COOLING BENCHMARKING STUDY

Study summary

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BY

Econoler

in Partnership with
The Collaborative Labeling and Appliance Standards Program (CLASP)

The Challenge of RAC Efficiency Evaluation Across Economies

Room air conditioners (RACs) represent a major share of energy use in most countries, and often contribute significantly to electrical grid peak loads. Furthermore, the number of RACs used in developing countries is rising rapidly due to an increase in living standards and a reduction in the price of these products globally. This, in turn, has resulted in a rapid increase in electricity demand and energy consumption caused by the RAC load in the commercial and residential sectors of many countries.

Even though RACs significantly impact energy demand and are traded worldwide, there is a lack of assembled information on market characteristics as well as on existing minimum energy performance standards (MEPS) and labeling schemes implemented in different economies. In addition, it is difficult to compare the performance criteria and policy measures for RACs across economies because of the differences in testing procedures and formulas used to derive seasonal efficiencies from individual laboratory tests.

A Tool for Policy Makers and S&L Program Developers

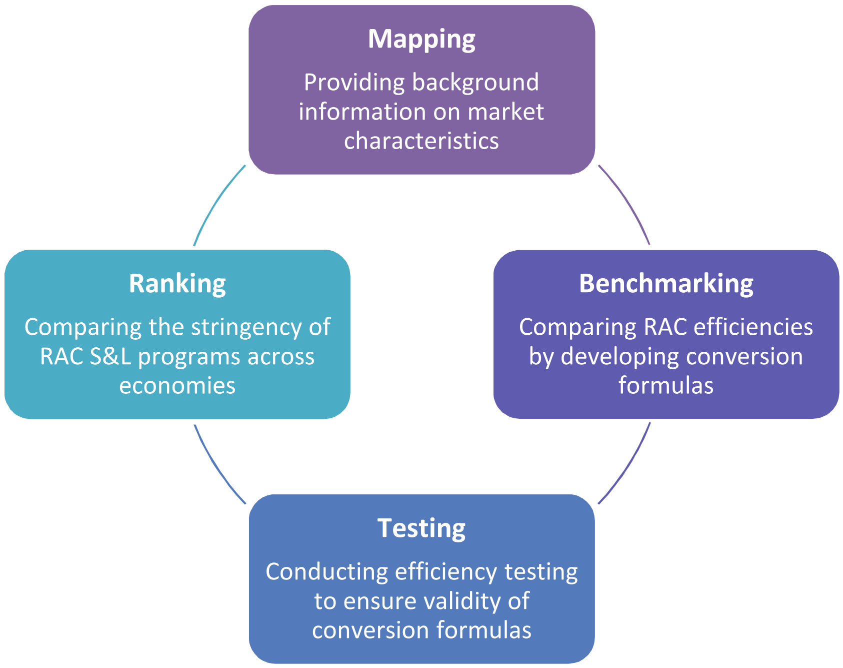
The cooling benchmarking study, funded by CLASP, provides policy makers and energy efficiency (EE) program managers with tools and important insights for developing or updating test procedures, labels, and MEPS for RACs. This study enables the comparison of RAC efficiency under various test procedures and EE metrics that are currently used in major world economies.

A review of the current and past RAC market in various economies provides background data to help policy makers analyze how their market compares with global trends. An in-depth review and comparison of the testing procedures used in major economies was also performed, leading to the derivation of conversion functions between metrics used in different economies. In addition, ranking criteria have been developed to allow comparison of the stringency and performance of residential and commercial RAC EE standards and labeling (S&L) programs implemented by countries around the world. The study focused on the comparison of EE performance and policy measures for RACs with a cooling capacity of up to 19 kW used in the residential and commercial sectors of the following eight economies: Australia, China, the European Union (EU), Japan, India, Korea, Taiwan and the United States (US).

The scope of the RAC products considered in this study includes the following sub-categories: (i) non-ducted single split units (mobile or fixed split units); (ii) non-ducted single split unit heat pumps; (iii) ducted single split units; (iv) multi-split units; (v) single-packaged AC units; (vi) single and double duct units (portable air conditioners); and (vii) central AC units – air handling units (AHUs). Absorption units were excluded, but the cooling mode of reverse cycle (heating and cooling) units was included in the study.

Project Component Overview

To enable comparison of RAC efficiencies among economies, the study comprised four interrelated components: mapping, benchmarking, testing, and ranking.



- The mapping component of the study provided background information for each selected economy on the main characteristics of the RAC market and the S&L program in place. These characteristics served as the basis for selecting the RAC models to include in the benchmarking and testing components of the study.
- The benchmarking component enabled the comparison of the efficiency of equipment from different economies by developing formulas to convert between the different metrics used.
- The testing component conducted energy performance measurements for four selected RAC models under laboratory conditions, in line with the test procedures used in selected economies representing a large proportion of the world market. The measurement results were compared to the theoretical conversion formulas developed through the benchmarking component to confirm their validity.
- Finally, a ranking tool was developed to compare the stringency and performance of various economies' RAC S&L programs. The tool is based on analysis of the S&L policy and regulation frameworks in the economies analyzed as well as input from S&L experts.

The project team included Econoler, which acted 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 their expertise on various issues related to the international comparison of RAC equipment efficiencies. A peer review of the final reports was performed by a senior energy efficiency expert external to CLASP and independent of the project team to ensure the high quality of the technical and policy analysis.

The following four reports were issued as a result of this study: (a) Cooling Benchmarking Study Report; (b) Mapping Component Report; (c) Benchmarking Component Report; (d) Testing Component Report.[1]

The main findings and policy implications of each component are presented below.

Mapping Component

This component of the study provided selected economies' RAC background characteristics including market size, market trends, and the EE performance of RAC products offered. The mapping component also includes a review of applicable existing S&L regulations or voluntary initiatives along with their characteristics. The research confirmed that there has been an upward trend in sales of RAC units over the last five years in most economies. The stock increased by 75% in the EU and 44% in China from 2005 to 2010. Growth of RAC stock has been moderate in Japan and the US, where stock increased by 15% and 10%, respectively, over the same period.

The RAC market is dominated by split system units in most economies. Inverter splits are widely available in industrialized countries, and market shares have shown progression in developing economies as well. The sales-weighted average energy efficiency ratio (EER) of single and multi-split AC products has trended upward in the economies analyzed over the past decade, showing an increase in efficiency. On the other hand, the sales-weighted average EER of window AC products has remained almost constant between 2006 and 2011 in the US while it has decreased in the EU over the same period.

In some of the economies analyzed, such as China and Australia, the RAC MEPS level has become more stringent over the years following one or several updates. As of 2011, India and Taiwan are considering implementing more stringent requirements in the near future. The mapping component provides an outline of RAC characteristics over the past decade and can be used as a benchmarking tool for economies undertaking RAC S&L activities.

Benchmarking Component

The EER and the seasonal energy efficiency ratio (SEER) are the two main metrics used internationally to rate the energy efficiency of ACs. To be able to explain the energy efficiency metric conversion formulae and how they were developed its first necessary to understand the characteristics of the metrics themselves. The EER is the ratio of cooling capacity to electricity consumption when measured at full

[1] All reports are available at http://clasponline.org/

load (i.e., at the maximum deliverable cooling capacity of the AC). Hence, the EER is not representative of seasonal energy performance because it does not take part load performance into consideration. In fact, ACs typically operate at full capacity only for a small number of hours during the cooling season. ACs run at part load the majority of the time, or they cycle on and off.

To address these shortcomings of the EER metric, the SEER has been created to provide a more representative measure of EE performance of AC units over the cooling season. The SEER metric is increasingly being used as an alternative to the EER to set MEPS and labeling requirements. Asian countries often use the cooling seasonal performance factor (CSPF) as a metric for RAC efficiency. This metric is very similar in concept to the SEER and is used as part of Japanese, Chinese and Korean test standards.

The benchmarking component of the project derives mathematical functions that can be applied to convert energy performance measurements of AC equipment in one economy into the values that would have been recorded for the same products if they had been tested and rated in other economies. These conversion functions are based on in-depth analysis of the differences between RAC energy performance metrics and measurement methods and the tolerances allowed by each test procedure. Conversion functions have been developed for both split non-ducted and split ducted ACs and for fixed-speed and variable-speed (inverter driven) units. As split systems are the most common RAC products sold internationally, the conversion functions cover a large percentage of the world market for RAC products.

The conversion function takes the following form:

$$\text{SEER Y} = \alpha\_\text{ave} * \text{SEER X}$$

where SEER X represents the rating observed in the source country, α_ave is the average conversion coefficient to be applied, and SEER Y is the resulting efficiency rating in the target country.

The study has also derived minimum and maximum conversion coefficients for non-ducted single speed RACs to determine the range of plausible solutions to the conversion functions.

The conversion coefficients incorporate additional parameters to reflect differences in the way ducted units are tested in the US versus elsewhere, and to take into account the inclusion of energy use associated with low power modes in the EU.

Once established, the conversion formulas were applied to current EE policy settings to compare the minimum energy performance requirements for the most common types of split RACs in the world's major economies. The main finding is that the Japanese Top Runner requirements are the most stringent existing requirements for split AC units and that 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.

The study does not intend to indicate that the Japanese requirements should be adopted worldwide given that the development of requirements needs to take into account factors such as energy and equipment costs, consumer behavior, and usage patterns often related to weather conditions. Economies with high electricity rates or that depend heavily on energy imports have a natural tendency to set more stringent energy performance requirements for the benefit of consumers and to respond to their market reality.

Testing Component

The testing component compared and highlighted the differences among test procedures for measuring the cooling capacity and the efficiency of RACs in cooling mode for the selected economies. Four samples were tested using different procedures to identify any additional practical considerations with the test procedures. Additionally, testing was performed to provide real data to check the coherence of the conversion functions developed as part of the benchmarking component.

Most of the economies included in the testing component (the US, the EU, Japan, China, Korea, and India) base their test procedures for RACs on the adaptation of two international standards: ISO 5151 and ISO 13253. The test procedures are conducted using one of two test methods: the indoor air enthalpy method and the calorimeter room method.

While differences among the test procedures used in different economies lead to various measurement uncertainties, most of the variations do not allow for the establishment of a systematic translation of those differences to the EER. The exceptions, or the differences among test procedures that do have a systematic effect on the EER measurement, are the testing temperature, the length of the refrigerant piping, and fan correction for ducted units.

- Testing temperature: The effect of testing temperature has been integrated into the conversion functions developed.
- Length of refrigerant piping: The effect of the varying lengths of refrigerant piping has not been accounted for in the study, but the study recommends unifying on a worldwide basis the requirements for the length of the refrigerant piping used for testing.
- Fan correction for ducted units: The study found that the fan correction applied to ducted units might introduce significant differences between test results and the actual efficiency of units. Fan correction has been integrated to some extent in the conversion formulas between metrics. A recommendation was made to review existing test procedures and to use a fan correction only when the fan is not part of the unit but to remove the fan correction when the fan is an integral component of the RAC.

The study also recommended selecting the calorimeter room method when it is allowed under a testing procedure as it provides lower uncertainty of measurement.

It was found that some test procedures require specific information from the manufacturer to perform the efficiency test for inverter units. This can cause problems for market monitoring and verification incorporated in S&L schemes when such data are not readily available. A recommendation was made to allow for an alternative testing method that does not require additional manufacturer information.

The testing component confirmed the coherence of the conversion functions and the various coefficients developed in the benchmarking component.

Ranking Component

The ranking component of the study focused on the elaboration of a ranking tool for RAC S&L policies, regulations or initiatives. The ranking tool guides users to collect the relevant data in order to assess the S&L programs of targeted countries. This tool provides evidence-based information for policy decisions in order to improve programs or identify requirements for further study. The objective is to pull the market towards higher levels of RAC efficiency and lay the foundation for strong and harmonized energy performance requirements at the global level.

The tool covers seven S&L components or characteristics:

(i) MEPS stringency;

(ii) MEPS program characteristics;

(iii) Technical characteristics of MEPS rating methods;

(iv) Endorsement labeling program context;

(v) Endorsement labeling program quality;

(vi) Comparison labeling program context;

(vii) Comparison labeling program quality.

The final survey instrument was built as a spreadsheet comprising the seven key components and including an Overall Ranking Score used to determine the effectiveness of RAC S&L programs.

The weighting for each characteristic covered by the ranking tool is based on input from experts representing government agencies, advocacy organizations, and consulting firms in Canada, China, India, Japan, and the US. Though it is subjective, the scoring reflects generally accepted principles regarding best practices in S&L programs (as reported in the literature), input from CLASP staff, and, in some cases, comments from expert reviewers. Application of weighting factors to the results of each category provided a final value that ranged from 0 to 100.

Study Limitations and Recommendations for Research and Development of Test Procedures

The conversion formulas developed within this study were intended to provide valid comparisons across economies through a balance between simplicity of use and thoroughness in incorporating various factors affecting RAC energy performance. The formulas were deemed accurate when considering the conversion of average figures of efficiency for a group of RACs, but showed divergence in individual units due to design specificity. The study identified that the compressor type, indoor and outdoor control fan strategy, fan correction calculation, and parasitic power (thermostat, standby power, crankcase heater) could contribute to divergence in units. The conversion formulas developed accounted for the maximum number of factors using average values whenever possible.

The study has identified several areas where conducting further research or modifying existing test procedures could more easily enable comparisons across various economies. These include the selection of the type of laboratory setup (calorimeter room vs. indoor air enthalpy measurement), the refrigerant piping length, the fan correction factor (especially for inverter type RACs), and the parasitic power consideration in efficiency metrics. The study also recommends changing a number of test procedures so as to incorporate pre-determined loading points on a permanent basis. This modification will provide an alternative for laboratories to perform testing when direct contact with manufacturers is not possible. This modification is proposed because some test procedures currently require information that is not usually found in the technical documentation delivered with units, thereby creating barriers to market surveillance and third-party verification.

Finally, the study found that humidity removal could be inconsistent among inverter type RACs. There is evidence from laboratory testing that several RACs have limited latent heat removal capability at part load. There is also evidence that a small segment of the units sold on the market have no humidity removal capability. The study, however, was not designed to explore such limitations of current RAC units in detail. Consequently, further research is recommended to determine whether humidity removal should be incorporated as a requirement in future test procedures.