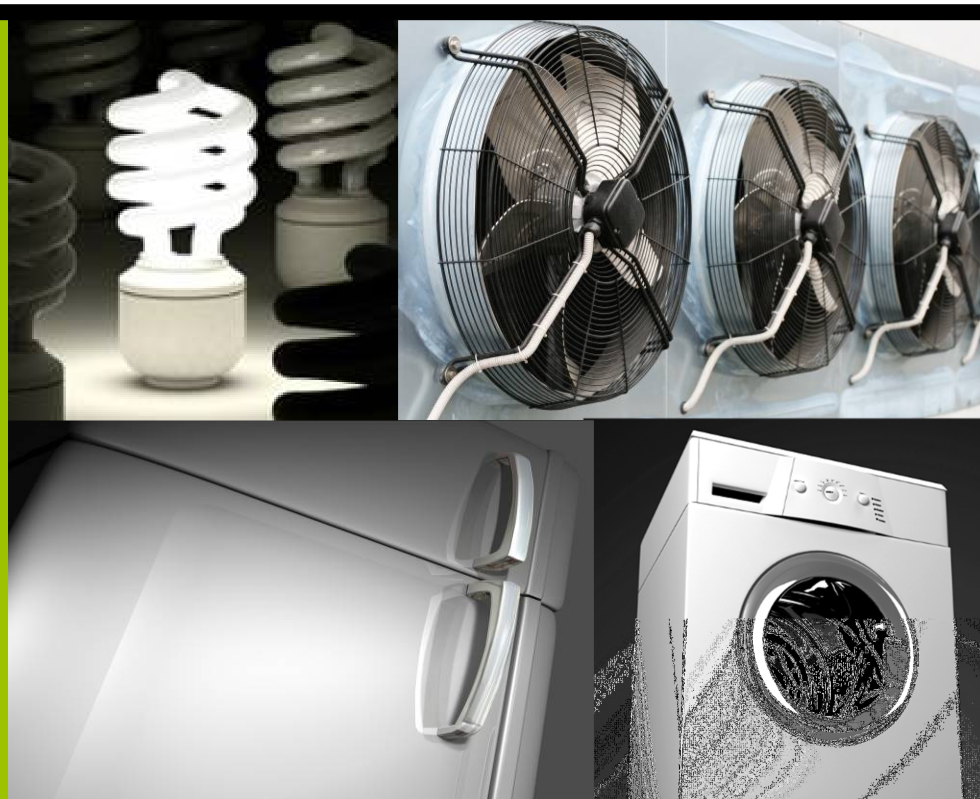

COOLING BENCHMARKING STUDY

Part 3: Testing Component Report

June 2011

BY

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CEIS

in Partnership with

The Collaborative Labeling and Appliance Standards Program (CLASP)

ACKNOWLEDGEMENTS

The project team wants to express its gratitude for the support received from CLASP during the execution of this mandate. In particular, we express our thanks to Ms. Ana Maria Carreño, project manager, for her insight and support during the execution of the mandate. We also want to express our thanks to Mrs. Christine Egan, Executive Director of CLASP, and Mr. Frank Klinckenberg, Technical Advisor of CLASP, for their technical review and direction during all steps of the project.

ABBREVIATIONS AND ACRONYMS

AC	**Air Conditioning**
CLASP	**Collaborative Labeling and Appliance Standards Program**
EE	**Energy Efficiency**
EER	**Energy Efficiency Ratio**
EU	**European Union**
ISO	**International Organization for Standardization**
MEPS	**Minimum Energy Performance Standards**
RAC	**Room Air Conditioner**
S&L	**Standards and Labeling**
SEER	**Seasonal Energy Efficiency Ratio**
SHR	**Sensible Heat Ratio**
US	**United States**

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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 third of three reports prepared as part of this global study on air conditioner energy efficiency. It presents the conclusions from a comparison of the testing of ACs under test procedures of various countries, and the actual testing of a limited sample of products under different test procedures. 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 2: Benchmarking component. This report presents an analysis to develop a series of conversion functions for metrics used in different economies around the world as well as a comparison of the relative stringencies of different MEPS and labeling schemes.

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; and
- 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 ACs); and
- Central AC units (rooftop units).

Purpose of the Testing Component

The testing component was designed to achieve two main goals:

Establish the differences between the test procedures used in major economies for measuring the capacity and the efficiency of ACs in cooling mode. This study also estimates the uncertainties of measurement that can be expected for each test method as functions of the test conditions and type of AC considered. This comparison has not been performed for Australia and Taiwan due to limited information on those economies. International Organization for Standardization (ISO) standards have been covered, as many economies use them as a starting point for the development of their own test procedures.

Test a limited set of samples in order to check, to the extent possible, the conversion factors developed by the benchmarking component to compare the rating of a given AC among several economies. Four samples have been selected in order to cover the largest portion of appliances included in the scope of this study.

Energy Performance Testing Procedures

Test procedures generally specify how to measure the energy efficiency ratio (EER) and capacity using stipulated test conditions. Seasonal performance test conditions and calculations are often described in a separate test procedure. However, this is not always the case and some economies, such as the US and China, elect to include EER test procedures and seasonal efficiency calculations in a single document.

Energy efficiency classes for labeling and MEPS requirements are generally described in other documents, such as specific standards or regulations, which make reference to the test procedure standards. This report deals with the EER test procedures only and does not cover seasonal EE calculations, which are dealt with in other components of the project.

It was not possible to retrieve the test procedures for all economies covered by the study. Consequently, the testing study covers only those economies for which it has been possible to access complete and up-to-date documents. However, the economies studied are representative of the worldwide situation regarding test procedures as they include major economies: the US, the EU, Japan, China, Korea, and India.

In addition, the ISO 5151 and ISO 13253 standards have been covered, as many economies base their own test procedures on these two international standards.

We have only studied the calorimeter room method and the indoor air enthalpy method. These are the most widely used procedures for small- and medium-size ACs. Other methods, like the compressor calibration method, the outdoor air enthalpy method, or the refrigerant enthalpy method, are not normally used for the type of ACs included in this study except as secondary test methods.

Part 1 compares the test procedures used in six major economies and mainly deals with the differences in the installation of the samples, temperature conditions, tolerances of measuring devices, test procedure sequences, and cooling capacity and EER calculations.

The effects on the uncertainties of measurement of the EER and cooling capacity test method are also covered in Part 1.

Equipment Testing

Part 2 describes the sample selection criteria, in-laboratory testing using different test procedures, and analysis of the results. Four samples of ACs were selected and tested under the US, EU, and Japanese methods. The samples and test methods used were the most representative of the ones covered by this study, thus allowing a good comparison without an excessive number of tests.

The results of these measurements are also used as an input for the benchmarking component, where further analysis and conclusions on the testing results are presented.

1 Test procedure description and comparison

This section first presents the testing standards used in each selected economy and then discusses the differences found among them. It also covers differences that can be introduced when testing the same AC in different laboratories (mainly due to installation settings not fully described by the standards) and finally analyzes the measurement tolerances and uncertainties with respect to the EER declared by the testing laboratory.

1.1 Energy Efficiency Test Procedures Reviewed

The latest version of the following testing procedures were obtained and analyzed as part of this study. They cover major economies that are currently among the most active in terms of MEPS and labeling initiatives to support a market change toward more efficient AC products.

There are two main measurement methods:

Calorimeter room method: An energy balance is maintained in the indoor side room, the sum of the energies given to the room being equal to the total cooling capacity of the AC when the air dry and wet bulb temperatures have remained constant during a sufficient time. The calorimeter can be either of the calibrated type (single wall separating the rooms from the outside) or of the balanced ambient type (two walls separating the rooms from the outside, with air between them maintained at the same dry bulb temperature as inside the room). The balanced ambient type is much more accurate than the calibrated type as heat losses through the walls are almost zero.

Indoor air enthalpy method: The air enthalpy is measured at the inlet and outlet of the indoor section of the AC, as well as the mass air flow through the indoor section. The air flow multiplied by the enthalpy variation gives the total cooling capacity.

ISO Test Procedures

The two ISO standards that have been used by many economies as a common basic document to elaborate their own standard are ISO 5151:1994 “*Non-ducted air conditioners and heat pumps – Testing and rating for performance*” and ISO 13253:1995 “*Ducted air conditioners and air-to-air heat pumps – Testing and rating for performance*.”

ISO 5151 describes both the calorimeter room method and the indoor air enthalpy method.

ISO 13253 describes only the indoor air enthalpy method.

Both standards are intended for the measurement of the EER only.

A revision of ISO 5151 has been published in 2010 and a revision of ISO 13253 will be published in 2011. Both revisions bring the ISO standards closer to the European EN 14511.

US Test Procedures

The mandatory US test procedure is contained in the Code of Federal Regulations 430 Appendix M. The test method for measuring the energy consumption of central ACs is AHRI 210/240 (2008), which modifies several clauses of the 2006 version of the same standard. This document also defines the test conditions. The cooling capacities, power input, and EERs are measured and computed according to the method described in ASHRAE-37:2005 "*Methods of testing for rating electrically driven unitary air-conditioning and heat pump equipment.*"

The only primary test method permitted is the indoor air enthalpy method.

EU Test Procedures

Test conditions and degradation coefficient (Cd) measurement test procedures are given in prEN 14825 "Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance" which should be published before the end of 2011.

In this document, the degradation coefficient is used to take into account the efficiency loss due to cycling of air to air units.

This standard also specifies the test conditions required to measure the different EER values at part load conditions which are used for the calculation of the Seasonal Energy Efficiency Ratio (SEER).

Test methods to measure the EER are described in EN 14511-3:2007 "Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling – Part 3: Test methods." A revision of this standard is currently under formal vote (deadline July 2011) and should be published before the end of 2011. It describes the calorimeter room method and the indoor air enthalpy method. The calorimeter room method is mandatory to check the requirements of the current Energy Labeling Directive EEC 2002/31, but in principle no test method will be mandatory for the application of the Ecodesign directive that will withdraw EEC 2002/31 and give the requirements for the EU SEER.

In the current study, we used the 2011 draft version of the standard instead of the current version in force to better reflect what will be the future EU requirements.

Japan Test Procedures

Test conditions are given in JRA-4046 (RACs) and JRA-4048 (packaged ACs). These documents also describe the calculation of seasonal energy efficiency.

Test methods are described in JIS B 8615-1:2009 "Non-ducted air-conditioners and air-to-air heat pumps – Testing and rating for performance" and JIS B 8615-2:2009 "Ducted air conditioners and heat pumps – Testing and rating for performance." These standards are based on ISO 5151:1994 and ISO 13253:1995. There are very few differences from the ISO standards, the most important one being a length of refrigerant piping of 5 m instead of 7.5 m for non-ducted units with a cooling capacity lower than 6 kW. Test methods are limited to the indoor air enthalpy method for ducted ACs and to either the calorimeter room method or the indoor air enthalpy method for non-ducted ACs.

China Test Procedures

Test procedures are described in GB/T 7725-2004 "*Room air conditioners*" and GB/T 17758-1999 "*Unitary air conditioners.*" The first one, based on ISO 5151:1994, allows both the calorimeter room method and the indoor air enthalpy method for ACs up to 7 kW but gives preference to the calorimeter room results in case of disagreement between results. The second test procedure only allows the indoor air enthalpy method. Both documents describe the test conditions and calculations for the determination of the seasonal energy efficiency.

Korea Test Procedures

The testing standard is KSC9306-2010 "Air conditioners." It is partially based on ISO standards and describes both the test procedures and test conditions.

Either the calorimeter room method or the indoor air enthalpy method can be used.

India Test Procedures

Test procedures and test conditions are specified in IS 1391-1:2005 "Room air conditioners – Specifications – Part 1 Unitary air conditioners" and IS 1391-2:2004 "Room air conditioners – Specifications – Part 2 Split air conditioners." Both parts are partially based on ISO 5151.

Either the calorimeter room method or the indoor air enthalpy method can be used.

1.2 Comparison between Test Procedures

As mentioned above, one of the main differences between test standards is the usage of the calorimeter room method versus the indoor air enthalpy method. The advantages and disadvantages of each method are given in Table 1.

Table 1: Differences between the Two Main Measurement Methods

Measurement Method	Advantages	Disadvantages
Calorimeter Room	- High accuracy (maximum uncertainty of 5% for the EER) - Low risk of systematic error - Easier to simulate a given part load ratio	- Very expensive facilities - Longer testing time - Higher cost of maintenance (high number of measuring devices) → Higher cost of the tests
Indoor Air Enthalpy	- Less expensive laboratory - Shorter testing time → Lower cost of the tests	- Lower accuracy (maximum uncertainty of 10% for the EER) - Higher risk of error (measurements of the air flow and of the air humidity at the outlet are difficult)

Maximum uncertainties given in Table 1 for each measurement method have been determined during the last revisions of the EN 14511, ISO 5151, and ISO 13253 standards, and are now commonly accepted.

In practice, experience shows that when the calorimeter method is not a mandatory requirement, the air enthalpy method is more often selected for initial cost reduction and productivity improvement, as this method lowers the cost of the testing facilities and shortens the time spent on tests.

The possible effect of the calorimeter test method compared to the indoor air enthalpy method on the resulting EER is discussed in Section 1.4 of this report.

The test procedures cover the following items:

- Installation of the RAC;
- Test conditions;
- Test sequence (stabilization period, data acquisition period, variations allowed for the test conditions); and
- Formulas to calculate the total cooling capacity and the EER.

After reviewing the different test procedures for the cooling mode, the immediate conclusion is that the calculations described in the different standards to calculate the total cooling capacity (energy balance for the calorimeter room method and air flow measurement and air enthalpy calculations for the indoor air enthalpy method) are identical or equivalent.

The test sequence is almost the same for each method, including stabilization time and data acquisition period duration. The data acquisition period has a fixed value of 35 minutes in all test procedures, except in EN 14511 in which 35 minutes is the minimum duration. The possibility to continue the measurement during more than 35 minutes is convenient for the measurement of low cooling capacities.

Some differences in the installation of the AC, the test procedure, or the test conditions may lead to differences in the results of the cooling capacity or the EER measured for the same AC sample.

The main differences found between the test procedures are summarized in Table 2, Table 3, and Table 4.

Table 2: Main Differences between Test Procedures: Test Conditions, Installation, Calculations

Economy	Standards Rating Conditions Outdoor Dry Bulb (wet bulb)[1]/indoor Dry Bulb (wet bulb) (°C)	Refrigerant Piping Length (m)	Fan Motor Correction (Ducted Units)
US	35/26.7 (19.4)	7.6	NO
EU 2011	35/27 (19)	5	YES
Japan	35/27 (19)	5 up to 6 kW 7.5 over 6 kW	YES
China	35/27 (19)	7.5	YES
Korea	35/27 (19)	5	NO
India	35 (30)/27 (19)	5	NO
ISO 1994/1995	35/27 (19)	7.5	YES[2]
ISO 2010/2011	35/27 (19)	5 to 7.5	NO[3]

[1]If not given, the outdoor humidity has not been controlled.
[2]The cooling capacity is modified only if the correction is greater than the specified uncertainty of measurement.
[3]No correction is done for a unit with integrated fan. For units without integrated fan, an estimated fan power for equipment without an outdoor fan, pfan, is used.

Table 3: Main Differences between Test Procedures: Uncertainties of Individual Measurements

Economy	Dry Bulb Temperature	Wet Bulb Temperature	Air Volume Flow	Static Pressure Difference	Electrical Inputs
US	± 0.1°C	± 0.1°C	±5%	± 2.5 Pa	± 1.0%
EU 2011	± 0.2°C	± 0.4°C	±5%	± 5 Pa / ± 5%	± 1.0%
Japan	± 0.2°C	± 0.2°C	± 5%	± 5 Pa / ± 5%	± 0.5%
China	± 0.2°C	± 0.2°C	+ 5%	± 5 Pa / ± 5%	± 0.5%
Korea	± 0.1°C	± 0.1°C	N/A	± 2 Pa	± 0.5%

Economy	Dry Bulb Temperature	Wet Bulb Temperature	Air Volume Flow	Static Pressure Difference	Electrical Inputs
India	± 0.1^{0}C	± 0.1^{0}C	N/A	± 1 Pa	± 0.5%
ISO 1994/1995	± 0.2^{0}C	± 0.2^{0}C	± 5%	± 5 Pa / ± 5%	± 0.5%
ISO 2010/2011	± 0.2^{0}C	± 0.2^{0}C	± 5%	± 5 Pa / ± 5%	± 0.5%

Table 4: Main Differences between Test Procedures: Variation Allowed for Test Readings from Specified Test Conditions (variations of arithmetical mean values/maximum variation of individual readings)

Economy	Indoor Dry Bulb Temperature	Indoor Wet Bulb Temperature	Outdoor Dry Bulb Temperature	Outdoor Wet Bulb Temperature	Air Volume Flow	Static Pressure Difference	Voltage
US	± 0.3^{0}C / ± 1.0^{0}C	± 0.2^{0}C / ± 0.5^{0}C	± 0.3^{0}C / ± 1.0^{0}C	± 0.2^{0}C / ± 0.5^{0}C	N/A	N/A	± 2%
EU 2011	± 0.3^{0}C / ± 1.0^{0}C	± 0.3^{0}C / ± 1.0^{0}C	± 0.3^{0}C / ± 1.0^{0}C	± 0.3^{0}C / ± 1.0^{0}C	± 5% / ± 10%	- / ±10 Pa	± 4% / ± 4%
Japan	± 0.3^{0}C / ± 1.0^{0}C	± 0.2^{0}C / ± 0.5^{0}C	± 0.3^{0}C / ± 1.0^{0}C	± 0.2^{0}C / ± 0.5^{0}C	± 5% / ± 10%	± 5 Pa / ±10 Pa	± 1% / ± 2%
China	± 0.3^{0}C / ± 0.5^{0}C	± 0.2^{0}C / ± 0.3^{0}C	± 0.3^{0}C / ± 0.5^{0}C	± 0.2^{0}C / ± 0.3^{0}C	± 5% / ± 10%	± 5 Pa / ±10 Pa	± 1% / ± 2%
Korea	± 0.3^{0}C / ± 0.5^{0}C	± 0.2^{0}C / ± 0.3^{0}C	± 0.3^{0}C / ± 0.5^{0}C	± 0.2^{0}C / ± 0.3^{0}C	N/A	± 10 Pa / or ±10 Pa	± 2%
India	± 0.3^{0}C / ± 0.5^{0}C	± 0.2^{0}C / ± 0.3^{0}C	± 0.3^{0}C / ± 0.5^{0}C	± 0.2^{0}C / ± 0.3^{0}C	N/A	N/A	± 2%
ISO 1994/1995	± 0.3^{0}C / ± 1.0^{0}C	± 0.2^{0}C / ± 0.5^{0}C	± 0.3^{0}C / ± 1.0^{0}C	± 0.2^{0}C / ± 0.5^{0}C	± 5% / ± 10%	± 5 Pa / ±10 Pa	± 1% / ± 2%
ISO 2010/2011	± 0.3^{0}C / ± 0.5^{0}C	± 0.2^{0}C / ± 0.3^{0}C	± 0.3^{0}C / ± 0.5^{0}C	± 0.2^{0}C / ± 0.3^{0}C	± 5% / ± 10%	± 5 Pa / ± 5 Pa	± 1% / ± 2%

Differences in Temperature Conditions

Small variations in the outdoor and indoor air temperature conditions give differences in the results. The effects of these variations can be quantified and are described in the benchmarking component report.

A lesser known effect is caused by the control (or absence of control) of the air humidity on the outdoor side during the tests. For most test procedures, the control of outdoor wet bulb temperature conditions is not required when testing units that do not evaporate cooling water on the condenser side, which is generally the case for small size ACs. Only India requires this control by specifying very high outdoor air humidity (see Table 2).

No data was available to evaluate the effect of this humidity on the EER result and this was not tested as part of the current project.

Refrigerant Piping Length

Depending upon the economy and sometimes the type of AC, the length of the refrigerant piping may be between 5 m and 7.5 m.

There is not enough available data to give an evaluation of the effect of this difference of length, coming from the extra pressure drop in the piping and sometimes also from the additional refrigerant charge required by the manufacturer. Some manufacturers provide estimations to this effect, proposing that the EER could be 1% to 3% less when using 7.5-m instead of 5-m piping.

Fan Motor Correction for Ducted Units

In some economies (see

Table 2 under Fan Motor Correction), a correction is performed to enable a comparison between ducted units with and without integral fan. The correction is done on the effective power input, with a fraction of the input of the fan motor excluded from (integral fan) or included in (units without fan) the total power absorbed by the unit.

This fraction is expressed in watts as: $\frac{q \times \Delta p_e}{\eta}$

where

η is 0.3 by convention;

Δp_e is the measured available external static pressure difference, expressed in pascal; and

q is the nominal air flow rate, expressed in cubic meters per second.

For a ducted indoor unit, the same power is also included in (integral fan) or excluded from (indoor unit without fan) the total cooling capacity in most of the economies.

The correction can vary from a few watts for small ACs to several hundred watts for large ACs. It is likely that this could result in EER differences ranging from 1% to 5% at full load ratio when calculated with versus without this correction.

The difference can be much larger for low part load ratios, for instance in the case of the EU 21% part load ratio where the fan correction for a ducted unit can lead to a difference of more than 10% between EER results calculated with versus without the correction.

For the effective power input and the EER, the correction is much larger when the outdoor unit is also ducted. For ducted units, this correction factor is by far the greatest systematic source of differences for the EER measurement between economies. This suggests that harmonizing the test procedure between economies for the fan correction will be beneficial to make the comparison between efficiency metrics meaningful.

Uncertainty of Individual Measurements

Table 3, above, presents a comparison of the requirements for the main measurement devices.

Although there are some differences between economies, and given that some requirements, like a maximum uncertainty of ± 0.1ºC for the measurement of the wet bulb temperature, are unlikely to be fulfilled, the differences in measurement uncertainties for individual readings are not very important and do not appear to be a major source of differences between economies.

Allowed Variations from Test Conditions

Table 4, above, presents a comparison of the requirements for the variation in the individual and average values of the readings for different parameters measured.

For temperature conditions, some differences appear, but they are relatively small and modern laboratories are able to meet the most stringent requirements in almost all cases. Therefore, it is probably not a source of large differences in the resulting EER.

One notable difference is the larger tolerance for voltage in the case of the EU. There is no data available to estimate the possible effect of a variation of ± 4% in voltage. Regardless, it would not be a systematic source of difference with other test procedures.

1.3 Other Possible Sources of Difference

Some details of the installation of AC samples in the testing set-up are not covered or are not described in sufficient detail by the test procedures. These can be a source of differences among laboratories, and sometimes among economies.

This may apply to non-ducted ACs when tested using the calorimeter room method or the air enthalpy method.

Using the calorimeter method, it is easy to set the maximum air flow rate for the indoor unit. This is not so easy for the air enthalpy method, where a discharge plenum has to be installed at the air outlet of the unit, between the unit and the air flow measuring apparatus. A static pressure of zero pascal has to be maintained in this plenum.

There is a high risk to modifying the normal air flow of the unit, first due to the presence of the plenum itself, and second by setting a static pressure slightly different from zero pascal due to the uncertainty of the measurement and control loop to maintain this value (normally ± 5 Pa). In addition, the presence of the plenum can make the adjustment of the louvers difficult at the air outlet of the unit.

This possible modification of the indoor air flow rate is greater for indoor units with several air outlets (cassettes, some wall or console types) due to the complex shape of the discharge plenum.

The changes in the normal air flow of the unit caused by the plenum can alter the performance of the unit in ways that are difficult to predict, thereby introducing additional measurement uncertainties when testing with the air enthalpy method.

The effect of this possible difference on the EER is not systematic and cannot be quantified. However, it is important to keep this effect in mind when analyzing test results of equipment with a complex air flow.

1.4 Uncertainty of measurement of the EER

Each test method has a prescribed maximum measurement uncertainty. This maximum uncertainty applies to the total cooling capacity measurement and has a value of 5% for the calorimeter room method and a value of 10% for the indoor air enthalpy method.

These values can also be applied almost directly for the determination of uncertainty of the EER measurement, as the measurement of the electrical input is normally achieved with a very small uncertainty. Results of round robin tests concerning both methods confirm these maximum uncertainties of measurement.

Most of the economies studied require testing at part load conditions; for small AC products, the cooling capacities can be very low, with the most difficult case probably being the 21% part load ratio prescribed in the EU’s prEN 14825. It is generally recognized that, for the measurement of a product with a nominal cooling capacity of less than 2 kW, the measurement uncertainty increases very quickly as the part load cooling capacity decreases. Furthermore, it is almost impossible to realize measurement of products with capacity of less than 1.5 kW with a reasonable uncertainty. This applies to all test methods.

For the calorimeter room method, uncertainty of EER measurement comes from the relatively high uncertainty of some measurements, such as the heat exchanges through the walls, and from the relation between the cooling capacity to be measured and the volume of the room where the indoor section of the RAC is installed – a small variation of the air temperature in the room becomes significant at very low cooling capacity part load conditions.

For the indoor air enthalpy method, the small temperature difference of the air between the outlet and the inlet of the indoor section of the RAC quickly increases the uncertainty of the capacity measurement at low part load ratio.

Uncertainty of EER measurement is not a systematic source of potential differences in the measurement of the EER in different economies, so it is not possible to derive a correction factor to take it into account. However, it is important to realize that these effects exist and to keep them in mind when analyzing test results.

2 Equipment testing

This section presents the results of laboratory testing of RAC samples under the different test standards of selected economies.

2.1 Choice of samples

One of the main objectives of the benchmarking component of the project is to define conversion formulas allowing the comparison of the EER and SEER measured in different economies. This task was undertaken using literature review and engineering methods to determine the appropriate conversion factors and equations.

The samples and the tests performed as part of the testing component of the study, which are presented herewith, have been selected in order to provide real data to check the coherence of the conversion factors proposed.

The cooling study mainly focuses on small domestic AC products. In accordance with the benchmarking objectives, two kinds of RACs have been selected, together representing the majority of models sold worldwide:

- Wall-mounted non-ducted split ACs from 2.0 kW to 4.0 kW; and
- Split or package ducted ACs from 8.0 kW to 12.0 kW.

For each type, the appliances can have a fixed-speed compressor or an inverter controlled one.

Fixed-capacity ACs are still widely sold in many of the economies in this study. On the other hand, ACs with inverter driven compressors regularly gain market share in economies like Japan and the EU.

Inverter driven RACs can continuously vary the compressor's frequency, and thus regulate the cooling capacity to precisely cover the room load. The unit adapts itself continuously to the part load of the room and has no energy losses due to on/off cycling, except for at very low part load ratios. The inverter RAC efficiency is deemed to improve at part load.

The improvement of efficiency at part load in the case of inverter controlled units is the result of two opposing phenomena:

With a reduced refrigerant flow rate at part load, the heat exchangers of the appliance become oversized. The temperature difference across them decreases, causing the pressure ratio to decrease and the efficiency of the compressor to increase. The poorer the full load efficiency of the heat exchangers, the larger the resulting improvement at part load.

With reduced speed (refrigerant flow rate) and compression ratio, the compressor isentropic efficiency will slightly decrease as well as the efficiency of the inverter itself. These two effects tend to reduce AC efficiency.

With very efficient small ACs, the part load improvement is deemed to be small or even null because heat exchangers are already oversized at full load.

With very inefficient products or with larger products, the heat exchangers may not be oversized at full load because size and cost are more important factors to design a low-cost unit. For these products, it is likely that the part load gain will be larger.

The capacities of the samples tested in this study were chosen in order to characterize typical products within the capacity range of the products under the scope of this study, while also taking into consideration practical limitations of part load testing.

The following samples were chosen:

Sample 1: split wall-mounted AC of 3.5 kW, with fixed compressor speed.

Sample 2: split wall-mounted ACs of 3.5 kW, with inverter-driven compressor. Two units of the same model were selected in order to have higher certainty of measurement of the EER at 21% part load ratio for the EU testing. This is needed because it is very difficult to measure a cooling capacity lower than 1.5 kW with an acceptable uncertainty of measurement. Both samples have also been tested at full load conditions in order to check that their capacities were similar.

Sample 3: split ducted AC of 10.5 kW, with fixed compressor speed.

Sample 4: split ducted AC of 10.5 kW, with inverter-driven compressor.

Table 5: Samples Selected for Testing

Sample	Type	Claimed Performances		
		Cooling Capacity (kW)	Power Input (kW)	EER (W/W)
1	Fixed-Capacity, Non-Ducted	3.52	1.12	3.14
2	Inverter, Non-Ducted	3.50	1.06	3.30
3	Fixed-Capacity, Ducted	10.5	3.48	3.02
4	Inverter, Ducted	10.5	3.73	2.82

For the two fixed-capacity samples, the units were obtained directly from the market as neither special customizing nor the knowledge of special set-up procedures was required for the tests.

For the inverter-driven models, we needed to find one or more manufacturers willing to participate in the study in order to acquire more knowledge about the efficiency of these units. This would have enabled us to select the most appropriate operating point when this was allowed under the test procedures. For sample 2, a manufacturer delivered two samples of the same model, together with the full information needed to fix the compressor frequency and the speed of the fans for each one of the test conditions.

For sample 4, in the absence of manufacturer collaboration, the sample was obtained directly from the market without any information about how to fix the compressor’s frequency or the fan speeds for the different test conditions required for testing. Consequently, tests according to the US procedure could not be performed because they require a lot of information from the manufacturer, which was not present in documents delivered with the unit.

2.2 Test conditions

Three different economies have been selected due to their market relevance and the influence of their testing procedures in the global market: the US, Japan, and the EU.

Because these economies use different power supply conditions (voltage and frequency), it is unlikely that manufacturers are producing units able to operate in all three regions. Moreover, it is reasonable to assume that the specific characteristics of the power supply will not have an impact on appliance efficiency itself but only on the specific design of the power electronics.

In order to get comparable results, all tests have been performed with a voltage of 230 V and a frequency of 50 Hz.

To minimize the number of tests, only the mandatory tests were performed in most cases and default values for the optional tests were used for the calculations. In some instances, as in the case of the Japan standard applied to fixed-capacity ducted and non-ducted units, optional tests were performed to assess how they compared to default calculations.

This refers particularly to the Cd used by all these procedures to assess the effect (energy losses) of the on/off switching of a fixed-capacity AC when cycling at part load conditions or of an inverter driven AC when running below its minimum compressor’s frequency.

The power input for the thermostat off, standby, or crankcase heater modes were also measured, as they are included in the calculation of the EU SEER as described below in Table 6.

Table 6: Modes Defined in the EU's prEN 14825

MODE	Description
Active Mode	The mode corresponding to the hours with a cooling or heating load of the building and whereby the cooling or heating function of the unit is switched on.
Thermostat Off Mode	The mode corresponding to the hours with no cooling or heating load of the building, whereby the cooling or heating function of the unit is switched on, but is not operational, as there is no cooling or heating load.
Standby Mode	The unit is switched off partially and can be reactivated by a control device or timer.
Off Mode	The unit is completely switched off and cannot be reactivated by control device or by timer.
Crankcase Heater Mode	The mode corresponding to the hours where a crankcase heater is activated.

2.3 Test results

Sample 1 – Fixed-Capacity, Non-Ducted

This section presents the results of the test of the fixed-capacity non-ducted unit under US, EU, and Japanese test procedures.

Table 7: Sample 1 - Test Results under US Conditions

Outdoor Temperature (°C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	Sensible Heat Ratio (SHR)	Power Input (W)	EER
35	26.7(19.4)	7.6	3,472	1,080	0.69	1,216	2.86
27.8	26.7(19.4)	7.6	3,783	1,271	0.66	1,088	3.48

For this sample, 0.08 kg of refrigerant were added to the factory charge due to the refrigerant piping length being greater than 5 m. The tests under EU and Japanese conditions were performed with the factory refrigerant charge.

Table 8: Sample 1 - Test Results under Japanese Conditions

Outdoor Temperature (°C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER
35	27(19)	5	3,350	923	0.72	1,214	2.76
29	27(19)	5	3,783	1,059	0.72	1,091	3.44

For fixed-capacity ACs, the test with the outdoor temperature of 29ºC is not mandatory. It was performed to check the default calculations given in JRA-4046.

Table 9: Sample 1 - Comparison of Test Results versus Calculations using Default Values of Φ_{CR}(29ºC) and P_c(29ºC)

	Measured	Default
Φ_{CR}(29ºC) / Φ_{CR}(35ºC)	1.122	1.077
P_c(29ºC) / P_c(35ºC)	0.899	0.914
EER (29ºC)	3.44	3.25

The EER measured is 6% higher than the default calculations.

Table 10: Sample 1 - Test Results under EU Conditions

Outdoor Temperature (^{0}C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER
35	27(19)	5	3,350	923	0.72	1,214	2.76
30	27(19)	5	3,655	1,052	0.71	1,121	3.26
25	27(19)	5	3,893	1,141	0.71	1,020	3.82
20	27(19)	5	4,196	1,285	0.69	943	4.45

Sample 2 – Inverter, Non-Ducted

For this sample, the manufacturer provided full information to set the unit at the correct conditions of compressor frequency and fan speed in order to achieve the requirements of the test procedures.

For cooling capacities under 2.0 kW, two samples of the same model were measured at the same time under the same test conditions, with the overall result divided by two.

At the beginning of the testing process, both samples were measured separately under the same test conditions (35ºC outdoor, 27ºC indoor dry bulb, 19ºC indoor wet bulb, full load) and the two sets of results were compared.

Table 11: Sample 2 - Initial Verification of the Two ACs of the Same Model

	Outdoor Temperature (^{0}C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER	Part Load
First Unit	35	27(19)	5	3,470	827	0.76	1,065	3.26	1.00
Second Unit	35	27(19)	5	3,484	813	0.77	1,088	3.20	1.00
Average	25	27(19)	5	3,477	820	0.76	1,077	3.23	1.00

The differences are much lower than the measurement uncertainties. The results for both samples match sufficiently to ensure that the measurements with both samples running at the same time will be representative of this AC model.

Table 12: Sample 2 - Test Results under US Conditions

Outdoor Temperature (^{0}C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER	Compressor Speed	Indoor Fan Speed
35	26.7(19.4)	7.6	3,480	895	0.74	1,048	3.32	Maximum	Standard Cooling
27.8	26.7(19.4)	7.6	3,741	1,080	0.71	939	3.98	Maximum	Standard Cooling
30.6	26.7(19.4)	7.6	2,606	560	0.79	569	4.58	Intermediate	Intermediate Cooling
27.8	26.7(19.4)	7.6	1,206	0	1.00	216	5.58	Minimum	Minimum Cooling
19.4	26.7(19.4)	7.6	1,403	0	1.00	183	7.67	Minimum	Minimum Cooling

Table 13: Sample 2 - Test Results under Japanese Conditions

Outdoor Temperature (^{0}C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER	Part Load
35	27(19)	5	3,477	820	0.76	1,077	3.23	1.00
35	27(19)	5	1,745	0	1.00	378	4.62	0.50

Table 14: Sample 2 - Test Results under EU Conditions

Outdoor Temperature (⁰C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER	Part Load
35	27(19)	5	3,477	820	0.76	1,077	3.23	1.00
30	27(19)	5	2,594	270	0.90	558	3.65	0.75
25	27(19)	5	1,647	0	1.00	226	7.29	0.47
20	27(19)	5	742	0	1.00	85	8.73	0.21

Sample 3 – Fixed-Capacity, Ducted

This section presents the results of the testing of the fixed-capacity, ducted unit.

Table 15: Sample 3 - Test Results under US Conditions

Outdoor Temperature (⁰C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER
35	26.7(19.4)	7.6	10,272	2,391	0.77	3,763	2.73
27.8	26.7(19.4)	7.6	11,256	2,942	0.74	3,397	3.31

For this sample, 0.16 kg of refrigerant were added to the factory charge due to the refrigerant piping length being greater than 5 m for the US and Japanese conditions. The tests under EU conditions were performed with the factory refrigerant charge.

The fan motor correction discussed in Section 1.2 of this report does not apply to the US test.

Table 16: Sample 3 - Test Results under Japanese Conditions

Outdoor Temperature (⁰C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER
35	27(19)	7.5	10,159	1,759	0.83	3,763	2.70
29	27(19)	7.5	11,992	2,229	0.80	3,397	3.24

For fixed-capacity ACs, the test with the outdoor temperature of 29ºC is not mandatory. It was performed to check the default calculations given in JRA-4046.

Table 17: Sample 3 – Comparison of Test Results versus Calculations using Default Values of Φ_{CR}(29ºC) and P_c(29ºC)

	Measured	Default
Φ_{CR}(29ºC) / Φ_{CR}(35ºC)	1.082	1.077
P_c(29ºC) / P_c(35ºC)	0.933	0.914
EER (29ºC)	3.12	3.27

In this case, the EER measured is 4.4% lower than the default calculations.

For sample 3, the fan motor correction applies, with q equal to 0.5 m^3/s for standard air and Δp_e equal to 47 Pa (both measured at the beginning of the test with dry coil).

Table 18: Sample 3 - Final Results under Japanese Conditions with Duct Correction

Outdoor Temperature (°C)	Effective Capacity (W)	Effective Input (W)	Effective EER	Effective EER vs. Measured EER (%)
35	10,237	3,691	2.77	$\pm$ 2.9
29	11,070	3,440	3.22	$\pm$ 3.0

The final result for the effective EER including duct correction is roughly 3% higher than the measured EER.

In Table 18, Table 20, Table 22, and Table 24, effective capacity, input, and EER refer to the results including the fan motor correction, as defined in Section 1.2 of this report.

Table 19: Sample 3 - Test Results under EU Conditions

Outdoor Temperature (°C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER
35	27(19)	5	10,218	2,010	0.80	3,806	2.68
30	27(19)	5	11,003	2,335	0.79	3,519	3.13
25	27(19)	5	11,583	2,583	0.78	3,272	3.54
20	27(19)	5	12,018	2,649	0.78	3,111	3.86

For sample 3, the fan motor correction applies, with q equal to 0.5 m^3/s for standard air and Δp_e equal to 47 Pa (both measured at the beginning of the test with dry coil).

Table 20: Sample 3 - Final Results under EU Conditions with Duct Correction

Outdoor Temperature (^oC)	Effective Capacity (W)	Effective Input (W)	Effective EER	Effective EER vs. Measured EER (%)
35	10,296	3,728	2.76	± 2.9
30	11,081	3,441	3.22	± 3.0
25	11,661	3,194	3.65	± 3.1
20	12,096	3,033	3.99	± 3.3

The final result for the effective EER including duct correction is roughly 3% higher than the measured EER.

Sample 4 – Inverter, Ducted

For this sample of ducted, inverter AC units, no information was available from the manufacturer to set up the unit in the correct conditions of compressor frequency and fan speed in order to achieve the requirements of the test procedures.

Fortunately, this unit was provided with an automatic detection of the test mode for the full load test and was fixing the compressor frequency to produce the rated cooling capacity.

For the part load test, we used a test procedure different from the standard due to lack of manufacturer information. The load was adjusted by the laboratory in the room where the indoor section of the sample was installed in order to obtain the rated part load ratio. The AC was running against this part load, adapting the compressor frequency to maintain the indoor temperature. Using this method, the measurement of the cooling capacity is done in the same way as in the case of the standard test but the test takes more time as it is the sample's control system which regulates the air temperature in the room.

It was not possible to perform the test for the US conditions, which require detailed information from the manufacturer on the correct setting for the test. The part load ratios and the compressor and fan speeds are not given in the procedure for the tests at part load conditions.

Table 21: Sample 4 - Test Results under Japanese Conditions

Outdoor Temperature (^0C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER	Part Load
35	27(19)	7.5	10,537	3,082	0.71	4,654	2.26	1.00
35	27(19)	7.5	5,340	540	0.90	1,501	3.56	0.50

For this sample 4, the fan motor correction applies, with q equal to 0.4 m^3/s for standard air and Δp_e equal to 37 Pa (both measured at the beginning of the test with dry coil).

Table 22: Sample 4 - Final Results under Japanese Conditions with Duct Correction

Part Load	Outdoor Temperature (°C)	Effective Capacity (W)	Effective Input (W)	Effective EER	Effective EER vs. Measured EER (%)
1.00	**35**	10,586	4,605	2.30	± 1.5
0.50	**35**	5,389	1,452	3.71	± 4.3

The difference between the effective and measured EER increases when the part load ratio decreases.

Table 23: Sample 4 - Test Results under EU conditions

Outdoor Temperature (°C)	Indoor Temperature (ºC) Dry (wet) Bulb	Piping Length (m)	Cooling Capacity (W)	Latent Capacity (W)	SHR	Power Input (W)	EER	Part Load
35	27(19)	5	10,750	3,485	0.68	4,740	2.27	1.00
30	27(19)	5	7,959	1,763	0.78	2,090	3.81	0.74
25	27(19)	5	5,063	287	0.94	947	5.35	0.47
20	27(19)	5	2,300	0	1.00	478	4.81	0.21

During the test at 21% part load ratio, the compressor was switching on and off to maintain the indoor side temperature, which is why the EER decreases in the other part load ratios.

For sample 4, the fan motor correction applies, with q equal to 0.4 m^3/s for standard air and Δp_e equal to 37 Pa (both measured at the beginning of the test with dry coil).

Table 24: Sample 4 - Final Results under EU Conditions with Duct Correction

Outdoor Temperature (°C)	Effective Capacity (W)	Effective Input (W)	Effective EER	Effective EER vs. Measured EER (%)
35	10,799	4,691	2.30	± 1.5
30	8,008	2,041	3.92	± 3.0
25	5,112	898	5.69	± 6.5
20	2,349	429	5.47	± 13.8

As can be observed in Table 24, the duct correction at low part load ratio can substantially affect the final result for the EER.

Other Power Inputs

For each sample, the power inputs in the different modes defined in the EU's prEN 14825 have been measured.

Table 25: All Samples – Power Inputs in Different Modes (W)

Mode	Sample 1	Sample 2	Sample 3	Sample 4
Thermostat Off	27.8	37.2	292.8	220.8
Standby	3.3	4.6	6.3	11.7
Crankcase	-	-	35.0	-
Off	-	-	-	-

There are some interesting observations about these results:

In thermostat off mode, the indoor unit fan was running permanently for all samples. This seems acceptable for ducted units as they have to maintain their air change and filtering function. It is less suitable for non-ducted units, where fans could be switched off when there is no load present. The control strategy for the indoor fan can be improved for non-ducted units.

In the case of sample 3, power inputs in thermostat off and standby modes were measured with the crankcase heater disconnected.

For sample 3, the only one providing this function, the crankcase heater was never switched off during the measurement (8 hours according to the standard, but we measured it for 15 hours). This means that the unit had no thermostat to switch the heater off when not needed, or that the control of the heater was not running properly.

2.4 Analysis of test results

These test results provide a set of real, measured data to check the conversion factors formulated by the benchmarking component of this study to propose EER and SEER conversions between test procedures. This use of the test results is described in the benchmarking component of this project.

The experience gained during these tests also provides useful information for comparing test procedures.

Variable-Capacity ACs

Variable-capacity ACs have a characteristic that differentiates them from fixed-capacity units. For fixed-capacity ACs, it is possible to perform all the prescribed tests with the manufacturer information available in the technical documentation. Therefore, the information published in the installation manual delivered with the AC is sufficient to adjust the unit for all testing. For variable-capacity ACs (inverters), however, the manufacturer has to provide additional information to the testing laboratory in order to set the unit in the correct mode, both for full load rating conditions and part load conditions.

This is clearly a barrier for third-party testing or market surveillance, when contact with the manufacturer may not be allowed or communication might be difficult. This is common to the three economies (US, EU, Japan) considered for the tests.

Nevertheless, we have shown that for the EU and Japan, these units can be tested if the testing laboratory has a test facility where it is possible to set the load the tested unit has to overcome, the speed of the fan is known, and the part load ratio is defined in the test procedure.

However, for the US test procedure, the part load ratio is unknown and the data required to test for intermediate and minimum cooling have to be provided by the manufacturer.

We recommend that the alternative approach of setting the part load capacity on the indoor side of the test sample be standardized to allow uniformity across laboratories. The only difference with the existing method would be to increase tolerance for the variation allowed for the test readings from specified test conditions (variations of arithmetical mean values and maximum variation of individual readings). This increase in tolerance is required because the control device of the sample under test has to maintain the indoor air dry bulb temperature rather than the laboratory equipment. From the experience gained during these tests, we can recommend that the maximum variation allowed for the arithmetical mean values of the indoor air dry and wet bulb temperatures be twice the value given in the existing standards. It is not necessary to change the requirements for the outdoor air temperature conditions. This revision would increase the uncertainty of the measurement of the EER by about 1%, which seems acceptable considering the advantage and flexibility offered by this part load testing method.

Corrections for Ducted Fans

As we found during the tests, the increase of the EER due to the correction for ducted fans in the EU and Japan is a few percent for fixed-capacity units. However, it can be much larger at part load conditions.

To have a better appreciation of the effect of this correction, we have calculated the difference for the EU SEER with and without this correction for two of the samples tested.

Table 26: Effect of the Fan Motor Correction on the EU SEER

Sample	SEER Without Fan Correction	SEER with Fan Correction	Difference (%)
3 - Fixed-Capacity	2.95	3.03	+ 2.7
4 - Variable-Capacity	4.04	4.29	+ 6.0

The increase of the SEER is quite significant, especially for inverter units, and does not reflect any real energy efficiency increase. The fan correction is only intended to make ratings comparable between ducted and non-ducted units.

Dehumidifying Capacity

For both inverter samples, it is interesting to note that the dehumidifying capacity decreases quickly with the load, being null for the lowest part load ratios.

In fact, several inverter models currently sold worldwide have no dehumidifying capacity at standard rating conditions (full load) or at part load conditions. The two inverter units tested for this project have some humidity removal capability at the higher end of their part load operation range. However, over the years CEIS has tested some units that have no humidity removal capability. The accumulated figures over the years of testing suggest that between 5% and 10% of inverter units on the market have no dehumidification capability. This is problematic if dehumidification is required for a given application.

This raises the question as to whether the humidity control capability of units should be included in future revisions of testing standards. This could be introduced as a minimum latent heat removal ratio at different part loading. However, the incorporation of such a requirement should be considered carefully taking into consideration technology limitations, the production cost for manufacturers, the willingness to pay from consumers, the comfort zone in houses, and specific market requirements. Some of the questions raised by humidity controls include:

- Is including humidity control requirements in inverter units technically feasible while maintaining the energy efficiency benefits brought about by this technology? For instance, if manufacturers respond to this requirement by cycling on and off their units at higher ranges of the loading, making them run more as an on-off unit, this will largely reduce the gain expected from inverter units.
- Does the lack of capability for humidity removal give a cost advantage to manufacturers or is this just a design decision without a large impact on unit cost?
- Is including a control loop for humidity in units, including humidity sensors and associated hardware and firmware, cost-effective considering market willingness to pay for this feature?
- What is the variation from the normal comfort zone provided by units with different latent heat removal ratios in different climates? For instance, the ASHRAE Fundamentals, which is the most used reference for indoor comfort in North America, provides a rather wide margin for acceptable ranges of operating conditions for internal space in summer. At a 24°C interior temperature, the higher range of acceptable humidity is close to 70% RH. Consequently, it would be interesting to understand the deviation from the range of acceptable indoor conditions caused by different designs of RACs.
- Market requirements can vary largely depending on the climate. In dry climates, the lack of humidity removal capability will not be a problem, while in humid climates, this can be an issue. How can a global standard procedure be developed that will not result in distorting real market requirements?

- Is it better to let the market decide whether humidity controls are desirable features in all units on the market or does this have to be pushed through a testing standard?

The current study was not intended to answer those types of questions fundamental to any decision on whether to incorporate humidity removal characteristics in energy efficiency metrics. We thus recommend that further research be conducted in this area to determine whether this should be considered for future revisions of testing standard procedures.

Parasitic Power Inputs for the EU SEER

In order to have a better appreciation of the effect of parasitic power (thermostat off, standby, crankcase heater input power) on the EU SEER, we have calculated the degradation of the SEER for each sample.

Table 27: Effect of the Parasitic Power Inputs on the EU SEER

Sample	SEER Without Correction	SEER with Correction	Difference (%)
1 - Fixed-Capacity, Non-Ducted	3.71	3.56	- 4.0
2 - Variable-Capacity, Non-Ducted	6.23	5.70	- 8.5
3 - Fixed-Capacity, Ducted	3.53	3.03	- 14.2
4 - Variable-Capacity, Ducted	4.69	4.29	- 8.5

It is clear that the SEER can be improved for most of the samples tested.

This improvement can be achieved in several ways:

Use fans with better efficiency.

Stop the fans when there is no load (non-ducted units). If the air temperature sensor is in the indoor unit, this may result in a loss of signal reading. A possibility to overcome this problem could be to start the fan from time to time to check the temperature condition.

Reduce the speed of the fan when there is no load (ducted units). This can be done if the ventilation and filtration needs can still be fulfilled at lower flow rate.

Reduce the power input in standby mode. This is or will soon be a requirement in many economies.

Control the crankcase heater so that it will function only when required.

Parasitic power over the cooling season is considered in the new EU testing procedures. It is recommended that similar adjustments be incorporated in all other testing procedures to send a clear signal to manufacturers that attention to the power consumption of those components is important.

CONCLUSIONS

The testing component of the project allowed the comparison of testing standards used in major economies. It also resulted in the creation of a measured dataset of EERs for a limited number of samples. Those results were then used as input by the benchmarking component of this project to validate conversion formulas allowing for the comparison of test metrics in different economies.

Several standards allow the choice of two different measurement methods. We recommend the use of the calorimeter room method whenever possible, as it reduces the uncertainty of measurement compared to the enthalpy method. This is particularly important when EE classes are defined.

Some differences were identified between the test procedures in use in different economies. Many of these lead to different measurement uncertainties but most of them do not induce systematic differences in EER results.

However, there are three differences that do lead to systematic differences:

- testing temperature conditions;
- the length of the refrigerant piping; and
- fan correction factors for ducted units.

Testing temperature condition variations were taken into consideration while developing the conversion formulas between energy efficiency metrics.

We recommend worldwide harmonization of requirements on the length of the refrigerant piping used for the tests.

We recommend revising the existing standards in order to remove the fan correction if the fan is an integral part of the AC, and to make a correction when the fan is not an integral part of the unit, to enable comparison between both types of AC designs.

For variable-capacity ACs (inverters), the manufacturer has to provide additional information to the testing laboratory in order to set the unit in the correct mode, both for full load rating conditions and part load conditions. This is clearly a barrier for third-party testing or market surveillance, when contact with the manufacturer may not be allowed or communication might be difficult. This is common to the three economies (US, EU, Japan) considered for the tests performed in this project.

Nevertheless, the study has demonstrated that for the EU and Japan, these units can be tested if the testing laboratory has a test facility where it is possible to set the load which the tested unit has to overcome, the speed of the fan is known, and the part load ratio is defined in the test procedure.

However, for the US test procedure, the part load ratio is unknown and the data required to test for intermediate and minimum cooling have to be provided by the manufacturer.

We recommend that the alternative approach of setting the part load capacity on the indoor side of the test sample be standardized to allow uniformity across testing standards and laboratories. The only difference with the existing methods would be to increase tolerance for the variation allowed for the test readings from specified test conditions (variations of arithmetical mean values and maximum variations of individual readings). This increase in tolerance is required by the fact that the control device of the sample under test has to maintain the indoor air dry bulb temperature rather than the laboratory equipment. From the experience gained during these tests, we can recommend that the maximum variation allowed for the arithmetical mean values of the indoor air dry and wet bulb temperatures be twice the value given in the existing standards. It is not necessary to change the requirements for outdoor air temperature conditions. This revision would increase the uncertainty of the measurement of the EER by about 1%, which seems acceptable considering the advantage and flexibility offered by this part load testing method.

Additionally, we recommend that manufacturers pay more attention to the improvement of power inputs in thermostat off and standby modes. In many cases, it is possible to achieve significant improvements without excessive cost. This would need to be incorporated in basic designs, and therefore would benefit EE worldwide, not only in regions where an improvement of this kind can improve the EE classification of ACs. Some strategies that could be considered include:

- Using fans with better efficiency.
- Stopping the fans when there is no load (non-ducted units). If the air temperature sensor is in the indoor unit, this may result in a loss of signal reading. A possibility to overcome this problem could be to start the fan from time to time to check the temperature condition.
- Reducing the speed of the fan when there is no load (ducted units). This can be done if ventilation and filtration needs can still be fulfilled at lower flow rates.
- Reducing the power input in standby mode. This is or will soon be a requirement in many economies.
- Controlling the crankcase heater so that it will function only when required.

These power inputs should be considered in all SEER calculations in order to include the whole electrical energy used during the cooling season. This has already been incorporated in the recent revision of draft EU SEER calculation procedures.

The study has confirmed that inverter units have poor latent heat removal characteristics at low load, and laboratory evidence shows that a small portion of units on the market have no latent heat removal characteristics, even at high loading. The study scope does not allow a clear conclusion on whether and how a humidity removal ratio should be incorporated as part of the requirements for energy efficiency metrics. We recommend that further research be conducted on this topic to determine technical implications, the manufacturing cost, the deviation from comfort conditions in different climates, and market requirements in dry or humid climates before deciding if this should be included in RAC testing procedures and in EER and SEER calculations.

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