



## Seasonal cooling performance of air conditioners: The importance of independent test procedures used for MEPS and labels



Carsten Palkowski<sup>a</sup>, Stefan von Schwarzenberg<sup>b</sup>, Anne Simo<sup>a,\*</sup>

<sup>a</sup>BAM Federal Institute for Materials Research and Testing, Unter den Eichen 87, Berlin 12205, Germany

<sup>b</sup>TÜV SÜD Industrie Service GmbH, Geiselbullacher Str. 2, Olching 82140, Germany

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### ABSTRACT

Minimum energy performance standards and labels are commonly used tools to reduce the household energy use thus mitigating greenhouse gas emissions. However, the technical foundation for minimum energy performance standards and labels are test procedures for rating and testing of appliances. To determine the seasonal cooling performance of air conditioners, the current test standards require fixing of the compressor speed of the units to achieve steady-state conditions; this way of operation, however, differs from real-life use. To make the seasonal cooling performance testing better reflect the real use conditions, this study proposes a compensation method which can be conducted independently from manufacturer data and still allows modulation of the tested units. Our results show that the tested units behave differently under part-load conditions, which results in a lower energy efficiency rating for some of the tested devices.

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## Importance des procédures de tests indépendants utilisés pour les normes minimales de performance énergétique et l'étiquetage

*Mots clés:* Conditionneur d'air; Méthode de test indépendante; Comportement en utilisation réelle; Ratio d'efficacité énergétique saisonnier; Normes minimales de performance énergétique; Étiquetage énergétique

### 1. Introduction

The electricity demand for space cooling and air conditioning has drastically increased over the past decades, and this trend is likely to persist due to the climate change and the rise of the average global temperature. Various studies report on the impact of climate change on the cooling demand. According to Casini (2009), the energy consumption for cooling in the EU is likely to increase by about 72 % until 2030. In the US, Miller et al. (2007) observed a similar trend in the consumers behavior regarding space cooling.

The objectives of research engineers and energy policy makers are to improve the energy efficiency of energy-related products

and identify inefficient products on the market to mitigate the effects of climate change and to reach the targets set in 2017 at the UN climate change conference in Bonn. The EU Climate and Energy Package proposes that by 2020 there should be a 20 % improvement of energy efficiency and a 20 % cut in greenhouse gas emissions (from 1990 level). For household appliances, Girod et al. (2017) and Schlomann et al. (2012) found out that labels and minimum energy performance standards (MEPS) are more effective than other demand-pull policy types energy-efficient inventions. Many countries worldwide set MEPS to withdraw inefficient products from the market. Due to their high energy consumption, residential air conditioners (ACs) represent a product group selected to be regulated first in many countries (Waide, 2011). By 2013 around 81 countries established the respective labels and standards (Harrington and Brown, 2013). Primarily, the target energy savings should be achieved by the deployment

\* Corresponding author.

E-mail address: [anne.simo@bam.de](mailto:anne.simo@bam.de) (A. Simo).

## Nomenclature

AC	air conditioner
EER	energy efficiency ratio
FCS	fixed compressor speed
MEPS	minimum energy performance standards
$\dot{m}$	mass flow rate, kg s <sup>-1</sup>
$P$	electrical power, W
PLR	part-load ratio, W W <sup>-1</sup>
$\dot{Q}$	capacity, W
$Q$	energy, J
SEER	seasonal energy efficiency ratio, J J <sup>-1</sup>

### Greek letters

$\vartheta$	temperature, °C
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### Subscripts

c	cooling
ce	annual electrical consumption
ci	condenser inlet
eh	electrical heater
ei	evaporator inlet
el	electrical
in	inlet
ir	indoor room
on	active-mode
out	outlet
or	outdoor room
PLR	part-load ratio
rated	declared value
spec	specific
w	water

of efficient energy-using technologies (European Commission, 2008). In the EU, the EU commission endorsed MEPS for ACs in the EU member states and issued a respective Regulation (EU) No 206/2012 (European Commission, 2012); since 2011 air conditioners bear an Energy label (European Commission, 2011).

While regulations set the legal framework, standardized laboratory testing is necessary to determine seasonal performance of the split-type air conditioner units. In different markets different technical standards are applied to determine seasonal performance, for example (DIN) EN 14825 (DIN Normenausschuss Kältetechnik FNKä, 2016), AS/NZS 3823 (Standards Australia and New Zealand Standard, 2014) and ANSI/AHRI Standard 201/240 (Air Conditioning, Heating and Refrigeration Institute, 2008). These standards are based on steady-state measurements. However, for the inverter-driven ACs, which are the prevalent type of split ACs, these steady-state conditions are achieved by fixing the inverter at a certain frequency and a correlated compressor speed. In real use the inverter regulates the cooling capacity using speed controlled drive to minimize the power consumption. Thus, fixing of the AC in an artificial operating mode does not consider the effectiveness of this control technology and could lead to significant differences between laboratory results and field operation. Additionally, testing according to the current test standards is not possible without manufacturer support since a specific software or test mode is required to fix the compressor frequencies and to achieve steady-state conditions. However, manufacturers could set frequency values to optimize the laboratory performance of their products. As a result, the current standards may allow devices on the market that comply with MEPS only under laboratory conditions but not when the consumer uses the product in practice. These devices should actually have been withdrawn from the market.

Therefore, there is an urgent need for a standardized seasonal performance test method that considers inverter-driven ACs appropriately and independently from manufacturer data. Menegon (2017) and also Haller (2013) developed approaches for the laboratory characterization of heating systems under a dynamic test mode. Mavuri (2015) presented an approach for the determination of the energy efficiency of air conditioners following AS/NZS 3823 (Standards Australia and New Zealand Standard, 2014) measurements. The study shows important approaches for a steady-state measurement that could be conducted independently from manufacturer support. However, the aforementioned approaches were not proven to deliver reproducible results, which is one of the most important features of a well-designed test procedure (Lutz et al., 2010).

This study proposes an independent test method to determine the seasonal cooling performance of ACs, applicable for both single split-type ACs, with and without inverter. The proposed compensation method delivers repeatable results and allows to better distinguish between efficient and inefficient ACs by considering the speed controlled drive of the tested unit, thus helping consumers in their buying decision. With a simple calculation, we demonstrate the discrepancy between expected and actually realizable energy and CO<sub>2</sub> - emission savings according to current test procedures and if the compensation method would be used for energy labelling.

## 2. Energy efficiency regulations in the EU

### 2.1. EU ecodesign directive

MEPS are the prescribed energy performance of manufactured products, prohibiting products with less energy efficiency than the minimum requirements (McMahon and Turiel, 1997). Thus, MEPS are an effective instrument for measuring energy savings (Gillingham et al., 2004) and eliminating energy-inefficient products (Newell et al., 1999). Manufacturers are encouraged to invest in further improvement of their products' performance, making their products more competitive (Nadel et al., 1997). In the European Union, the EU Ecodesign directive (European Commission, 2009) sets minimum energy efficiency requirements for energy-related products such as household appliances, heating and cooling products. Products that do not meet the mandatory requirements are not allowed to be sold in the EU. Since January 2014, according to Commission Regulation (EU) No 206/2012 (European Commission, 2012), split-type ACs with rated capacity < 6 kW, using a refrigerant with global warming potential (GWP) > 150 shall have a minimum seasonal energy efficiency ratio (SEER) of 4.6.

### 2.2. EU energy labelling framework regulation

Energy labels do not refer to a specific technology and thus make products comparable. The Energy label classes give indication for energy efficiency improvements (Siderius, 2013) and annual electricity savings (Fridley et al., 2007).

In the European Union, the Energy label is used as a tool to reduce the energy consumption of selected products since 1995 (European Commission, 1992, 2010). The EU's Energy Labelling framework Regulation (2017/1369) (European Commission, 2017) sets mandatory labelling requirements for energy-related products, in form of energy use and efficiency, to support the consumer in their buying decision in favor of choosing energy efficient products (Granda, 2017; Stadelmann and Schubert, 2018; Wstenhagen and Sammer, 2006). Indeed, a large majority of European consumers are aware of the energy label and use it in their purchasing decisions (Molenbroek et al., 2013) due to the cost savings from the

reduced energy consumption (Bull, 2012; Camilleri and Larrick, 2014; Cole, 2018). Sales data from 5 European countries (France, Germany, Italy, Poland, Great Britain) from 2005 - 2008 show that the AC market could be shifted towards high efficiency. This market evolution most likely was triggered mainly by the introduction of the energy label for ACs in 2002 (Bertoldi and Atanasiu, 2009). In 2011 additional energy classes above A, namely A+, A++ and A+++, were added to the label. According to Commission Delegated Regulation (EU) No 626/2011 (European Commission, 2011), on the European energy label the energy efficiency of the appliances is rated in terms of a set of energy efficiency classes ranging from A+++ to D, A+++ (SEER  $\geq$  8.5) being the most energy efficient, D ( $3.6 \leq$  SEER  $<$  4.1) the least efficient. However, policies need to continuously adjust the energy label regarding consumer patterns (Dianshu et al., 2010).

### 2.3. Test procedures

To improve the energy efficiency of energy-related products, MEPS and labels are effective tools. Standardized test procedures are mandatory as they provide consistent measurements of appliance energy performance. Thus, a test procedure should fulfill the following criteria (Siderius, 1991; International Organization for Standardization, 2002):

- Repeatability: the consistency of results, e.g. regarding energy consumption or performance when the same product is retested under the same conditions, e.g. in the same laboratory by the same staff.
- Reproducibility: the consistency of results when the same product is retested under somewhat different conditions, e.g. in another laboratory, but using the same test procedure.
- Representativeness: the correspondence of the results from applying the test procedure to the results obtained in practice (at the end-users).
- Affordability: reasonable costs for carrying out the test procedure.

The need for new test procedures which better reflect typical usage conditions has already been pointed out for different appliances in many studies (Blum and Okwelum, 2018; Meier and Hill, 1997; Stawberg and Wikström, 2011; Toulouse, 2014). Another criterion to be added could be the aspect of independency. To ensure for consumer trust in the declaration on the Energy label, the market surveillance authorities carry out random product testing, verifying the values on the Energy label declared by the manufacturer. Those tests, should be conducted independently from manufacturers. But currently, split-type ACs with an inverter can only be tested under specific test modes. This study shows the necessity for independent testing and the resultant impact on AC labelling.

## 3. Methodology

As it is not adequate to compare ACs only with respect to their nominal cooling capacity  $\dot{Q}_{c,100\%}$ , since 2013 the European standard EN 14825 (DIN Normenausschuss Kältetechnik FNKä, 2016) gives a specific test procedure on how to determine a seasonal cooling performance of ACs by means of laboratory tests. For both the capacity tests at full load and at part-load, it sets out requirements and defines conditions for the part-load ratio PLR and related dry-bulb and wet-bulb temperatures for the indoor room and the outdoor room. These requirements are dependent on whether we are considering the heating case or the cooling case. For example, for the cooling case the EN 14825 sets out requirements for four different test points. The permissible deviations of the measured values from the set values during the test and the experimental setup

are defined in the technical standard EN 14511 (DIN Normenausschuss Kältetechnik FNKä, 2013). This standard also defines the test method, thereby giving further particular instructions e.g. on the position of the measuring devices in the calorimeter room or the minimum required test time. For the evaluation of the capacity test results the EN 14825 defines a calculation method by which we can determine the seasonal energy efficiency ratio in active-mode (SEER<sub>on</sub>). For the determination of the SEER<sub>on</sub>, it is necessary to interpolate our test results and thus conclude for a characteristic curve of the energy efficiency ratio (EER) as a function of a defined outdoor room temperature range. The measured and also the interpolated EER data is then used to calculate the SEER<sub>on</sub> by further consideration of the nominal cooling capacity  $\dot{Q}_{c,100\%}$  and the given climate data. By considering the climate data we are giving a defined and higher weight for particular EERs that relate to recurring temperatures. As we aim to conclude for an overall seasonal cooling performance of ACs, which should represent the performance of ACs in the field at best, we have to consider that ACs are not cooling continuously over the whole year. Hence, the energy use for the following non-active-modes are determined under defined conditions according to the EN 14825 OFF-mode, thermostat-OFF-mode, standby-mode and crankcase heater mode. These values of energy use are added to the SEER<sub>on</sub> to conclude for an overall seasonal performance of the AC, the SEER.

In this study, the cooling capacity measurements were carried out with seven ACs according to the proposed compensation method. (Table 1) For the determination of the seasonal cooling performance, all units were tested under the same steady-state conditions as given by EN 14825 to be compared with the declared value on the EU Energy label. In the EU, according to Commission Regulation (EU) No 206/2012 (European Commission, 2012), these AC units are required to achieve a minimum SEER of 4.6.

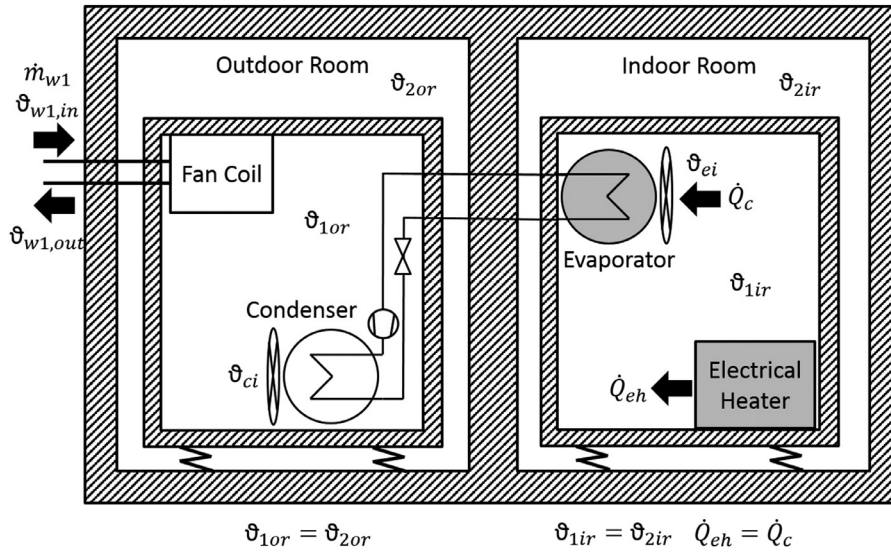
The cooling capacity measurements were carried out in two doubled calorimeter rooms, one room for the indoor unit and one for the outdoor unit, respectively. Each calorimeter room was equipped with supply applications such as cooling coils, heaters, humidifiers, fans and air mixers to ensure the desired and stable conditions in each chamber. Fig. 1 shows the experimental setup of the cooling capacity test.

The performance of ACs depends on a variety of parameters, such as outdoor air temperature, indoor air temperature, part-load ratio (PLR) and combinations thereof. Thus a variety of combinations could be used to test the AC's performance. However, to make the results comparable to manufacturers' declaration, we put the focus on the investigation of (compressor unfixed) part-load behavior. For this reason, the measurements were carried out under the same four operating conditions, prescribed in the EN 14825 (DIN Normenausschuss Kältetechnik FNKä, 2016), including conditions for (i) indoor room air temperatures, (ii) outdoor room air temperatures and (iii) part-load ratios. Therefore our tests include one full load cooling capacity test (PLR = 100 % of cooling capacity at evaporator) and three part-load capacity tests (PLR = 74 %, 47 %, 21 %). Each outdoor room air temperature is associated with a unique PLR as shown in Table 2. The full load cooling capacity test was carried out at A35/A27 ('A' stands for 'Air', 35 for the outdoor room temperature  $\vartheta_{1or}$  and 27 for the indoor room temperature  $\vartheta_{1ir}$ , in °C, respectively). To ensure constant relative humidity, the wet bulb temperature was set to 19 °C for all measurements.

The measurement conditions are achieved via the following procedure: the set points of both rooms are set according to Table 2 and a certain heating capacity  $\dot{Q}_{eh,PLR}$ , identical to the PLRs given in Table 2, is set for the electrical heater of the test stand. The AC runs in a non-fixed mode responding with an equivalent cooling capacity  $\dot{Q}_{c,PLR}$  at the evaporator of the indoor unit. For the full load cooling capacity test  $\dot{Q}_{eh,100\%}$  is set equal to the rated capacity of the AC unit,  $\dot{Q}_{rated}$ . Steady-state conditions are defined

**Table 1**  
Tested air/air type AC models.

AC#	Rated cooling capacity (kW)	Declared seasonal energy efficiency ratio SEER (dimensionless)	Energy efficiency class	Refrigerant
1	2.5	7.57	A++	R410A
2	3.5	7.31	A++	R410A
3	2.6	6.66	A++	R410A
4	3.7	6.5	A++	R410A
5	3.5	6.1	A++	R410A
6	2.7	6.1	A++	R410A
7	3.96	5.6	A+	R410A



**Fig. 1.** Experimental setup of the cooling capacity test.

**Table 2**  
Test conditions of the compensation method taken from the EN 14825 (DIN Normenausschuss kältetechnik FNKä, 2016) and permissible deviations from set values.

Operating Point (PLR)	Condenser Inlet Dry Bulb Temperature $\vartheta_{ci}$ (°C)	Evaporator Inlet Dry Bulb Temperature $\vartheta_{ei}$ (°C)	Evaporator inlet wet bulb temperature $\vartheta_{eiw}$ (°C)	Permissible temperature deviation of the arithmetic mean values from set values (dry bulb/wet bulb)	Permissible temperature deviations of each of the individual measured values from set values (dry bulb/wet bulb)
A35/A27 (100 %)	35	27	19	$\pm 0.3 \text{ K} / \pm 0.4 \text{ K}$	$\pm 1 \text{ K} / \pm 1 \text{ K}$
A30/A27 (74 %)	30	27	19	$\pm 0.3 \text{ K} / \pm 0.4 \text{ K}$	$\pm 1 \text{ K} / \pm 1 \text{ K}$
A25/A27 (47 %)	25	27	19	$\pm 0.3 \text{ K} / \pm 0.4 \text{ K}$	$\pm 1 \text{ K} / \pm 1 \text{ K}$
A20/A27 (21 %)	20	27	19	$\pm 0.3 \text{ K} / \pm 0.4 \text{ K}$	$\pm 1 \text{ K} / \pm 1 \text{ K}$

as constant temperatures at heat exchangers inlet ( $\pm 0.3 \text{ K}$ ). The calorimeter room temperatures  $\vartheta_{1or}$  and  $\vartheta_{1ir}$ , are allowed to vary as long as the heat exchanger inlet temperatures stay constant. The set temperature of the AC is adjusted via remote control until the desired average cooling capacity and the temperatures according to Table 2 are achieved.

The desired cooling capacities  $\dot{Q}_{c,PLR}$  for each measurement are determined by the calculation of a theoretical cooling curve based on the cooling capacity under full load conditions  $\dot{Q}_{c,100\%}$  (PLR = 100 %) and is equivalent to the heating capacity  $\dot{Q}_{eh,PLR}$  to be set for the electrical heater of the test stand.

$$\dot{Q}_{c,PLR} (= \dot{Q}_{eh,PLR}) = \dot{Q}_{c,100\%} \cdot \frac{PLR}{100\%} \quad (1)$$

The part-load measurements at 74 %, 47 % and 21 % follow the same procedure as the full load test. Despite the precise settings of the compensation load, we observed deviations between the theoretical cooling curve and the measured cooling capacities. Deviations can occur when units from the same manufacturer are fitted with the same compressor but are declared with different rated capacities. However, according to the EN 14825 deviations between

the theoretical cooling curve and the measured average cooling capacity should not exceed values of  $\pm 10 \%$  as depicted in Fig. 2. The measurements start when steady-state conditions are reached for a minimum duration of 30 minutes, as required according to EN 14511 (DIN Normenausschuss kältetechnik FNKä, 2013).

Beside the cooling capacity  $\dot{Q}_{c,PLR}$ , we simultaneously measured the electric power consumption  $P_{el,PLR}$  to calculate the  $EER_{PLR}$  for the four tested operating conditions according to Eq. (2).

$$EER_{PLR} = \frac{\dot{Q}_{c,PLR}}{P_{el,PLR}} \quad (2)$$

Based on the EER values and additional tests in further modes like standby - or OFF - mode, we calculated the SEER according to the EN 14825 for the average European climate (DIN Normenausschuss kältetechnik FNKä, 2016).

To validate the compensation method, we conducted cooling capacity measurements according to EN 14825 at the same operating points and conditions as described above, but with fixed compressor-speed (FCS). Hence, we used the frequency settings

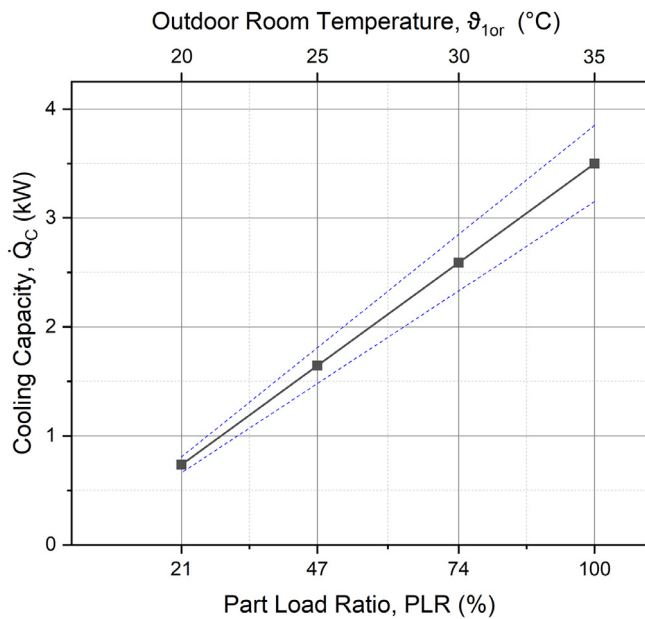


Fig. 2. Calculated cooling curve and permissible deviations for the compensation method.

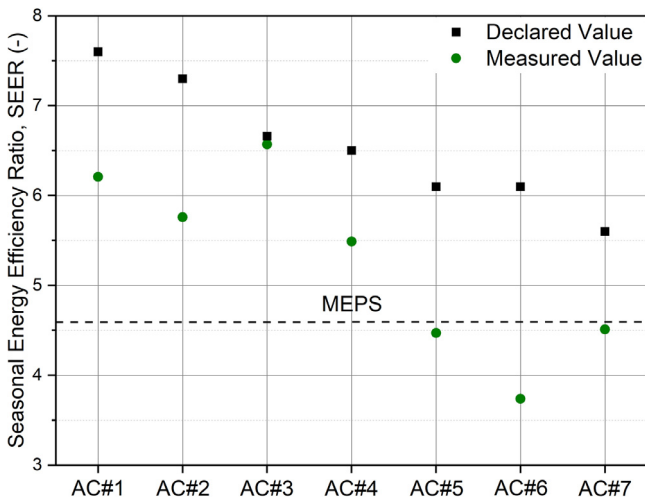


Fig. 3. SEER values of the tested ACs determined with the compensation method (circles) and according to the declaration on the Energy label (squares).

which were provided by the manufacturers to fix the frequency of the inverter. To compare the repeatability of both methods, the measurements were repeated at least three times.

#### 4. Results and discussion

We tested seven ACs according to the compensation method determining the EERs for each of the tested operating points. Based on these results, we calculated the SEER. Fig. 3 shows both the SEER results of the compensation method and the declared SEER according to the EU Energy label for the tested ACs. The results match the declared ones only for AC#3 SEER whereas for the majority of AC units the measured values are significantly lower. AC#5 AC#7 have even lower SEER values than the minimum permitted SEER value in the European Union, which is 4.6 since 2014 (European Commission, 2012).

Table 3 shows the classification of energy efficiency class in which the units are labelled. Most ACs had energy efficiency class A++ when tested with FCS. When tested according to the compen-

sation method, however, most ACs could not be assigned to A++ class and some could only be assigned to classes C or D.

A simple calculation on the example of the AC#6 illustrates the discrepancy between expected energy savings and reduction of CO<sub>2</sub> - emissions if the compensation method, which better represents real operation conditions, would be used for energy labelling instead of FCS - testing. The SEER of the AC#6 is declared to be 6.1, whereas we measured a value of 3.74. Eq. (3) shows the relation of the SEER, the reference annual cooling load  $Q_c$  and the annual power consumption  $Q_{ce}$ .

$$SEER = \frac{Q_c}{Q_{ce}} \quad (3)$$

Assuming a consistent reference annual cooling load  $Q_c$ , by such a decrease of the SEER for AC#6 the labelled annual power consumption would increase from 155 kWh/a to 252 kWh/a. It means an increase of costs of about 2/3 for the consumer (32 Euro to 52 Euro), based on the European average electricity price of 20.4 ct/kWh (Eurostat, 2018). The equivalent CO<sub>2</sub> - emissions per AC unit would increase from 42.76 kg/a to 69.53 kg/a, based on the average CO<sub>2</sub> - emissions per kWh electricity generation in Europe, which is 275.9 gCO<sub>2</sub>/kWh (European Energy Agency, 2016). This would be only the increase caused by one single split unit, out of more than 30 million currently installed split units in Europe (Pezzutto et al., 2017).

Fig. 4(a) can explain the aforementioned increase of the annual power consumption as it shows the EER values for the four operating points determined with the compensation method.

At full load condition A35/A27, the EER (100 %) values determined with the compensation method are identical to the EER (100 %) values from manufacturer declaration. For the part-load conditions, the gradient generally decreases and for some ACs even the EER decreases again at low outdoor room temperatures, especially for the operating point A20/A27. The differences in the EERs for the different ACs can be attributed to the product design (compressor efficiencies, heat exchanger dimensioning etc.).

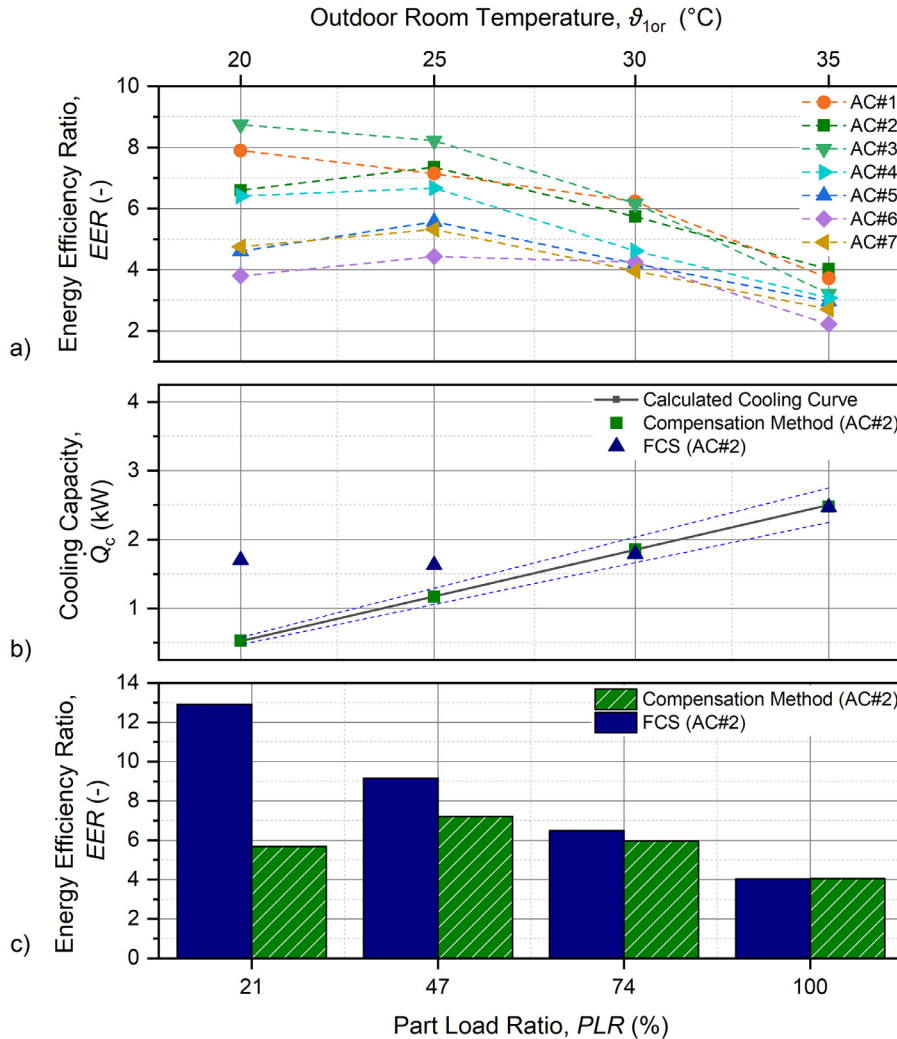
Fig. 4(b) gives a comparison of the cooling capacities of AC#2 for the four operating conditions, determined with the compensation method (unfixed compressor) and with the standard method EN 14825 (fixed compressor speed). The cooling capacities determined with the compensation method are close to the demanded cooling curve, whereas in the standard test a cooling excess can be observed at low PLRs. Most likely the compressor is fixed at the lowest possible speed. In consequence, the control of the AC is inactive and the cooling capacity cannot be further reduced. Fig. 4(c) shows the corresponding EERs for the compensation method and for the standard method EN 14825 (FCS). The EER determined with the EN 14825 increases continuously with decreasing PLR, whereas the EER determined with the compensation method also increases initially with decreasing PLR, but decreases again at PLRs of 21 %.

Basically, the decrease of EER can be explained with the control behavior of the ACs in the lower part-load range. The ACs should regulate their capacities continuously with the speed controlled drive of the inverter, but beyond a specific temperature  $\vartheta_{1or,spec}$  ( $25^\circ\text{C} < \vartheta_{1or,spec} < 30^\circ\text{C}$ ) the unit switches into ON/OFF operation, as depicted in Fig. 5.

The upper part of Fig. 5 shows cooling capacity and power consumption for the operating points A35/A27 and A30/A27. In these operating points the unit regulates its cooling capacity by using the speed controlled drive which results in constant power consumption. The bottom part of Fig. 5 shows cooling capacity and power consumption for the operating points A25/A27 and A20/A27. For these operating points ON/OFF operation was observed. For A25/A27, ON/OFF operation occurs with ON-cycles of about 800 s. This behavior still enables constant average values of the

**Table 3**  
Declared vs. determined energy efficiency class.

AC#	Rated cooling capacity (kW)	Declared energy efficiency class	Energy efficiency class according to the compensation method
1	2.5	A++	A++
2	3.5	A++	A+
3	2.6	A++	A++
4	3.7	A++	A
5	3.5	A++	C
6	2.7	A++	D
7	3.96	A+	C



**Fig. 4.** EER results and interpolated values of the ACs determined with the compensation method.

temperatures and the cooling capacity of the AC but leads to slight changes in the average values of power consumption. For A20/A27, the ON/OFF operation has ON-cycles of approximately 200 s. Furthermore, during tests with the compensation method, it was observed that humidifiers of all ACs are inactive for A25/A27 and A20/A27. Thus, humidity has no impact on the energy consumption and could be neglected for these operating points.

We also investigated whether the ON/OFF operation is caused by temperature fluctuation or by a specific temperature level at the evaporator inlet  $\vartheta_{1or}$ . By common sensors temperature fluctuations could not be detected, therefore we installed a sensor without radioprotection to measure a continuous temperature profile during testing at A25/A27 and A20/A27. It is found that the temperature

is constant, with fluctuations of  $\leq 0.1$  K. At a specific evaporator inlet temperature  $\vartheta_{1or,spec}$  the compressors of the tested ACs seem to have reached their minimum possible speed. This is most likely due to the fact that lubrication imposes a minimum speed of the compressor. Consequently, when the evaporator inlet temperature  $\vartheta_{1or}$  falls below this specific value the AC changes into ON/OFF operation. Thus, the ON/OFF operation appears to be part of the ACs capacity modulation and occurs during real use.

We conducted additional measurements for A25/A27 with over 12 h duration. The results show slight deviations in the average power consumption of a maximum of 6.2 % (236 W, 224 W and 232 W). Additional 12-h tests were also conducted for the operating point A20/A27. The results show that only small variation

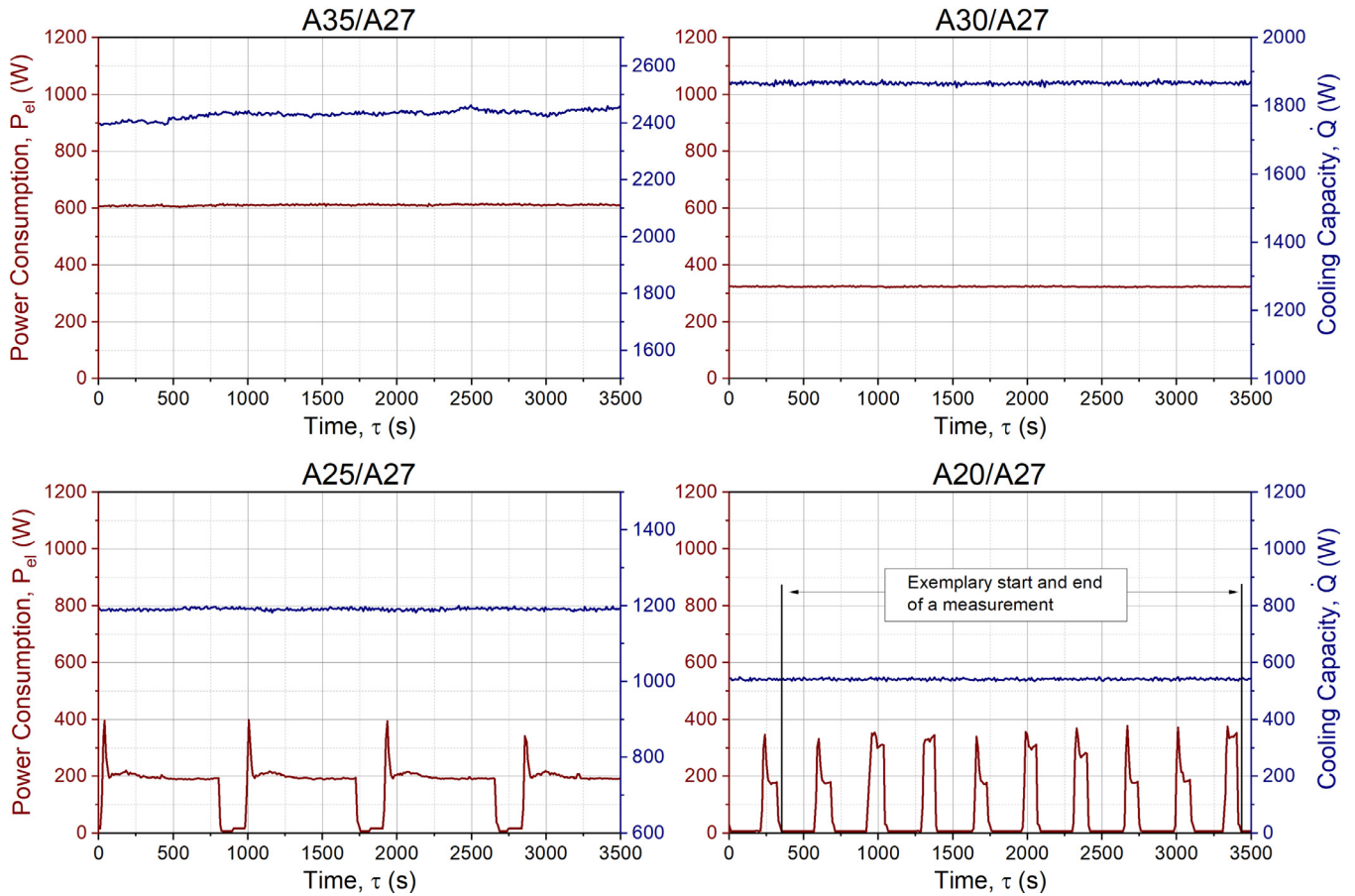


Fig. 5. Comparison of AC behavior in the observed operating points according to the compensation method.

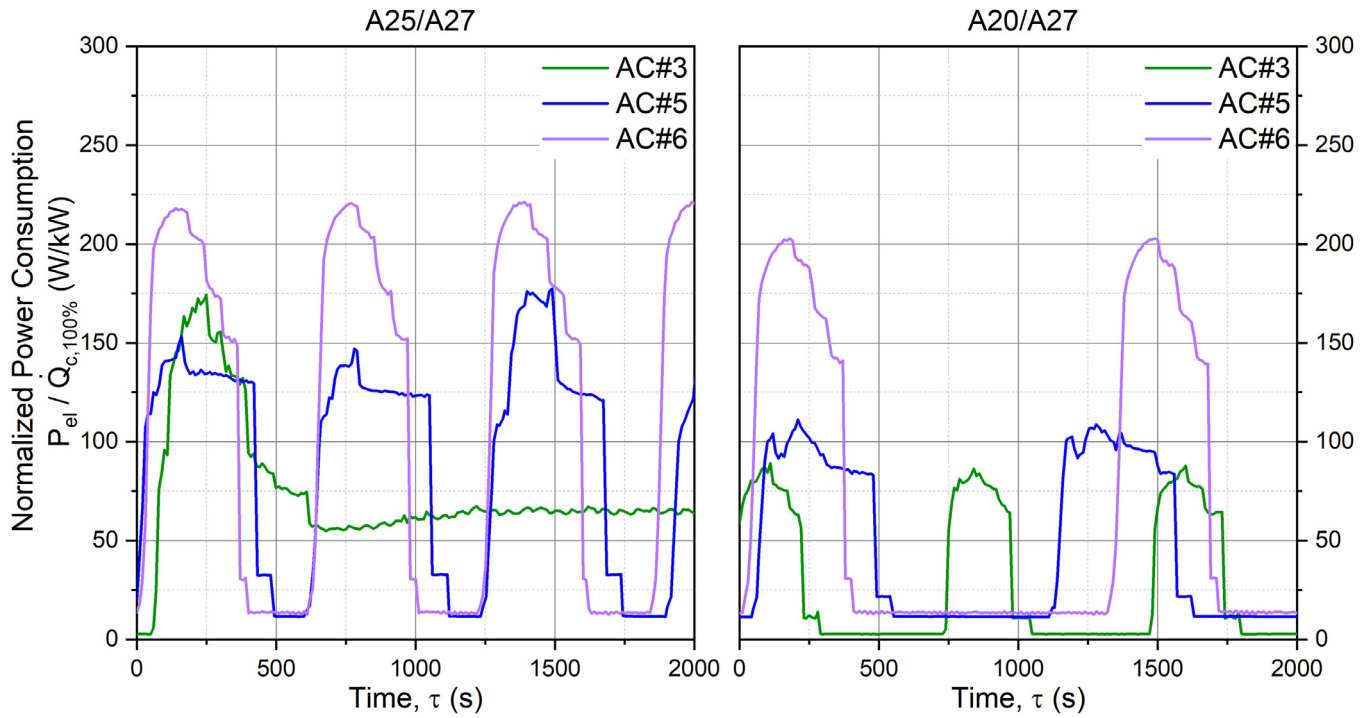


Fig. 6. Comparison of the part load behavior of high and low performance ACs.

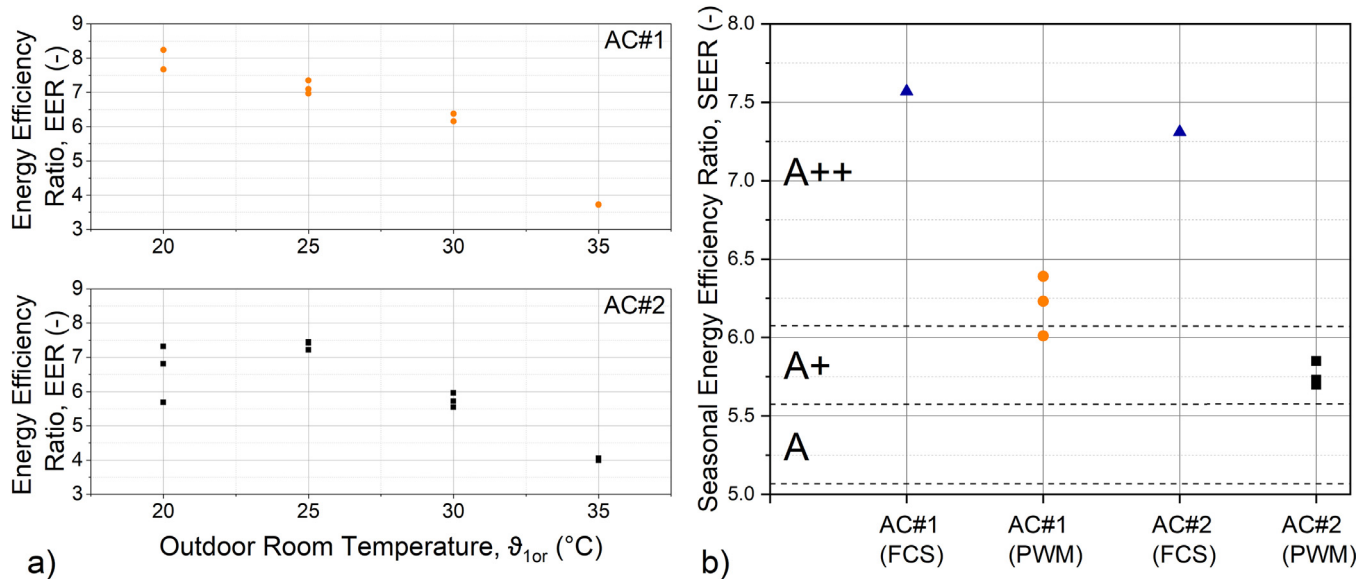


Fig. 7. EER and SEER results of AC#1 and AC#2 tested with repeated measurements according to the compensation method.

in the power consumption (5 W) can affect the EER significantly by changes of  $\pm 10\%$ . For this reason, to obtain repeatable results it is necessary to set the beginning and the end of the measurement intervals at a fixed position of the cycles, such as depicted on the bottom right of Fig. 5. In our tests, we mostly set the beginning and the end of the intervals at the end of an ON-cycle when the power consumption just reaches its lowest value.

Having a closer look on the causes of the EER gap between the tested ACs at part load conditions (Fig. 4(a)) we investigated the relative power consumption of selected ACs for the operating points A25/A27 and A20/A27. To enable a qualitative comparison we divided the measured power consumption  $P_{el}$  with the cooling capacity at full load  $\dot{Q}_{c,100\%}$  for each AC, respectively, and obtained the relative power consumption. Fig. 6 shows the relative power consumption of high performance ACs (AC#3) compared with low performance ACs (AC#5 and AC#6). Low performance ACs have peaks of relative power consumption that are significantly higher than the peaks of high performance ACs. Additionally, only the high performance ACs switch off almost completely, with only 2.75 W/kW of relative power consumption remaining, whereas poor performance ACs at all time have a continuous relative power consumption of at least 13 W/kW in our experiments. On the contrary and in our case, the number of cycles per time unit appears to have no significant influence. Ultimately, all of the mentioned aspects impact the integral of the relative power consumption, which results in the energy consumption, and has to be considered when characterizing the performance of ACs.

To determine the repeatability of the compensation method, two ACs were tested three times each using this method. In Fig. 7(a), the EER results measured at the four operating points with the compensation method are shown. At full load, the repeatability standard deviations are 0.75 % for AC#1 and 0.16 % for AC#2, respectively. With the decrease of the outdoor room temperature, the repeatability decreases, too. In comparison, round robin tests revealed a repeatability standard deviation of 0.92 % for the FCS - testing according to EN 14825.

However, in Fig. 7(b) it is shown that despite the ON/OFF-behavior at part-load a reasonable repeatability of the compensation method regarding the SEER results is given. For AC#1 and AC#2, all SEER values determined with the compensation method

are lower than the SEERs determined with FCS - testing. The repeatability standard deviation of the compensation method is slightly higher (AC#1: 3.07 %; AC#2: 1.38 %) than the repeatability standard deviation of FCS - testing (1.02 %).

## 5. Conclusion

This study shows the importance of a well-designed test procedure used for MEPS and labels. We revealed that, in case of inverter-type ACs, testings so far could not be conducted independently from manufacturers. Furthermore, most ACs could only be tested in particular test modes, which fix the compressor speed. Therefore, this study proposes a compensation method to determine the seasonal cooling performance of single split-type ACs, which is still compliant to the currently used test standards, but independent from manufacturers.

The proposed compensation method is applicable for both, ACs with and without inverter, and can be used for the same experimental setup and conditions as applied in current test standards. Hence, the AC is not fixed into a test mode but achieves the required test conditions by using its variable speed controller. It appears that below a critical outdoor room temperature range ( $25\text{ }^{\circ}\text{C} < \vartheta_{1or,spec} < 30\text{ }^{\circ}\text{C}$ ), the ACs start to switch to ON/OFF-mode. The compensation method delivers SEER results and moreover has the following advantages:

- It considers the real control behavior of ACs and thus gives a better approximation for the field performance of ACs.
- It can be conducted independently from manufacturer data and makes special test modes obsolete.
- It enables a fair comparison of the energy efficiency of different ACs on the market.
- It allows to identify AC units which do not reach the minimum permitted SEER value in the European Union and thus must be withdrawn from the market.

The growing market penetration of ACs indicates the need for a performance test method for ACs which better reflects their capacity modulation. This allows (i) market surveillance authorities to conduct verification tests independently and (ii) to consider real use behavior for MEPS. Using test procedures that do not accurately allow to distinguish between high efficient and less efficient



products could lead to energy saving deficits compared to what has been expected by policymakers.

Our research shows that the energy efficiency of most tested ACs currently differs from their labelling on the Energy label. Energy labels can be misleading, if test procedures deliver results which are not relevant to consumers and financial savings in practice are far from what consumers expected. The ascribed effects and implications could be comparable in other world-regions with similar regulations (MEPS, Energy label/star) due to similar national test methods being used for AC performance measurement and rating.

Since reversible AC units are a technology which becomes more and more widespread, the adaptation of this method to the heating case of ACs should be subject of further investigations. Due to their technical similarity heat pumps are tested according to the same test method in the EU and the findings presented in this paper on the example of inverter split ACs could also apply to heat pumps.

Furthermore, we showed the necessity for independency when it comes to test procedures as the technical foundation for MEPS and labels. We therefore suggest the consideration of a fifth criterion of a well-designed test procedure: independency. The installation process and the performance test measurements need to be conducted independently from any additional (product-specific) data or requirements on the technical configuration of manufacturers. Hence, the following criteria should be fulfilled by a well-designed test method: (i) repeatability, (ii) reproducibility, (iii) representativeness, (iv) affordability and (v) independency.

The compensation method meets all of the aforementioned requirements and should be considered for the revision of current standards.

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