

## 2. ROOM AIR CONDITIONERS (NON DUCTED AIR CONDITIONERS)

### Overview of the product

Room air conditioners are a mainstream product in developed economies and many developing economies are experiencing rapid increases in ownership. A range of technologies can be used for air conditioners. This section concentrates on systems that use the vapour compression cycle and air to air heat exchangers for cooling and/or heating of an indoor space. The systems covered have no air interchange between the outdoors and the conditioned space and they discharge conditioned air directly into the conditioned space (non-ducted configuration).

The main configurations are split systems (single or multi) and unitary systems (mainly window wall, but also some small packaged systems). Typically, these have a limited capacity (usually up to around 15kW cooling output) and are usually designed to condition a limited space within a residential dwelling or office.

Room air conditioners are a global commodity and there is widespread international trade. There are generally only small differences in product design at a regional level. North America treats split systems as central units, which means they have to be tested in a different fashion, but the product is otherwise the same as elsewhere. North America also has a product type called a packaged terminal air conditioner which appears to be limited to the USA – this is effectively a unitary non-ducted system.

There are differences in terminology in some parts of the world, particularly in North America. There is no international standard which defines air conditioner types and configurations<sup>3</sup>.

### Comparison of energy performance test procedures

#### *Key parameters to consider for efficiency testing and measurement*

A room air conditioner is essentially a heat pump that that collects energy from one space and moves it to another space using the vapour compression cycle. The main components are a compressor, refrigerant in a distribution system (including an expansion valve), an evaporator and a condenser. The direction of heat flow depends on the mode of operation: while cooling, the heat is collected from the inside space and moved outside. In heating mode, heat is collected from outside and moved to the inside space. The amount of heat that can be moved is generally considerably greater than the energy used to drive the refrigeration system, hence the apparent efficiency is typically in the range 200% to 500% (defined as output over input). For products that can operate in heating and cooling mode, the heating efficiency generally appears more efficient as the energy used to drive the compressor can also contribute to the overall output.

The key parameters used for efficiency testing and measurement are the input energy (electricity) and output (total heating or cooling capacity). These two parameters can be used to define overall efficiency of the product during operation.

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<sup>3</sup> Note: the technologies not included in this section are evaporative coolers, water sourced heat pumps, chillers (that provide cooled water), systems that use cooling towers and ducted systems.

As set out in great detail in expert and academic literature, the efficiency of a refrigeration system (like the one used in an air conditioner) is affected by the indoor/outdoor temperatures and temperature difference (or more correctly the operating temperature of the evaporator and condenser) and the overall operating efficiency of the refrigeration system under that condition (which is a function of the compressor parameters and the heat transfer rate and surface area of the evaporator and condenser). Some energy is used by components such as fans and to some extent electronics and in some cases auxiliary heaters (e.g. for defrosting).

In order to obtain accurate comparative efficiency value of the air conditioner system itself, the indoor and outdoor conditions need to be carefully controlled. Accurate determination of the output of an air conditioner also requires careful measurement (volume and temperature of air, plus dehumidification effect in the case of cooling) – this parameter can be subject to large errors when some approaches are used.

The most accurate approach to testing for efficiency is a calorimeter where there is an overall check on the energy balance of the indoor and outdoor sides of the system. Calorimeters also give the best result for non ducted product where conditioned air is delivered directly to the room.

The air enthalpy method can be used to measure the capacity and efficiency of non-ducted products, but there can be problems in accurately measuring the energy discharge into the conditioned space as it is difficult to replicate the natural mixing and recirculation of the product under normal use conditions. The air enthalpy method does not provide an overall check of energy balance during testing.

The other key parameter which affects the overall energy consumption of room air conditioners is the non-operational energy consumption. Most test procedures do not currently deal with this parameter.

### *Overview of the international test method*

The international test method for room air conditioners: ISO5151 - *Non-ducted air conditioners and heat pumps -- Testing and rating for performance*. This standard is used very widely around the world. The standard defines the following parameters for testing purposes:

- Definitions
- Determination of capacity and energy efficiency;
- A range of performance tests in cooling and heating mode;
- Uncertainties and tolerances.

For the determination of capacity, 3 possible combinations of indoor and outdoor conditions are defined. Condition T1 is used almost universally for cooling capacity determination and efficiency claims. T2 (mild conditions) and T3 (very hot conditions) are rarely specified. Condition “high” for heating is most commonly used, although “low” is sometimes specified for colder climates. Condition “extra-low” is not used widely for rating (climates with sub-zero temperatures tend to opt for other technologies like ground source heat pumps).

**Table 1: Cooling and heating conditions in ISO5151**

<b>Cooling conditions</b>	<b>T1</b>	<b>T2</b>	<b>T3</b>
Indoor	27°C DB, 19°C WB	21°C DB, 15°C WB	29°C DB, 19°C WB
Outdoor	35°C DB, 24°C WB	27°C DB, 19°C WB	46°C DB, 24°C WB
<b>Heating conditions</b>	<b>High</b>	<b>Low</b>	<b>Extra Low</b>
Indoor	20°C DB, <15°C WB	20°C DB, <15°C WB	20°C DB, <15°C WB
Outdoor	7°C DB, 6°C WB	2°C DB, 1°C WB	-7°C DB, -8°C WB

Notes: DB = dry bulb, WB = wet bulb

Importantly, ISO5151 defines a range of performance tests that check whether the air conditioner is fit for purpose. For cooling these include maximum cooling, minimum cooling, enclosure sweat and condensate disposal tests and a freeze up test. For heating these include maximum heating, minimum heating and an automatic defrost test. Some of these tests are mandated within some testing regimes. Not all tests are relevant for all users.

In terms of efficiency the standard defines Energy Efficiency Ratio (EER) as the ratio of cooling output (W) to electrical input (W) – this variable is dimensionless (W/W). It also defines the Coefficient of Performance (COP) for heating in a similar fashion.

ISO5151 specifies both calorimeter and air enthalpy test setups for energy and capacity determination.

ISO5151 does not address non operating power.

*Adequacy of the international test method*

There are two main limitations to ISO5151 as it is currently written regarding operating efficiency.

The first limitation is that most regulatory regimes specify condition T1 for cooling performance and condition “high” for heating performance. While this provides good comparative data of overall system efficiency at the defined operating conditions, this may not necessarily represent the actual efficiency achieved during normal use. For many products, the relative efficiency will not change much with operating condition, which is why this limitation has largely been ignored until recently.

The second limitation is a more significant problem (but of a similar nature) that has come about due to recent changes in the technology used in air conditioners. Over the past 10 years, the share of inverter driven products (or more correctly, compressor with variable output) has increased dramatically to a point where these are used almost universally in Japan and are dominant in Australia and other regions (for example).

For a standard single speed compressor (which used to predominate), the refrigeration system always runs at “full load” when operating. The overall output of the system is modulated by changing the compressor on time and off time (50% output for example would be achieved by operating the compressor approximately half of the time).

A variable output system operates on different basis. In order to achieve a reduced capacity, the speed or output of the compressor is reduced to match the load required. This means that the units run continuously across a wide range of required outputs. The key advantage of these systems is that they avoid compressor start-up losses and generally they can operate at increased efficiency at part load conditions. This increased efficiency occurs because at part load the refrigerant flow from compressor is reduced but the surface area of the evaporator and condenser remains the same, resulting in an overall improvement of heat transfer. Thus the operating efficiency during normal use is likely to be better than the value obtained at rated capacity (full load). However, there can be some so called “parasitic losses” to run the variable output system, so the efficiency gains vary by model and by output.

To some extent these two limitations are related in that the standardized test conditions (T1 and “High”) when measured at rated capacity do not necessarily reflect the operating efficiency at other conditions and outputs for some types. When the market was dominated by single speed compressors, the differences in operating efficiency at conditions that were different to T1 were relatively small and part load efficiency of single speed compressors changes little at reduced capacity (if anything this should deteriorate slightly), so the problems were ignored. However, with a large share of variable output product on the market, the test procedure as written does not provide a good representation of part load or seasonal variation in efficiency. Unless this is addressed, divergence from the test procedure that has to date been widely used globally may begin to occur.

The other issue which is not covered by ISO5151 is the measurement of non-operating energy of room air conditioners. Most room air conditioners now use some power when the refrigeration system is not operating. This power can be used for a range of functions such as remote controls, timers and even remote communications (including load control). Some room air conditioners also have heating systems (commonly called crank case heaters) which are used to stop refrigerant condensing and pooling in the compressor chamber (liquid in the compressor can damage it during starting). Crank case heaters are uncommon for room air conditioners (although they can be present) but are more common on larger ducted systems.

Typical power consumption for crank case heaters is 30W to 100W, but some systems can use as much as 200W. Over a year this can account for a large amount of energy.

The measurement of non operating power is usually straight forward when only functions related to communications and controls are involved (as these usually remain constant under different ambient conditions). The control and operation of crank case heaters can be complex in some cases – these range from simple heaters that are on when the system is not operating to more complex systems that are controlled by ambient temperature and/or by operating schedules (e.g. heaters may not operated for a specified period after the operation has stopped due to residual heat in the system).

### *Regional differences in products and testing approaches*

There are surprising few significant variations in testing approaches to room air conditioners globally. There are some minor variations in web bulb requirements in some Asian countries and some small differences due to conversion from Celsius to Fahrenheit temperature scales, but these are minor variations. There are also some differences in the expression of efficiency (EER) in the some regions, where outputs are expressed in British Thermal Units (BTU) or kilo-Calories, but the underlying concept of output over input is used fairly universally.

The most significant variation to the fundamental test requirements is in North America where split systems have to be tested to the requirements for central air conditioners, which requires the determination of a Seasonal Energy Efficiency Ratio (SEER). This requires test data at 4 different test conditions which are then combined to reflect an overall annual efficiency for a specified average

North American climate. One of the test points is equivalent condition T1. The other points have the same indoor conditions with reduced (milder) outdoor conditions.

**Table 2: North American SEER test conditions for room air conditioners**

Condition	Indoor	Outdoor
Condition A (equivalent to ISO T1)	27°C DB, 19°C WB	35°C DB, 24°C WB
Condition B	27°C DB, 19°C WB	28°C DB, NS - WB
Condition C	27°C DB, 14°C WB	28°C DB, NS – WB
Condition D	27°C DB, 14°C WB	28°C DB, NS – WB

Testing to conditions “C” and “D” are optional in that if the tests are not done, a value of 0.25 is assigned for the degradation co-efficient CD. Only four tests are required for single speed compressors. Where there is a two speed compressor, tests at condition “A” and “B” are to be done for each speed. For variable speed compressors, up to seven tests are required as follows:

- “A” and “B” wet coil tests at maximum compressor speed
- “B” wet coil is tested at minimum speed
- Low temperature wet coil test is conducted at minimum speed (indoor and outdoor 19.4/13.9oC dry/wet)
- Final wet coil test is conducted at an intermediate speed
- if a value for CD of 0.25 is not used, dry coil tests “C” and “D” at minimum speed.

### *Comparability of regional testing approaches*

As most regions globally have used the standard ISO5151 T1 and “High” test conditions to rate and compare their products, there is generally very good alignment and comparability of test data for air conditioners. The exception is North American due to the SEER requirement for split systems. However, data for the T1 test condition should be available for all products, which would allow direct comparison of products.

### *Subjective assessment of the level of international harmonisation for testing*

There is a high degree of international harmonisation regarding the use of ISO5151, with the exception of North American requirements for split systems. The historical domination of single speed compressor units has meant that the imperfections in ISO5151 are relatively minor under many usage conditions and could be ignored. However, the growing dominance of variable output units now means that there is a lot of pressure to provide better information on the relative efficiency of these units under a range of operating conditions. Unless this issue is addressed in the near future, there may be moves to diverge from ISO5151 by the addition of more test conditions.

### *Prospects and key directions for international harmonisation of testing*

There is already good international harmonisation for room air conditioners through ISO5151. However, the test procedure needs to be made more relevant for variable output products, which can change their efficiency with changes in output and operating conditions.

Work is under way in ISO to develop a basis for a seasonal rating system for air conditioners. The approach is to define a series of standard test conditions. The standard test points can then be used to estimate, via a series of equations, operating efficiency under different operating conditions and different output levels, which can be used to estimate performance under different climates. The intent is to provide a standard comparative annual performance rating for international comparative purposes, but more importantly, to provide a standard methodology to calculate the annual performance of a product under a wide range of possible climate and usage conditions using data from a limited number of standard test points. The methodology under development, if accepted, will provide a sound basis for providing more accurate performance data for a large number of climates and usage levels without the need for extensive testing and it will also address current concerns regarding the relative efficiency of variable output air conditioners. For this approach to be successful, the data for each of the standard test points needs to be separately reported.

### **Comparison of energy efficiency metrics**

#### *Common Efficiency Metrics and Regional Approaches*

The most widely used efficiency metric for room air conditioners is the EER for cooling and COP for heating that is derived from ISO5151. This measure is essentially output power over input power and provides a direct measure of operating efficiency. When stated with the cooling output and the heating output, EER and COP provides all of the data required for efficiency comparisons.

In terms of energy labelling, there are a wide different systems for depicting the categorical efficiency of air conditioners within individual country rating systems. Categories are depicted by various symbols such as numbers, letters and stars. However, all of these rating systems use EER and COP as the underlying efficiency measure to determine the category rating. In some regions (e.g. North America) the raw EER number is quoted as the efficiency metric (noting that that this is in BTU/W rather than W/W).

Similarly, EER and COP are generally used to define minimum energy performance standards (MEPS) where applicable.

The exception is North America that uses SEER for split systems. SEER is specifically determined for a specified North American climate, which makes this parameter of little value to most other regions in the world (and many parts of North America). The values for each of the test points are generally not reported as separate parameters.

Some countries now include non-operating power consumption in their overall efficiency requirements. This is an important measure to ensure that manufacturers minimize this as far as possible.

#### *Performance Issues*

The approach to performance requirements varies by country.

In North America, single speed compressor split systems are subject to four performance tests:

- high temperature test,

- cyclic test,
- frost accumulation test
- low temperature test.

Variable speed units are subject to: high temperature test (one maximum speed, two at minimum speed), cyclic test (minimum speed), frost accumulation test (maximum and intermediate speeds).

Other countries specify one or more of the performance tests in ISO5151 as a prerequisite to their energy labelling or MEPS programs.

It is usually advisable to mandate certain minimum performance tests to ensure that the products are fit for purpose and will actually work under the range of expected operated conditions normally encountered.

### *Comparability of efficiency metrics*

At this stage, there is very good comparability of efficiency data across different regions where this is reported at ISO5151 condition T1 for cooling and “High” for heating. North American data for split systems tends to report SEER only, which cannot be directly compared to results at T1. However, efficiency at T1 is one of the standard test points that makes up the SEER value so separate reporting of this value in addition to SEER would make data highly comparable across regions.

### **Recommended directions**

There is already a good level of global harmonisation in the testing and reporting of room air conditioner energy efficiency. The main exception is in North America where SEER is used for split systems. SEER is not directly comparable to ISO T1 conditions. However, ISO T1 data makes up one of the test conditions used to calculate SEER, so if this value could also be separately reported, this would allow direct regional comparability.

There is growing international pressure to take into account the improved performance of variable output compressors under both part load output and milder operating conditioners. Unless this issue is adequately addressed in the near future, there is likely to be a divergence of testing approaches around the globe. ISO are working on a globally applicable approach to determine a seasonal performance for air conditioners which is based on measured performance at a set of specified rating conditions which can be used to estimate efficiency under a range of operating conditions and outputs. Most importantly, a methodology is being developed to allow seasonal performance to be calculated for any selected climate zone. Once accepted, this should address many of the current concerns.

It is important that a global test procedure for air conditioners define the conditions of measurement for non operating power in an accurate and relevant manner. This can then be used by different regions as required within efficiency programs without the need to generate local requirements to address this issue. The seasonal calculation approach also needs to address non operating power as this can be a significant element of total energy consumption.

This work by ISO should be supported on the understanding that it will be based on a limited number of standard testing points and the methodology will allow these test point results to be converted into a seasonal rating for any selected climate. It is also critical that the methodology to calculate seasonal ratings be publicly available. The resulting standard should also mandate the separate reporting of all data for all of the standard test conditions which are specified to allow different regions to apply relevant weightings to reflect their local conditions.