggests that on average the correction for static pressure lies between 1% and 4% of the rated power input (T1 condition) with 2.5% as the average value. This leads to a US SEER decrease of 7.5% +/- 4%. Table 32 presents the same results as given in Table 31 but for ducted units derived using the average degradation values.

Table 32: Conversion coefficients for VSD ducted mini-split units for US versus China, Korea, and Japan

Y	X	Slope	Cte	R2	Std dev	Dev min	Quartile 25 %	Median	Quartile 75%	Dev max
Japan APF	US SEER	0.935	0.733	0.952	0.191	-7.1%	-1.7%	0.2%	2.7%	6.7%
China SEER	US SEER	1.079	-0.258	0.991	0.094	-5.2%	-1.1%	0.2%	1.4%	3.2%
Korea SEER	US SEER	1.096	0.559	0.967	0.184	-7.5%	-1.7%	0.3%	1.8%	10.1%
US SEER	Japan APF	1.018	-0.482	0.952	0.200	-7.0%	-2.4%	-0.2%	2.7%	9.0%
US SEER	China SEER	0.918	0.287	0.991	0.087	-3.1%	-1.3%	-0.2%	0.9%	5.8%
US SEER	Korea SEER	0.883	-0.313	0.967	0.165	-7.5%	-2.0%	-0.5%	1.7%	9.5%
Japan CSPF	US SEER	1.136	0.384	0.986	0.126	-5.6%	-1.0%	0.3%	1.3%	6.8%

Y	X	Slope	Cte	R2	Std dev	Dev min	Quartile 25 %	Median	Quartile 75%	Dev max
US SEER	Japan CSPF	0.868	-0.253	0.986	0.110	-5.7%	-1.2%	-0.4%	1.0%	6.7%

The EU

The EU conversion factors should take into account low power modes. As with the US SEER, this may lead to separate conversion factors for ducted units because of their higher thermostat off-mode energy demand.

The impact of low power modes for default values already established in section 4.1.6 for single speed units is presented in Table 33. As the standby is in W, its impact is higher when the performance of the unit increases. Hence, a standard and a high efficiency unit are compared. This leads to an average value of -7% for non-ducted units and -10% for ducted units.

Table 33: EU SEER and impact of low power modes on the EU SEER

	Non-ducted			Ducted		
Pto	2%	3%	4%	4,5%	6,0%	7,5%
Psb	2	5	12	2	5	12
Poff	-	-	-	-	-	-
Pck	0%	0%	1%	0%	0%	1%
UNIT 1						
EU $SEER_{on}$	7.53	7.53	7.53	7.53	7.53	7.53
EU SEER	7.20	6.89	5.69	7.01	6.68	5.52
%	-4%	-8%	-24%	-7%	-11%	-27%
UNIT 2						
EU $SEER_{on}$	3.84	3.84	3.84	3.84	3.84	3.84
EU SEER	3.72	3.63	3.12	3.64	3.53	3.04
%	-3%	-6%	-19%	-5%	-8%	-21%
Average impact of low power modes						
%	-4%	-7%	-22%	-6%	-10%	-24%

Given the uncertainty of the estimates, and because of the absence of published values until now, it does not seem necessary to differentiate ducted and non-ducted units, and a single value of -8% is used for both units. It should be noted, however, that the impact of low power modes in the worst case may be very high (up to -25%). The conversion coefficients including the EU SEER are presented in Table 34 below.

Final conversion factors

The final conversion factors which we recommend should be applied to VSD units, and which present our best estimates of conversions between the different SEERs[16], are presented below in Table 34. The table presents the values to be used in a linear relationship that converts between the different seasonal efficiency metrics and that takes the form: $Y = C_{te} + slope * X$.

The statistical reliability of the regression is indicated by the standard deviation, Std Dev, and the percentages indicating the maximum and minimum deviations, as well as the 25th and 75th percentiles. The position of the median in relation to the mean of the distribution is also indicated as a percentage of the mean.

The potential variations around the average corrections used for low power modes in Europe are not included in the deviation estimates. These deviations refer to the dispersion of the values within the database used to perform the regressions. For any product with characteristics that lie outside the database, such as the US VSD mini-split with low rated EER but high SEER, caution is recommended in the use of these conversion factors.

In general, the conversion coefficients are robust within the deviations indicated in the table, especially for products, such as VSD mini-splits, commonly found on Asian markets.

For ducted units and EU SEER values, we recommend that users check the low power mode values and make adequate corrections to the default value used here in order to improve the conversion estimates.

Table 34: Conversion coefficients for VSD mini-split for the EU, US non-ducted, China, Korea, and Japan SEERs

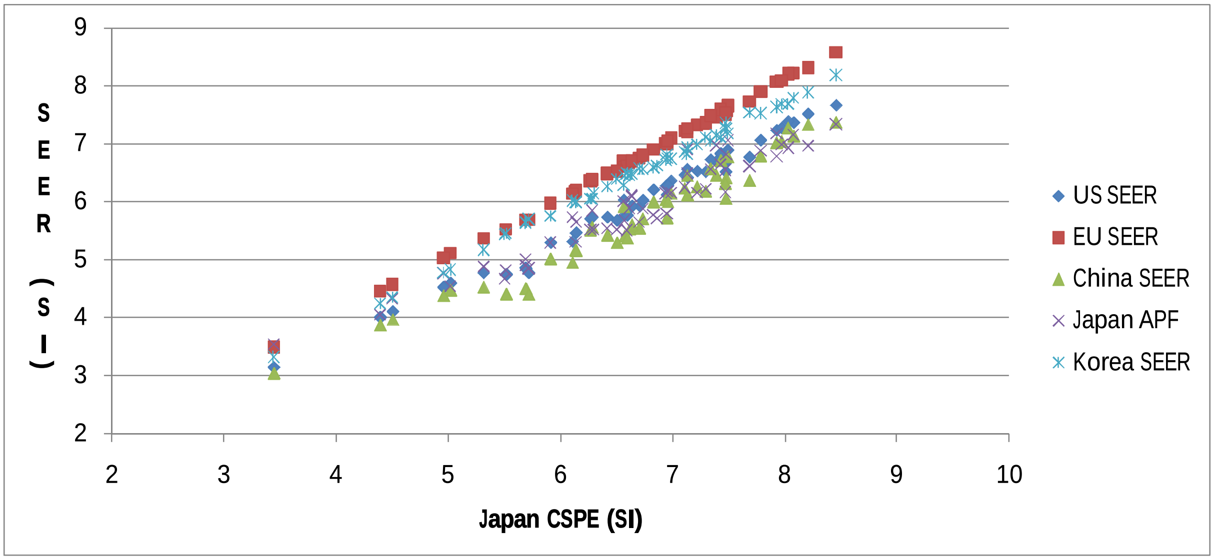
Y	X	Slope	C_{te}	R2	Std dev	Dev min	Quartile 25 %	Median	Quartile 75%	Dev max
Japan APF	US SEER	0.865	0.733	0.952	0.191	-7.1%	-1.7%	0.2%	2.7%	6.7%
EU SEER	US SEER	1.080	0.286	0.992	0.095	-4.5%	-0.7%	0.2%	0.9%	5.1%
China SEER	US SEER	0.998	-0.258	0.991	0.094	-5.2%	-1.1%	0.2%	1.4%	3.2%
Korea SEER	US SEER	1.014	0.559	0.967	0.184	-7.5%	-1.7%	0.3%	1.8%	10.1%
US SEER	Japan APF	1.101	-0.521	0.952	0.216	-7.0%	-2.4%	-0.2%	2.7%	9.0%
EU SEER	Japan APF	1.187	-0.265	0.942	0.259	-6.0%	-2.8%	-0.3%	2.7%	12.9%
China SEER	Japan APF	1.102	-0.798	0.949	0.223	-7.8%	-2.0%	-0.1%	2.5%	11.5%
Korea SEER	Japan APF	1.111	0.062	0.912	0.301	-8.2%	-3.3%	-0.1%	3.2%	17.9%
Japan APF	EU SEER	0.793	0.556	0.942	0.211	-8.4%	-2.6%	0.5%	2.7%	5.8%
US SEER	EU SEER	0.919	-0.216	0.992	0.088	-4.5%	-1.0%	-0.2%	0.7%	5.2%

[16] These conversion factors take into account all the corrections previously described and include compensation for the differences in the permitted tolerances.

Y	X	Slope	C_{te}	R2	Std dev	Dev min	Quartile 25 %	Median	Quartile 75%	Dev max
China SEER	EU SEER	0.910	-0.426	0.968	0.176	-9.1%	-2.4%	0.0%	2.1%	8.3%
Korea SEER	EU SEER	0.946	0.240	0.991	0.097	-3.4%	-1.0%	-0.1%	0.9%	4.5%
US SEER	China SEER	0.993	0.310	0.991	0.094	-3.1%	-1.3%	-0.2%	0.9%	5.8%
EU SEER	China SEER	1.064	0.668	0.968	0.191	-6.2%	-2.1%	-0.1%	2.0%	11.3%
Japan APF	China SEER	0.861	0.987	0.949	0.197	-8.4%	-1.9%	0.2%	1.8%	7.1%
Korea SEER	China SEER	0.989	0.969	0.927	0.275	-8.8%	-3.0%	0.0%	2.6%	16.9%
US SEER	Korea SEER	0.954	-0.338	0.967	0.178	-7.5%	-2.0%	-0.5%	1.7%	9.5%
EU SEER	Korea SEER	1.047	-0.189	0.991	0.102	-3.7%	-1.1%	0.0%	1.0%	3.8%
Japan APF	Korea SEER	0.822	0.466	0.912	0.259	-10.1%	-3.1%	-0.2%	3.6%	8.3%
China SEER	Korea SEER	0.937	-0.491	0.927	0.267	-11.2%	-3.2%	-0.3%	3.1%	13.1%
Japan CSPF	China SEER	1.032	0.773	0.956	0.220	-7.1%	-2.4%	0.0%	2.1%	13.3%
China SEER	Japan CSPF	0.926	-0.464	0.956	0.208	-10.1%	-2.4%	-0.2%	2.5%	9.9%
Japan CSPF	US SEER	1.051	0.384	0.986	0.126	-5.6%	-1.0%	0.3%	1.3%	6.8%
US SEER	Japan CSPF	0.938	-0.273	0.986	0.119	-5.7%	-1.2%	-0.4%	1.0%	6.7%
Japan CSPF	EU SEER	0.975	0.088	0.999	0.037	-1.2%	-0.4%	-0.1%	0.4%	1.6%
EU SEER	Japan CSPF	1.024	-0.081	0.999	0.038	-1.5%	-0.4%	0.1%	0.4%	1.3%
Japan CSPF	Korea SEER	1.025	-0.119	0.996	0.065	-2.4%	-0.7%	-0.1%	0.6%	2.5%
Korea SEER	Japan CSPF	0.972	0.141	0.996	0.063	-2.3%	-0.6%	0.1%	0.6%	2.7%

Figure 12, below, illustrates the conversion factors when applied to the Japanese CSPF (cooling SEER) values.

Figure 12: SEERs for US, EU, Korea, Japan, and China metrics, computed for the database of Japanese models



It is interesting to note that in this figure:

- The maximum APF value is 7.3, which is close to the best product on the Japanese market (APF 7.2, see Annex 1 to this report);
- The maximum US SEER value is about 7.6 (or about 26 in Btu/Wh), which is the most efficient product available on the US market; and
- From the TopTen website (www.top10.cn), it is possible to find the most efficient products sold on the Chinese market; the most efficient product available (in the category VSD mini-split with a rated cooling power below 2.8 kW) has a China SEER of 7.33, which also matches the information in the graph.

These findings tend to confirm that the metrics differ but the best mini-split VSD products available for sale on each of the major markets are almost the same.

5 Application of the conversion formulae to compare the stringency of energy efficiency policy settings

In this section, the conversion factors developed in the preceding sections are applied to compare the ambition of AC policy settings across the different economies on an equivalent basis. The section begins by describing the policy requirements (MEPS and energy labeling thresholds) in place in each economy and then presents comparisons for the most common type of ACs. The policy settings are a function of a number of parameters including:

- Cooling capacity;
- Heating capacity;
- Whether the product is ducted or non-ducted;
- In some cases, whether the product is fixed speed or variable speed; and
- Other product features including whether or not it is dimension constrained (Japan), or the total equivalent warming impact of the refrigerant used (EU).

We only present comparisons for specific product cases. The products chosen are the most common types sold internationally and thus representative of the largest part of the market. The products used for the policy comparison are:

- Fixed speed mini-split non-ducted unit of 3kW cooling capacity; and
- Variable speed mini-split non-ducted unit of 3kW cooling capacity.

5.1 Standards and labeling policy settings in place by country

5.1.1 China

China applies MEPS and labeling requirements for RACs. The MEPS requirements are only specified in terms of EER values, while the energy labeling requirements are expressed in terms of SEER for variable speed units and EER for fixed speed units.

Table 35: Chinese energy labeling thresholds for fixed-speed RACs and MEPS thresholds (the class 3 minimum) for all ACs (from 2010 onwards)

Type	Rated Cooling Capacity (CC) W	EE Grades (EER (W/W))		
		1	2	3
Unitary Type	CC≤14000	3.30	3.10	2.90
Split Type	CC≤4500	3.60	3.40	3.20
	4500<CC≤7100	3.50	3.30	3.10
	7100<CC≤14000	3.40	3.20	3.00

Table 36: Energy labeling thresholds for variable speed RACs (from 2008 onwards)[17]

Type	Rated Cooling Capacity (CC) W	Seasonal Energy Efficiency Ratio (SEER W/W)				
		5	4	3	2	1
Split Type	CC≤4500	3.00	3.40	3.90	4.50	5.20
	4500<CC≤7100	2.90	3.20	3.60	4.10	4.70
	7100<CC≤14000	2.80	3.00	3.30	3.70	4.20

5.1.2 The EU

The EU has applied energy labeling for RACs since 2006; however, a new study has been conducted under the auspices of the Ecodesign directive that has led to proposals to revise the energy label and to set MEPS for RACs as indicated in the tables below. These values were adopted at the recent regulatory committee meeting and hence are the only ones considered for the policy comparison exercise.

The current European energy labeling classes for cooling and heating modes are shown in the following tables.

Table 37: Current European Energy Labeling Classes for Cooling Modes

Cooling: Air-cooled			
Energy Efficiency Class	Split and multi-split appliances	Packaged (through the wall)	Single duct and double ducts
A	3.2 < EER	3.0 < EER	2.6 < EER
B	3.2 ≥ EER > 3.0	3.0 ≥ EER > 2.8	2.6 ≥ EER > 2.4

[17] Source: GB 21455-2008 the limited values of energy efficiency and grading criteria for room air conditioners (variable speed)

Cooling: Air-cooled			
Energy Efficiency Class	Split and multi-split appliances	Packaged (through the wall)	Single duct and double ducts
C	3.0 ≥ EER > 2.8	2.8 ≥ EER > 2.6	2.4 ≥ EER > 2.2
D	2.8 ≥ EER > 2.6	2.6 ≥ EER > 2.4	2.2 ≥ EER > 2.0
E	2.6 ≥ EER > 2.4	2.4 ≥ EER > 2.2	2.0 ≥ EER > 1.8
F	2.4 ≥ EER > 2.2	2.2 ≥ EER > 2.0	1.8 ≥ EER > 1.6
G	2.2 ≥ EER	2.0 ≥ EER	1.6 ≥ EER

These labeling requirements are currently undergoing revision, as of June 2011. The most recent Working Document on possible Ecodesign requirements for AC appliances and comfort fans (November 2010) sets out a scheme wherein the rating of split, multi-split, and single packaged (window) RACs is treated consistently, whereas moveable units have a separate scale (as at present). Seasonal performance will be rated for split systems. Ten ratings from A+++ to G are proposed, with separate ratings for the cooling and heating modes for reversible units. In the cooling mode the requirements are set in terms of SEER, whereas in the heating mode a seasonal coefficient of performance (SCOP) is applied.

Table 38: Proposed New Energy Labeling Requirements, Europe

Energy efficiency class	SEER (W/W)	SCOP (W/W)
A+++	SEER ≥ 8.50	SCOP ≥ 5.10
A++	6.10 ≤ SEER < 8.50	4.60 ≤ SCOP < 5.10
A+	5.60 ≤ SEER < 6.10	4.00 ≤ SCOP < 4.60
A	5.10 ≤ SEER < 5.60	3.40 ≤ SCOP < 4.00
B	4.60 ≤ SEER < 5.10	3.10 ≤ SCOP < 3.40
C	4.10 ≤ SEER < 4.60	2.80 ≤ SCOP < 3.10
D	3.60 ≤ SEER < 4.10	2.50 ≤ SCOP < 2.80
E	3.10 ≤ SEER < 3.60	2.20 ≤ SCOP < 2.50
F	2.60 ≤ SEER < 3.10	1.90 ≤ SCOP < 2.20
G	SEER < 2.60	SCOP < 1.90

The proposed new MEPS requirements are indicated in the table below.

Table 39: Proposed New MEPS Requirements, Europe

From January 2013		
	SEER (W/W)	SCOP (W/W)
If GWP of refrigerant > 150	3.60	3.4
If GWP of refrigerant < 150	3.24	3.06
From January 2014		
Pc < 6 kW, If GWP of refrigerant > 150	4.6	3.8
Pc < 6 kW, If GWP of refrigerant < 150	4.14	3.42
12 > Pc >= 6 kW, If GWP of refrigerant > 150	4.3	3.8
12 > Pc > 6 kW, If GWP of refrigerant < 150	3.87	3.42

5.1.3 Japan

Japan applies minimum fleet average energy efficiency requirements through its Top Runner program as specified below in Table 40 to Table 42. The 2010 requirements are specified in terms of the APF in Table 42 and are in addition to those specified in terms of the COP in Table 40 and Table 41. Products must thus satisfy both seasonal and full capacity energy efficiency requirements for both the cooling and heating modes.

Table 40: ACs whose target fiscal year is 2007 freezing year and each freezing year after that

Category[18]			Standard energy consumption efficiency (COP)
Unit Type	Cooling capacity	Category Name	
Non-ducted window/ wall-installed type		A	2.85
Non-ducted wall-mounted type (except multi-type operating indoor units individually)	Up to 2.5kW	B	5.27
	Over 2.5kW up to 3.2kW	C	4.9
	Over 3.2kW up to 4.0kW	D	3.65
	Over 4.0kW up to 7.1kW	E	3.17
	Over 7.1kW	F	3.1
Other non-ducted type (except multi-type operating indoor units	Up to 2.5kW	G	3.96
	Over 2.5kW up to 3.2kW	H	3.96

18 Remarks:

1. “Ducted type” indicates systems connected to ducts at the outlet.
2. “Multi-type” indicates a type that has two or more indoor units connected to an outdoor unit.

Category[18]			Standard energy consumption efficiency (COP)
Unit Type	Cooling capacity	Category Name	
individually)	Over 3.2kW up to 4.0kW	I	3.2
Ducted type (except multi-type operating indoor units individually)	Over 4.0kW up to 7.1kW	J	3.12
	Over 7.1kW	K	3.06
	Up to 4.0kW	L	3.02
Multi-type operating indoor units individually	Over 4.0kW up to 7.1kW	M	3.02
	Over 7.1kW	N	3.02
	Up to 4.0kW	O	4.12

Table 41: Cooling ACs

Category			Standard energy consumption efficiency (COP)
Unit Type	Cooling capacity	Category Name	
Non-ducted window/ wall-installed type		A	2.67
Non-ducted wall-mounted type (except multi-type operating indoor units individually)	Up to 2.5kW	B	3.64
	Over 2.5kW up to 3.2kW	C	3.64
	Over 3.2kW up to 4.0kW	D	3.08
	Over 4.0kW up to 7.1kW	E	2.91
	Over 7.1kW	F	2.81
Other non-ducted type (except multi-type operating indoor units individually)	Up to 4.0kW	G	2.88
	Over 4.0kW up to 7.1kW	H	2.85
	Over 7.1kW	I	2.85
Ducted type (except multi-type operating indoor units individually)	Up to 4.0kW	J	2.72
	Over 4.0kW up to 7.1kW	K	2.71
	Over 7.1kW	L	2.71
Multi-type operating indoor units individually	Up to 4.0kW	M	3.23
	Over 4.0kW up to 7.1kW	N	3.23
	Over 7.1kW	O	2.47

Table 42: ACs whose target fiscal year is FY 2010 and each subsequent fiscal year

Category			Standard energy consumption efficiency (APF)
Cooling capacity	Dimension type of indoor units[19]	Category Name	
Up to 3.2 kW	Dimension-defined type	A	5.8
	Free-dimension type	B	6.6
Over 3.2 kW up to 4.0 kW	Dimension-defined type	C	4.9
	Free-dimension type	D	6.0

The Top Runner requirements are specified for the Japanese fiscal year, rather than a calendar year. In addition, so called "freezing years" are defined as the part of the fiscal year that runs through the winter period. The Top Runner targets specified in Table 42 were required to be met for the following periods:

- 2007 freezing year (October 1, 2006, through September 30, 2007) and each subsequent freezing year (until "the period from October 1, 2009 through March 31, 2010");
- For non-ducted wall-mounted type cooling-cum-heating ACs whose cooling capacity is up to 4kW, the requirements had to be met for the 2004 freezing year (October 1, 2003 through September 30, 2004) and each subsequent freezing year after that; and
- For non-ducted wall-mounted type cooling-cum-heating ACs covered by the Household Good Quality Labeling Law, enforcement order, appendix no. 3, the requirements had to be met by FY 2010 and each subsequent fiscal year after that.

From 2012 and 2015, new requirements will come into force as set out in Table 43 and Table 44.

[19] Remarks: "Dimension type of indoor units" means that AC models having an indoor unit with horizontal width of 800 mm or less and height of 295 mm or less shall be defined as a dimension-defined type. ACs other than those of dimension-defined type shall be free-dimension type.

Table 43: Japanese APF Top Runner efficiency target - ACs for home use: Fiscal year 2012

Category			Standard energy consumption efficiency (APF)
Unit type	Cooling capacity	Category name	
Non-ducted wall-hung type (except multi-type controlling operation of indoor units individually)	Over 4.0kW up to 5.0kW	E	5.5
	Over 4.0kW up to 6.3kW	F	5.0
	Over 6.3kW up to 28.0kW	G	4.5
Other non-ducted type (except multi-type controlling operation of indoor units individually)	Up to 3.2 kW	H	5.2
	Over 3.2 kW up to 4.0 kW	I	4.8
	Over 4.0 kW up to 28.0 kW	J	4.3
Multi-type controlling operation of indoor units individually	Up to 4.0 kW	K	5.4
	Over 4.0 kW up to 7.1 kW	L	5.4
	Over 7.1 kW up to 28.0 kW	M	5.4

Remarks : "Multi-type" refers to a type that has two or more indoor units connected to one outdoor unit.

Table 44: Japanese APF Top Runner efficiency target - ACs for business use: Fiscal year 2015

Category				Standard energy consumption efficiency or calculation formula thereof
Type & function	Indoor unit type	Cooling capacity	Category name	
Combination of plural types or any type other than following	4-directional cassette type	Less than 3.6 kW	aa	E = 6.0
		Not less than 3.6 kW but less than 10.0 kW	ab	E = 6.0 - 0.083 × (A - 3.6)
		Not less than 10.0 kW but less than 20.0 kW	ac	E = 6.0 - 0.12 × (A - 10)
		Not less than 20.0 kW and up to 28.0 kW	ad	E = 5.1 - 0.060 × (A - 20)
	Other than 4-directional cassette type	Less than 3.6 kW	ae	E = 5.1
		Not less than 3.6 kW but less than 10.0 kW	af	E = 5.1 - 0.083 × (A - 3.6)
		Not less than 10.0 kW but less than 20.0 kW	ag	E = 5.1 - 0.10 × (A - 10)
		Not less than 20.0 kW and up to 28.0 kW	ah	E = 4.3 - 0.050 × (A - 20)
Multi-type controlling operation of indoor units individually		Less than 10.0 kW	ai	E = 5.7
		Not less than 10.0 kW but less than 20.0 kW	aj	E = 5.7 - 0.11 × (A - 10)
		Not less than 20.0 kW but less than 40.0 kW	ak	E = 5.7 - 0.065 × (A - 20)
		Not less than 40.0 kW and up to 50.4 kW	al	E = 4.8 - 0.040 × (A - 40)
Ducted type whose indoor unit is set on floor or any like type	Non-ducted type	Less than 20.0 kW	am	E = 4.9
		Not less than 20.0 kW and up to 28.0 kW	an	E = 4.9
	Ducted type	Less than 20.0 kW	ao	E = 4.7
		Not less than 20.0 kW and up to 28.0 kW	ap	E = 4.7

Remarks : 1. "Ducted type" indicates systems connected to ducts at the outlet.
2. "Multi-type" indicates a type that has two or more indoor units connected to an outdoor unit.
3. E and A represent the following values, respectively.
E: Standard energy consumption efficiency (in full-year energy consumption efficiency units)
A: Cooling capacity (in kilowatts)

5.1.4 Korea

In Korea, mandatory MEPS regulations were published in 2002 and became effective in 2004 for window and split AC units up to 23 kW cooling capacity. Table 45 gives the current MEPS level in the country. According to Choi (2009), the measured performance is the EER for fixed speed units and the Korean CSPF (SEER) for VSD units.

Table 45: Specification of MEPS in Korea (EER (W/W))

Type		MEPS (From January 2010 onwards)
Room air conditioner		2.88
Split Type	RCC < 4.0 kW	3.37
	4.0 kW < RCC < 10.0 kW	2.97
	10.0 kW < RCC < 17.5 kW	2.76
	17.5.0 kW < RCC < 23.0 kW	2.63

The table below presents the performance per label class for heat pumps in Korea. According to Choi (2009), the measured performance is the average (EER + COP)/2 for both fixed speed and VSD units.

Table 46: EER per Label Class and RCC in Korea (W/W)

Label Level	Non-Ducted and Ducted Unitary (including window type)	Split Type (RCC< 4 kW)	Split Type (4 kW RCC< 10 kW)	Split Type (10 kW RCC< 23 kW)
1	More than 3.20	More than 4.00	More than 3.80	More than 3.20
2	2.90 – 3.20	3.60 – 4.00	3.40 – 3.80	2.90 – 3.20
3	2.60 – 2.90	3.20 – 3.60	3.00 – 3.40	2.60 – 2.90
4	2.30 – 2.60	2.80 – 3.20	2.60 – 3.00	2.30 – 2.60
5	2.00 – 2.30	2.4 – 2.80	2.20 – 2.60	2.00 – 2.30

5.2 International comparison of MEPS stringency

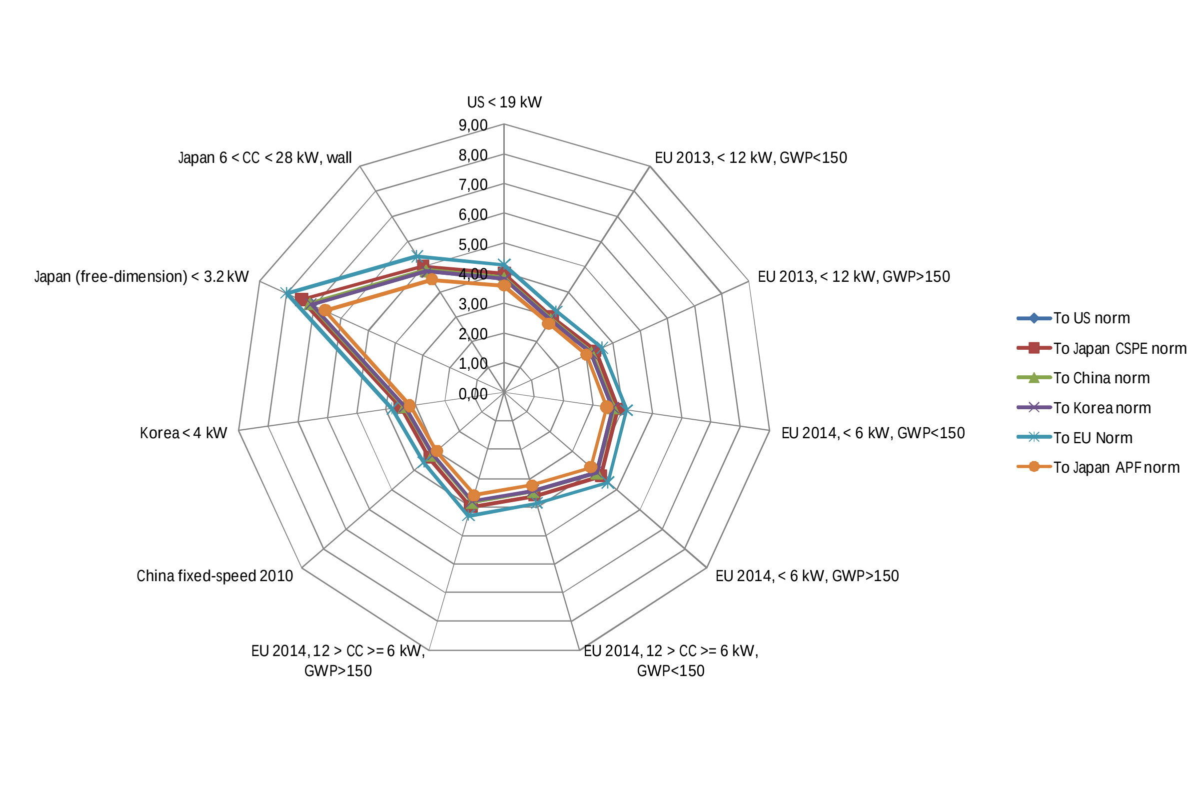
5.2.1 Fixed-speed, non-ducted, mini-split AC units

Applying the conversion formulae given in Table 25 to the MEPS and Top Runner requirements specified in Table 35 to Table 46 gives the values expressed below in Table 47 and Figure 13. This table and figure show the MEPS requirements for each economy as they would be once converted into the economy-specific seasonal energy efficiency requirement indicated in the left hand column. The values in bold indicate the MEPS requirements specified according to the seasonal energy efficiency norm of the economy issuing the MEPS. The values not in bold are conversions made using the conversion equations developed in this report.

Table 47: Comparable MEPS requirements (W/W) by economy under each test procedure

	US	EU (SEER)						China	Korea	Japan	
	2006	2013	2013	2014	2014	2014	2014	2008	2004	2012	2012
	< 19 kW	< 12 kW, GWP<150	< 12 kW, GWP>150	< 6 kW, GWP<150	< 6 kW, GWP>150	6 - 12 kW, GWP<150	6 - 12 kW, GWP>150	fix speed < 4.5 kW	fix speed < 4 kW	(free-dimension) < 3.2 kW	6 - 28 kW, wall
To US norm	**3.80**	2.88	3.20	3.68	4.09	3.44	3.82	3.17	3.37	7.13	4.81
To Japan CSPF norm	3.98	3.02	3.35	3.85	4.28	3.60	4.00	3.33	3.54	**7.47**	**5.05**
To China norm	3.83	2.90	3.22	3.71	4.12	3.47	3.85	**3.20**	3.40	7.19	4.86
To Korea norm	3.80	2.87	3.19	3.67	4.08	3.43	3.81	3.17	**3.37**	7.12	4.81
To EU Norm	4.28	**3.24**	**3.60**	**4.14**	**4.60**	**3.87**	**4.30**	3.57	3.80	8.02	5.42
To Japan APF norm	3.58	2.74	3.03	3.47	3.84	3.25	3.59	3.01	3.19	**6.60**	**4.50**

Figure 13: Comparison of SEER levels for MEPS for fixed-speed, non-ducted, mini-split AC units for China, EU, Japan, Korea, and the US



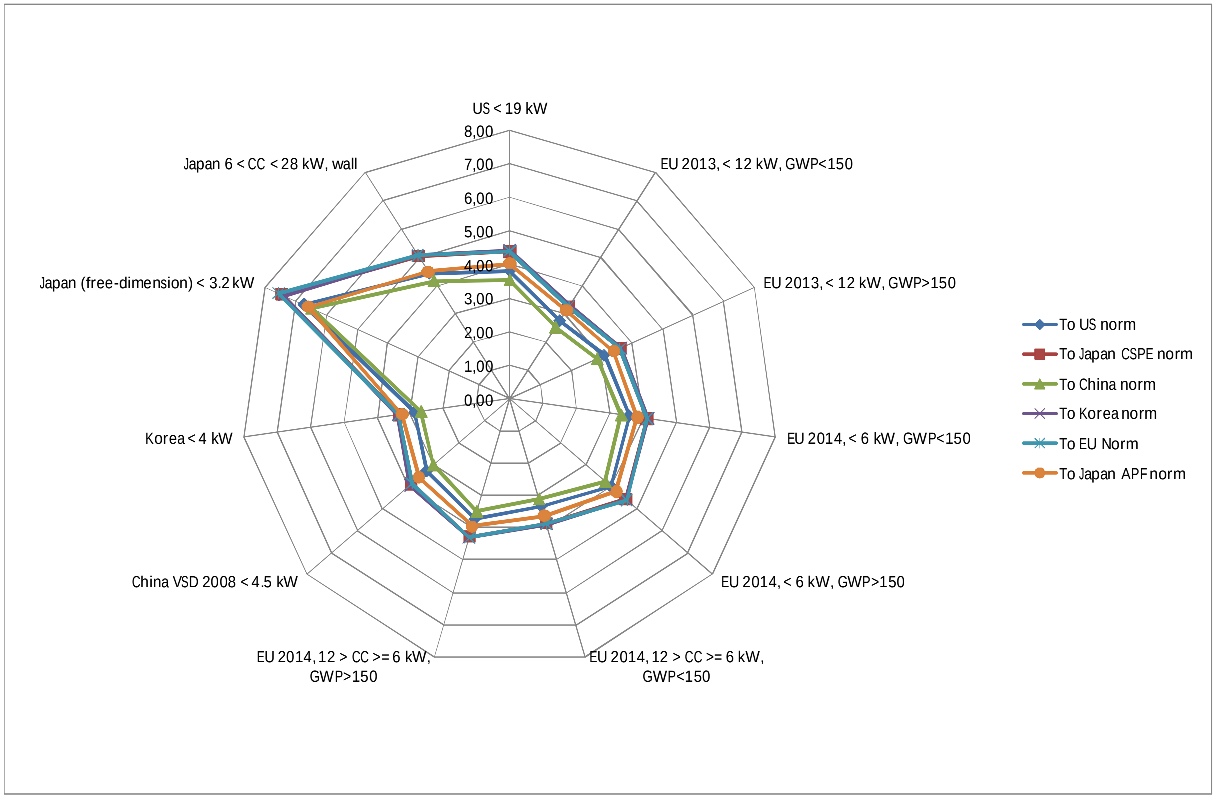
5.2.2 Variable-speed or frequency, non-ducted, mini-split AC units

Applying the conversion formulae given in Table 34 to the MEPS and Top Runner requirements specified in Table 35 to Table 46 gives the values expressed below in Table 48 and Figure 14. These should be read in the same way as described for Table 47 and Figure 13 above.

Table 48: Comparable MEPS requirements by economy under each test procedure

	US	EU (SEER)						China	Korea	Japan	
	2006	2013	2013	2014	2014	2014	2014	2008	2004	2012	2012
	< 19 kW	< 12 kW, GWP<150	< 12 kW, GWP>150	< 6 kW, GWP<150	< 6 kW, GWP>150	6 - 12 kW, GWP<150	6 - 12 kW, GWP>150	VSD < 4.5 kW	VSD < 4 kW	(free-dimension) < 3.2 kW	6 - 28 kW, wall
To US norm	**3.80**	2.76	3.09	3.59	4.01	3.34	3.74	3.29	2.88	6.75	4.43
To Japan CSPF norm	4.38	3.25	3.60	4.12	4.57	3.86	4.28	3.87	3.34	**7.47**	**5.05**
To China norm	3.53	2.52	2.85	3.34	3.76	3.10	3.49	**3.00**	2.67	6.48	4.16
To Korea norm	4.41	3.31	3.65	4.16	4.59	3.90	4.31	3.94	**3.37**	7.39	5.06
To EU Norm	4.39	**3.24**	**3.60**	**4.14**	**4.60**	**3.87**	**4.30**	3.86	3.34	7.57	5.08
To Japan APF norm	4.02	3.13	3.41	3.84	4.20	3.62	3.97	3.57	3.24	**6.60**	**4.50**

Figure 14: Comparison of SEER levels for MEPS for variable-speed, non-ducted, mini-split AC units for China, EU, Japan, Korea, and the US



CONCLUSIONS

This study has produced viable conversion coefficients that can be applied to convert between the room air conditioner (RAC) energy efficiency requirements in place in the major economies of the world. Conversion coefficients have been developed that allow conversions between energy efficiency ratios measured at full capacity, EER, and that allow conversions between seasonal energy efficiency ratios, SEER, that take into account part-load performance. The conversion metrics are applicable to non-ducted split-type RACs of either fixed speed or variable-speed as well as ducted split-type units. In addition, the impact of differences in permitted tolerances has been identified and addressed.

The uncertainty of applying these measures has been assessed and documented by comparison to detailed test results, and while the error margins are often too large for the conversion metrics to be practically applied for the purpose of rating individual products, they are sufficiently small to permit the meaningful comparison of the broad ambition of regulatory policy settings. The conversion coefficients have thus been applied to compare the minimum energy performance requirements in place in the major economies for the most common types of split RAC used internationally. These results show that the existing Japanese requirements are comfortably the most stringent of the existing requirements, and that they are between 17% (for more than 6 kW units) and 68% (for less than 3.2 kW units) more demanding than any current or proposed requirements in other economies.

While the conversion formulae developed in the report appear to be robust for the most common types of RAC sold internationally, and are applicable to both fixed-speed and variable-speed units, they should be used with caution whenever they are applied to models with significantly different characteristics to those considered in the statistical analyses used to derive the regressions. The conversions are based on a fairly limited data set, and minor refinements to the regressions are made from the evidence supplied by a very limited number of tests. It is not yet clear that the conversion formulae will be valid for products with somewhat different characteristics, such as for US split-ducted units with high SEER but low EER. Ideally, more work would be done to verify or refine the conversion coefficients applicable to such units.

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APPENDIX: VSD mini-split on the Japanese market, database 2011

Manufacturer	Model	Model Series / Description	Cool CAP kW	Heat CAP kW	EER	COP	COPj	APF
Daikin	AN22MRS-W	R Series	2.2	2.5	5.37	5.95	5.66	6.5
Daikin	AN22MHS-W	H Series	2.2	2.5	5.37	5.95	5.66	6.5
Daikin	AN22LCS-W	C Series	2.2	2.2	4.84	5.71	5.27	5.8
Daikin	AN22LPS-W	P Series	2.2	2.2	4.84	5.71	5.27	5.8
Daikin	AN22LES-W	E Series	2.2	2.2	4.84	5.71	5.27	5.8
Fujitsu	AS-J22W-W	Inverter AC 2010	2.2	2.2	4.84	5.71	5.27	5.8
Fujitsu	AS-R22W-W	Inverter AC 2010	2.2	2.2	4.89	5.64	5.26	5.8
Fujitsu	AS-S22W-W	Inverter AC 2010	2.2	2.5	5.12	5.68	5.40	6.5
Fujitsu	AS-V22W-W	Inverter AC 2010	2.2	2.2	5.06	5.71	5.39	6.5
Fujitsu	AS-Z22A	Inverter AC 2011	2.2	2.5	5.64	6.02	5.83	6.8
Fujitsu	AS-S22A-W	Inverter AC 2011	2.2	2.5	5.12	5.68	5.40	6.5
Fujitsu	AS-R22A-W	Inverter AC 2011	2.2	2.2	4.58	5.37	4.97	5.8
Fujitsu	AS-V22A-W	Inverter AC 2011	2.2	2.2	4.94	5.87	5.41	6.7
Fujitsu	AS-J22A	Inverter AC 2011	2.2	2.2	3.83	5.12	4.47	5.8
Mitsubishi	MSZ-ZXV221-W-IN	ZXV wall type series - Indoor unit (white)	2.2	2.5	5.43	5.62	5.53	6.9
Mitsubishi	MSZ-ZXV220-W-IN	ZXV wall type series - Indoor unit (white)	2.2	2.5	5.79	5.56	5.67	7.1
Mitsubishi	MSZ-BXV220-W-IN	BXV wall type series - indoor unit (white)	2.2	2.5	4.84	5.62	5.23	5.9
Mitsubishi	MSZ-GV220-W-IN	GV wall type series - indoor unit (white)	2.2	2.5	5.06	5.49	5.28	5.8
Mitsubishi	MSZ-GW220-W-IN	GW wall type series - indoor unit (white)	2.2	2.5	4.94	5.62	5.28	6.4
Mitsubishi	MSZ-HS221-W-IN	HS wall type series - indoor unit (white)	2.2	2.5	4.11	5.00	4.56	5.8
Mitsubishi	MSZ-JXV220-W-IN	JXV wall type series - indoor unit (white)	2.2	2.5	4.94	5.62	5.28	6.4
Mitsubishi	MSZ-AXV220-W-IN	AXV wall type series - indoor unit (white)	2.2	2.5	5.06	5.49	5.28	5.8
Mitsubishi	MSZ-ZW221-W-IN	ZW wall type series - indoor unit (white)	2.2	2.5	5.43	5.62	5.53	6.9
Mitsubishi	MSZ-ZW220-W-IN	ZW wall type series - indoor unit (white)	2.2	2.5	5.79	5.56	5.67	7.1
Mitsubishi	MSZ-GR220-W-IN	GR wall type series - indoor unit (white)	2.2	2.5	4.94	5.62	5.28	5.9
Mitsubishi	MSZ-GM221-W-IN	GM wall type series - indoor unit (white)	2.2	2.5	4.11	5.00	4.56	5.8

Mitsubishi	MSZ-GM220-W-IN	GM wall type series - indoor unit (white)	2.2	2.5	5.06	5.49	5.28	5.8
Panasonic	CS-X221C / Cxr	Inverter type RAC dehumidification	2.2	2.5	5.95	6.10	6.02	7.1
Panasonic	CS-HX220C	Inverter type RAC dehumidification	2.2	2.5	6.67	6.85	6.76	7.2
Panasonic	CS-SX221C	RAC CS-type inverter AC dehumidification	2.2	2.2	5.06	5.71	5.39	6.3
Panasonic	CS-G220C	Inverter type RAC dehumidification	2.2	2.2	5.43	6.20	5.81	6.5
Panasonic	CS-EX221C	RAC CS-type inverter AC dehumidification	2.2	2.2	4.94	5.57	5.26	6.3
Panasonic	CS-V221C	Inverter type RAC dehumidification	2.2	2.2	4.63	5.43	5.03	5.9
Panasonic	CS-F221C / CS-2201fr	Inverter type RAC dehumidification	2.2	2.2	4.63	5.43	5.03	5.9
Daikin	AN25MRS-W	R Series	2.5	2.8	5.21	5.60	5.40	6.5
Daikin	AN25MHS-W	H Series	2.5	2.8	5.21	5.60	5.40	6.5
Daikin	AN25LCS-W	C Series	2.5	2.5	4.81	5.75	5.28	5.8
Daikin	AN25LPS-W	P Series	2.5	2.5	4.81	5.75	5.28	5.8
Daikin	AN25LES-W	E Series	2.5	2.5	4.59	5.95	5.27	5.8
Fujitsu	AS-J25W-W	Inverter AC 2010	2.5	2.5	4.85	5.68	5.27	5.8
Fujitsu	AS-R25W-W	Inverter AC 2010	2.5	2.5	4.59	5.95	5.27	5.8
Fujitsu	AS-S25W-W	Inverter AC 2010	2.5	2.8	5.00	5.54	5.27	6.5
Fujitsu	AS-V25W-W	Inverter AC 2010	2.5	2.5	5.10	5.81	5.46	6.5
Fujitsu	AS-Z25A	Inverter AC 2011	2.5	2.8	5.32	5.89	5.61	6.8
Fujitsu	AS-S25A-W	Inverter AC 2011	2.5	2.8	4.90	5.66	5.28	6.5
Fujitsu	AS-R25A-W	Inverter AC 2011	2.5	2.8	4.39	5.00	4.69	5.8
Fujitsu	AS-V25A-W	Inverter AC 2011	2.5	2.8	5.10	5.60	5.35	6.7
Fujitsu	AS-J25A-W	Inverter AC 2011	2.5	2.8	4.39	4.91	4.65	5.8
Mitsubishi	MSZ-ZXV251-W-IN	ZXV wall type series - Indoor unit (white)	2.5	2.8	5.43	5.38	5.41	6.9
Mitsubishi	MSZ-ZXV250-W-IN	ZXV wall type series - Indoor unit (white)	2.5	2.8	5.56	5.60	5.58	6.9
Mitsubishi	MSZ-BXV250-W-IN	BXV wall type series - indoor unit (white)	2.5	2.8	4.90	5.66	5.28	5.9
Mitsubishi	MSZ-GV250-W-IN	GV wall type series - indoor unit (white)	2.5	2.8	5.00	5.54	5.27	5.8
Mitsubishi	MSZ-GW250-W-IN	GW wall type series - indoor unit (white)	2.5	2.2	4.95	4.36	4.65	6.4
Mitsubishi	MSZ-GW280-W-IN	GW wall type series - indoor unit (white)	2.5	2.5	4.24	3.52	3.88	6.4
Mitsubishi	MSZ-HS251-W-IN	HS wall type series - indoor unit (white)	2.5	2.8	3.85	4.91	4.38	5.8
Mitsubishi	MSZ-JXV250-W-IN	JXV wall type series - indoor unit (white)	2.5	2.8	4.95	5.60	5.28	6.4
Mitsubishi	MSZ-AXV250-W-IN	AXV wall type series - indoor unit (white)	2.5	2.8	5.00	5.54	5.27	5.8

Mitsubishi	MSZ-ZW251-W-IN	ZW wall type series - indoor unit (white)	2.5	2.8	5.43	5.38	5.41	6.9
Mitsubishi	MSZ-ZW250-W-IN	ZW wall type series - indoor unit (white)	2.5	2.8	5.56	5.60	5.58	6.9
Mitsubishi	MSZ-GR250-W-IN	GR wall type series - indoor unit (white)	2.5	2.8	4.90	5.66	5.28	5.9
Mitsubishi	MSZ-GM251-W-IN	GM wall type series - indoor unit (white)	2.5	2.8	3.85	4.91	4.38	5.8
Mitsubishi	MSZ-GM250-W-IN	GM wall type series - indoor unit (white)	2.5	2.8	5.00	5.54	5.27	5.8
Mitsubishi	MSZ-HXV251-T-IN	High heating capacity HXV type wall type series - indoor unit	2.5	3.2	5.21	5.52	5.36	6.7
Mitsubishi	MSZ-HXV251-W-IN	High heating capacity HXV type wall type series - indoor unit	2.5	3.2	5.21	5.52	5.36	6.7
Panasonic	CS-X251C / Cxr	Inverter type RAC dehumidification	2.5	2.8	5.43	5.83	5.63	6.9
Panasonic	CS-HX250C	Inverter type RAC dehumidification	2.5	2.8	6.33	6.59	6.46	7.1
Panasonic	CS-RX250C2	Air conditioning refrigerant heater with "full warm air"	2.5	2.8	6.33	6.67	6.50	6.5
Panasonic	CS-SX251C	RAC CS-type inverter AC dehumidification	2.5	2.8	5.05	5.60	5.33	6.3
Panasonic	CS-G250C	Inverter type RAC dehumidification	2.5	2.5	5.21	5.95	5.58	6.5
Panasonic	CS-EX251C	RAC CS-type inverter AC dehumidification	2.5	2.8	4.72	5.19	4.95	6
Panasonic	CS-V251C	Inverter type RAC dehumidification	2.5	2.8	4.72	5.09	4.90	5.9
Panasonic	CS-F251C / CS-251Cfr	Inverter type RAC dehumidification	2.5	2.8	4.72	5.09	4.90	5.9
Daikin	AN28MRS-W	R Series	2.8	3.6	5.09	5.37	5.23	6.7
Daikin	AN28MHS-W	H Series	2.8	3.6	5.09	5.37	5.23	6.7
Daikin	AN28LCS-W	C Series	2.8	3	4.38	5.45	4.91	5.8
Daikin	AN28LPS-W	P Series	2.8	3	4.38	5.45	4.91	5.8
Daikin	AN28LES-W	E Series	2.8	2.8	4.27	5.60	4.94	5.8
Daikin	S28LTDXP-W	DX Series	2.8	4	4.83	5.19	5.01	6.3
Daikin	S28LTDXV-W	DX Series - outdoor power type	2.8	4	4.83	5.19	5.01	6.3
Fujitsu	AS-J28W-W	Inverter AC 2010	2.8	2.8	4.31	5.49	4.90	5.8
Fujitsu	AS-R28W-W	Inverter AC 2010	2.8	2.8	4.41	5.38	4.90	5.8
Fujitsu	AS-S28W-W	Inverter AC 2010	2.8	3.2	4.63	5.33	4.98	6.5
Fujitsu	AS-V28W-W	Inverter AC 2010	2.8	2.8	4.75	5.60	5.17	6.5
Fujitsu	AS-Z28W-W	Inverter AC 2010	2.8	3.6	5.28	5.50	5.39	6.7
Fujitsu	AS-Z28A	Inverter AC 2011	2.8	3.6	5.14	5.58	5.36	6.8
Fujitsu	AS-S28A-W	Inverter AC 2011	2.8	3.6	4.63	5.18	4.90	6.5
Fujitsu	AS-R28A-W	Inverter AC 2011	2.8	3.6	3.94	4.44	4.19	5.8

Fujitsu	AS-V28A-W	Inverter AC 2011	2.8	3.6	4.83	5.33	5.08	6.7
Fujitsu	AS-J28A-W	Inverter AC 2011	2.8	3.6	4.06	4.56	4.31	5.8
Mitsubishi	MSZ-ZXV281S-W-IN	ZXV wall type series - Indoor unit (white)	2.8	3.6	5.49	5.71	5.60	7.1
Mitsubishi	MSZ-ZXV281-W-IN	ZXV wall type series - Indoor unit (white)	2.8	3.6	5.19	5.54	5.36	6.9
Mitsubishi	MSZ-ZXV280-W-IN	ZXV wall type series - Indoor unit (white)	2.8	3.6	5.33	5.71	5.52	6.7
Mitsubishi	MSZ-ZXV280S-W-IN	ZXV wall type series - Indoor unit (white)	2.8	3.6	5.33	5.71	5.52	6.7
Mitsubishi	MSZ-BXV280-W-IN	BXV wall type series - indoor unit (white)	2.8	3.2	4.38	5.42	4.90	5.9
Mitsubishi	MSZ-GV280-W-IN	GV wall type series - indoor unit (white)	2.8	3.2	4.41	5.38	4.89	5.8
Mitsubishi	MSZ-HS281-W-IN	HS wall type series - indoor unit (white)	2.8	3.6	4.00	4.44	4.22	5.8
Mitsubishi	MSZ-JXV280-W-IN	JXV wall type series - indoor unit (white)	2.8	3.6	4.75	5.07	4.91	6.4
Mitsubishi	MSZ-JXV280S-W-IN	JXV wall type series - indoor unit (white)	2.8	3.6	4.75	5.07	4.91	6.4
Mitsubishi	MSZ-AXV280-W-IN	AXV wall type series - indoor unit (white)	2.8	3.2	4.41	5.38	4.89	5.8
Mitsubishi	MSZ-AXV280S-W-IN	AXV wall type series - indoor unit (white)	2.8	3.2	4.41	5.38	4.89	5.8
Mitsubishi	MSZ-ZW281S-W-IN	ZW wall type series - indoor unit (white)	2.8	3.6	5.49	5.71	5.60	7.1
Mitsubishi	MSZ-ZW281-W-IN	ZW wall type series - indoor unit (white)	2.8	3.6	5.19	5.54	5.36	6.9
Mitsubishi	MSZ-ZW280-W-IN	ZW wall type series - indoor unit (white)	2.8	3.6	5.33	5.71	5.52	6.7
Mitsubishi	MSZ-GR280-W-IN	GR wall type series - indoor unit (white)	2.8	3.2	4.38	5.42	4.90	5.9
Mitsubishi	MSZ-GM281-W-IN	GM wall type series - indoor unit (white)	2.8	3.6	4.00	4.44	4.22	5.8
Mitsubishi	MSZ-GM280-W-IN	GM wall type series - indoor unit (white)	2.8	3.2	4.41	5.38	4.89	5.8
Mitsubishi	MSZ-HXV281S-T-IN	High heating capacity HXV type wall type series - indoor unit	2.8	4	5.00	5.26	5.13	6.6
Mitsubishi	MSZ-HXV281S-W-IN	High heating capacity HXV type wall type series - indoor unit	2.8	4	5.00	5.26	5.13	6.6
Panasonic	CS-X281C / C2 / Cxr	Inverter type RAC dehumidification	2.8	3.6	5.09	5.37	5.23	6.7
Panasonic	CS-HX280C	Inverter type RAC dehumidification	2.8	3.2	6.09	6.34	6.21	7
Panasonic	CS-RX280C2	Air conditioning refrigerant heater with "full warm air"	2.8	3.2	6.02	6.60	6.31	6.5
Panasonic	CS-SX281C	RAC CS-type inverter AC dehumidification	2.8	3.6	5.00	5.22	5.11	6.3
Panasonic	CS-G280C	Inverter type RAC dehumidification	2.8	2.8	4.91	5.83	5.37	6.5
Panasonic	CS-EX281C	RAC CS-type inverter AC dehumidification	2.8	3.6	4.31	4.62	4.46	6
Panasonic	CS-V281C / C2	Inverter type RAC dehumidification	2.8	3.6	4.27	4.53	4.40	5.9
Panasonic	CS-F281C / CS-281Cfr	Inverter type RAC dehumidification	2.8	3.6	4.27	4.53	4.40	5.9
Daikin	AN36MRS-W	R Series	3.6	4.2	4.00	5.00	4.50	6.1

Daikin	AN36MHS-W	H Series	3.6	4.2	4.00	5.00	4.50	6.1
Daikin	AN36LCS-W	C Series	3.6	4.2	3.24	4.12	3.68	4.9
Daikin	AN36LPS-W	P Series	3.6	4.2	3.30	4.04	3.67	4.9
Daikin	AN36LES-W	E Series	3.6	4.2	3.30	4.04	3.67	4.9
Mitsubishi	MSZ-ZXV361S-W-IN	ZXV wall type series - Indoor unit (white)	3.6	4.2	4.39	5.38	4.89	6.5
Mitsubishi	MSZ-ZXV361-W-IN	ZXV wall type series - Indoor unit (white)	3.6	4.2	4.04	5.22	4.63	6.3
Mitsubishi	MSZ-ZXV360-W-IN	ZXV wall type series - Indoor unit (white)	3.6	4.2	4.21	5.32	4.76	6.1
Mitsubishi	MSZ-ZXV360S-W-IN	ZXV wall type series - Indoor unit (white)	3.6	4.2	4.21	5.32	4.76	6.1
Mitsubishi	MSZ-BXV360-W-IN	BXV wall type series - indoor unit (white)	3.6	4.2	3.35	4.24	3.80	5
Mitsubishi	MSZ-GV360-W-IN	GV wall type series - indoor unit (white)	3.6	4.2	3.27	4.02	3.65	4.9
Mitsubishi	MSZ-GW360-W-IN	GW wall type series - indoor unit (white)	3.6	4.2	3.35	4.24	3.80	5.2
Mitsubishi	MSZ-HS361-W-IN	HS wall type series - indoor unit (white)	3.6	4.2	3.08	3.78	3.43	4.9
Mitsubishi	MSZ-JXV360-W-IN	JXV wall type series - indoor unit (white)	3.6	4.2	3.35	4.24	3.80	5.2
Mitsubishi	MSZ-JXV360S-W-IN	JXV wall type series - indoor unit (white)	3.6	4.2	3.35	4.24	3.80	5.2
Mitsubishi	MSZ-AXV360-W-IN	AXV wall type series - indoor unit (white)	3.6	4.2	3.27	4.02	3.65	4.9
Mitsubishi	MSZ-AXV360S-W-IN	AXV wall type series - indoor unit (white)	3.6	4.2	3.27	4.02	3.65	4.9
Mitsubishi	MSZ-ZW361S-W-IN	ZW wall type series - indoor unit (white)	3.6	4.2	4.39	5.38	4.89	6.5
Mitsubishi	MSZ-ZW361-W-IN	ZW wall type series - indoor unit (white)	3.6	4.2	4.04	5.22	4.63	6.3
Mitsubishi	MSZ-ZW360-W-IN	ZW wall type series - indoor unit (white)	3.6	4.2	4.21	5.32	4.76	6.1
Mitsubishi	MSZ-GR360-W-IN	GR wall type series - indoor unit (white)	3.6	4.2	3.35	4.24	3.80	5
Mitsubishi	MSZ-GM361-W-IN	GM wall type series - indoor unit (white)	3.6	4.2	3.08	3.78	3.43	4.9
Mitsubishi	MSZ-GM360-W-IN	GM wall type series - indoor unit (white)	3.6	4.2	3.27	4.02	3.65	4.9
Panasonic	CS-X361C / C2 /Cxr	Inverter type RAC dehumidification	3.6	4.2	4.34	4.88	4.61	6.1
Panasonic	CS-SX361C	RAC CS-type inverter AC dehumidification	3.6	4.2	3.60	4.31	3.95	5.3
Panasonic	CS-EX361C	RAC CS-type inverter AC dehumidification	3.6	4.2	3.56	4.26	3.91	5.3
Panasonic	CS-V361C2	Inverter type RAC dehumidification	3.6	4.2	3.33	4.24	3.79	5
Panasonic	CS-F361C2	Inverter type RAC dehumidification	3.6	4.2	3.33	4.24	3.79	5
Daikin	AN40MRS-W	R Series	4	5	4.30	5.10	4.70	6
Daikin	AN40MRP-W	R Series	4	5	4.49	5.26	4.88	6.4
Daikin	AN40MHP-W	H Series	4	5	4.49	5.26	4.88	6.4
Daikin	AN40LCP-W	C Series	4	5	3.57	4.17	3.87	4.9

Daikin	AN40LPP-W	P Series	4	5	3.25	4.07	3.66	4.9
Daikin	AN40LEP-W	E Series	4	5	3.25	4.07	3.66	4.9
Daikin	S40LTDXP-W	DX Series	4	6	4.35	4.44	4.40	6
Daikin	S40LTDXV-W	DX Series - outdoor power type	4	6	4.35	4.44	4.40	6
Fujitsu	AS-J40W-W	Inverter AC 2010	4	5	3.35	3.94	3.64	4.9
Fujitsu	AS-R40W-W	Inverter AC 2010	4	5	3.16	4.13	3.65	4.9
Fujitsu	AS-S40W2W	Inverter AC 2010	4	5	3.70	4.46	4.08	5.8
Fujitsu	AS-V40W-W	Inverter AC 2010	4	5	3.45	4.17	3.81	5.5
Fujitsu	AS-Z40W2W	Inverter AC 2010	4	5	4.12	4.95	4.54	6.2
Fujitsu	AS-Z40A2	Inverter AC 2011	4	5	4.10	5.00	4.55	6.3
Fujitsu	AS-S40A2W	Inverter AC 2011	4	5	3.70	4.46	4.08	5.8
Fujitsu	AS-R40A-W	Inverter AC 2011	4	5	3.00	3.88	3.44	4.9
Fujitsu	AS-V40A-W	Inverter AC 2011	4	5	3.45	4.17	3.81	5.7
Fujitsu	AS-J40A-W	Inverter AC 2011	4	5	3.23	3.62	3.42	4.9
Mitsubishi	MSZ-ZXV401S-W-IN	ZXV wall type series - Indoor unit (white)	4	5	4.12	4.63	4.38	6.3
Mitsubishi	MSZ-ZXV400S-W-IN	ZXV wall type series - Indoor unit (white)	4	5	4.44	5.05	4.75	6.1
Mitsubishi	MSZ-BXV400S-W-IN	BXV wall type series - indoor unit (white)	4	5	3.64	4.39	4.01	5
Mitsubishi	MSZ-GV400S-W-IN	GV wall type series - indoor unit (white)	4	5	3.45	3.85	3.65	4.9
Mitsubishi	MSZ-GW400S-W-IN	GW wall type series - indoor unit (white)	4	5	3.70	4.33	4.02	5.2
Mitsubishi	MSZ-HS401S-W-IN	HS wall type series - indoor unit (white)	4	5	3.17	3.79	3.48	4.9
Mitsubishi	MSZ-JXV400S-W-IN	JXV wall type series - indoor unit (white)	4	5	3.70	4.33	4.02	5.2
Mitsubishi	MSZ-AXV400S-W-IN	AXV wall type series - indoor unit (white)	4	5	3.45	3.85	3.65	4.9
Mitsubishi	MSZ-ZW401S-W-IN	ZW wall type series - indoor unit (white)	4	5	4.12	4.63	4.38	6.3
Mitsubishi	MSZ-ZW400S-W-IN	ZW wall type series - indoor unit (white)	4	5	4.44	5.05	4.75	6.1
Mitsubishi	MSZ-GR400S-W-IN	GR wall type series - indoor unit (white)	4	5	3.64	4.39	4.01	5
Mitsubishi	MSZ-GM401S-W-IN	GM wall type series - indoor unit (white)	4	5	3.17	3.79	3.48	4.9
Mitsubishi	MSZ-GM400S-W-IN	GM wall type series - indoor unit (white)	4	5	3.45	3.85	3.65	4.9
Mitsubishi	MSZ-HXV401S-T-IN	High heating capacity HXV type wall type series - indoor unit	4	6	4.17	4.29	4.23	5.6
Mitsubishi	MSZ-HXV401S-W-IN	High heating capacity HXV type wall type series - indoor unit	4	6	4.17	4.29	4.23	5.6
Mitsubishi	MSZ-HXV400S-T-IN	High heating capacity HXV type wall type series - indoor	4	6	4.35	4.56	4.46	5.6

		unit						
Mitsubishi	MSZ-HXV400S-W-IN	High heating capacity HXV type wall type series - indoor unit	4	6	4.35	4.56	4.46	5.6
Panasonic	CS-X401C / C2 / Cxr / Cxr2	Inverter type RAC dehumidification	4	5	3.74	4.39	4.06	5.8
Panasonic	CS-HX400C2	Inverter type RAC dehumidification	4	5	4.91	5.65	5.28	6.7
Panasonic	CS-RX400C2	Air conditioning refrigerant heater with "full warm air"	4	5	4.57	5.49	5.03	5.9
Panasonic	CS-SX401C2	RAC CS-type inverter AC dehumidification	4	5	3.48	4.24	3.86	5.3
Panasonic	CS-G400C2	Inverter type RAC dehumidification	4	5	3.67	4.42	4.05	5.5
Panasonic	CS-EX401C2	RAC CS-type inverter AC dehumidification	4	5	3.45	4.20	3.82	5.3
Panasonic	CS-V401C2	Inverter type RAC dehumidification	4	5	3.10	3.85	3.47	5
Panasonic	CS-F401C2 / CS-401Cfr2	Inverter type RAC dehumidification	4	5	3.10	3.85	3.47	5
Fujitsu	AS-V50W2W	Inverter AC 2010	5	6	2.96	4.11	3.53	5.5
Fujitsu	AS-Z50W2W	Inverter AC 2010	5	6.3	3.14	4.26	3.70	5.7
Fujitsu	AS-J50A2W	Inverter AC 2011	5	6	2.96	4.11	3.53	5.5
Panasonic	CS-X501C2 / Cxr2	Inverter type RAC dehumidification	5	6	3.40	4.35	3.87	5.7
Panasonic	CS-HX500C2	Inverter type RAC dehumidification	5	6	3.65	4.82	4.23	5.9
Panasonic	CS-RX500C2	Air conditioning refrigerant heater with "full warm air"	5	6	3.44	4.82	4.13	5.6
Daikin	AN56MRP-W	R Series	5.6	6.7	2.96	4.50	3.73	5.4
Daikin	AN56MHP-W	H Series	5.6	6.7	2.96	4.50	3.73	5.4
Daikin	AN56LCP-W	C Series	5.6	6.7	2.93	4.09	3.51	5.1
Daikin	AN56LPP-W	P Series	5.6	6.7	2.99	4.09	3.54	5.1
Daikin	AN56LEP-W	E Series	5.6	6.7	2.99	4.09	3.54	5
Daikin	S56LTDXP-W	DX Series	5.6	6.7	2.48	4.32	3.40	5.3
Daikin	S56LTDXV-W	DX Series - outdoor power type	5.6	6.7	2.48	4.32	3.40	5.3
Fujitsu	AS-S56A2W	Inverter AC 2011	5.6	6.7	2.68	3.66	3.17	5
Fujitsu	AS-V56A2W	Inverter AC 2011	5.6	6.7	2.89	3.62	3.25	5
Mitsubishi	MSZ-ZXV561S-W-IN	ZXV wall type series - Indoor unit (white)	5.6	6.7	2.96	4.21	3.59	5.4
Mitsubishi	MSZ-ZXV560S-W-IN	ZXV wall type series - Indoor unit (white)	5.6	6.7	3.14	4.47	3.80	5.3
Mitsubishi	MSZ-BXV560S-W-IN	BXV wall type series - indoor unit (white)	5.6	6.7	2.67	3.66	3.16	5
Mitsubishi	MSZ-GV560S-W-IN	GV wall type series - indoor unit (white)	5.6	6.7	2.57	3.76	3.17	5
Mitsubishi	MSZ-GW560S-W-IN	GW wall type series - indoor unit (white)	5.6	6.7	3.03	4.59	3.81	5.1

Mitsubishi	MSZ-HS561S-W-IN	HS wall type series - indoor unit (white)	5.6	6.7	2.57	3.76	3.17	5
Mitsubishi	MSZ-JXV560S-W-IN	JXV wall type series - indoor unit (white)	5.6	6.7	3.03	4.59	3.81	5.1
Mitsubishi	MSZ-AXV560S-W-IN	AXV wall type series - indoor unit (white)	5.6	6.7	2.57	3.76	3.17	5
Mitsubishi	MSZ-ZW561S-W-IN	ZW wall type series - indoor unit (white)	5.6	6.7	2.96	4.21	3.59	5.4
Mitsubishi	MSZ-ZW560S-W-IN	ZW wall type series - indoor unit (white)	5.6	6.7	3.14	4.47	3.80	5.3
Mitsubishi	MSZ-GR560S-W-IN	GR wall type series - indoor unit (white)	5.6	6.7	2.67	3.66	3.16	5
Mitsubishi	MSZ-GM561S-W-IN	GM wall type series - indoor unit (white)	5.6	6.7	2.57	3.76	3.17	5
Mitsubishi	MSZ-GM560S-W-IN	GM wall type series - indoor unit (white)	5.6	6.7	2.57	3.76	3.17	5
Mitsubishi	MSZ-HXV561S-T-IN	High heating capacity HXV type wall type series - indoor unit	5.6	6.7	2.99	4.19	3.59	5.3
Mitsubishi	MSZ-HXV561S-W-IN	High heating capacity HXV type wall type series - indoor unit	5.6	6.7	2.99	4.19	3.59	5.3
Mitsubishi	MSZ-HXV560S-T-IN	High heating capacity HXV type wall type series - indoor unit	5.6	6.7	3.20	4.41	3.80	5.3
Mitsubishi	MSZ-HXV560S-W-IN	High heating capacity HXV type wall type series - indoor unit	5.6	6.7	3.20	4.41	3.80	5.3
Panasonic	CS-EX561C2	RAC CS-type inverter AC dehumidification	5.6	6.7	2.95	3.64	3.29	5.1
Panasonic	CS-V561C2	Inverter type RAC dehumidification	5.6	6.7	2.95	3.64	3.29	5.1
Panasonic	CS-F561C2 / CS-561Cfr2	Inverter type RAC dehumidification	5.6	6.7	2.95	3.64	3.29	5.1
Daikin	AN63MRP-W	R Series	6.3	7.1	2.83	4.13	3.48	5
Daikin	AN63MHP-W	H Series	6.3	7.1	2.83	4.13	3.48	5
Fujitsu	AS-Z63W2W	Inverter AC 2010	6.3	7.1	2.75	3.98	3.36	5.2
Fujitsu	AS-V63A2W	Inverter AC 2011	6.3	7.1	2.90	3.72	3.31	5
Mitsubishi	MSZ-ZXV631S-W-IN	ZXV wall type series - Indoor unit (white)	6.3	7.1	2.90	4.21	3.56	5
Mitsubishi	MSZ-ZXV630S-W-IN	ZXV wall type series - Indoor unit (white)	6.3	7.1	3.30	4.57	3.93	5
Mitsubishi	MSZ-ZW631S-W-IN	ZW wall type series - indoor unit (white)	6.3	7.1	2.90	4.21	3.56	5
Mitsubishi	MSZ-ZW630S-W-IN	ZW wall type series - indoor unit (white)	6.3	7.1	3.30	4.57	3.93	5
Panasonic	CS-X631C2 / CS-631Cxr2	Inverter type RAC dehumidification	6.3	7.1	2.69	3.88	3.29	5.1
Panasonic	CS-HX630C2	Inverter type RAC dehumidification	6.3	7.1	2.90	4.18	3.54	5.3
Daikin	AN71MRP-W	R Series	7.1	8.5	2.52	3.60	3.06	4.6
Daikin	AN71MHP-W	H Series	7.1	8.5	2.52	3.60	3.06	4.6
Fujitsu	AS-Z71W2W	Inverter AC 2010	7.1	7.5	2.37	3.96	3.17	4.8
Fujitsu	AS-V71A2W	Inverter AC 2011	7.1	8.5	2.54	2.97	2.75	4.5

Mitsubishi	MSZ-ZXV711S-W-IN	ZXV wall type series - Indoor unit (white)	7.1	8.5	2.41	3.92	3.16	4.7
Mitsubishi	MSZ-ZXV710S-W-IN	ZXV wall type series - Indoor unit (white)	7.1	7.5	2.64	4.39	3.51	4.6
Mitsubishi	MSZ-ZW711S-W-IN	ZW wall type series - indoor unit (white)	7.1	8.5	2.41	3.92	3.16	4.7
Mitsubishi	MSZ-ZW710S-W-IN	ZW wall type series - indoor unit (white)	7.1	7.5	2.64	4.39	3.51	4.6
Panasonic	CS-X711C2 / CS-711Cxr2	Inverter type RAC dehumidification	7.1	8.5	2.59	3.37	2.98	4.7
Panasonic	CS-HX710C2	Inverter type RAC dehumidification	7.1	7.5	2.59	3.95	3.27	5

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