Lower efficiency but a higher efficiency rating? A case study in air conditioner circumvention under the ISO 16358:2013 calculation method

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Abstract

Identifying and rewarding more efficient products is a key goal of energy efficiency labeling programs for air conditioners. Towards that end, many countries around the world, from Brazil to India to Thailand, have adopted energy efficiency standards and labeling policies based on variations of the ISO 16358:2013 calculation method, which is designed to estimate the energy performance of inverter air conditioners over the course of the year, in the form of the Cooling Seasonal Performance Factor (CSPF) metric. These policies have been crucial in creating a global market shift towards more efficient inverter air conditioners, reducing energy demand and CO_2 emissions in the process. However, there is a major loophole in the ISO 16358:2013 calculation method that has allowed some manufacturers to achieve a better CSPF with a less efficient product.

This paper examines a case identified by the Brazilian National Institute of Metrology, Quality, and Technology (Inmetro) where some manufacturers operating in Brazil achieved a higher CSPF by substantially reducing their product's efficiency during one of the tests used in the calculation of that metric. We explain how reducing efficiency during the testing process can exploit a loophole in the calculation method when using the option test point, as well as how policymakers can address this issue in a cost-effective manner in order to ensure that their energy efficiency policies are indeed promoting the most efficient products

Introduction

The motivation for this paper arises from the finding by the team responsible for maintaining Brazilian Labelling Program (PBE for its initials in Portuguese) at Inmetro that it is possible for an air conditioner to achieve a better performance rating than other models that consume less energy. This intriguing situation gave rise to an in-depth study of the mathematical calculations defined in ISO 16358:2013, as well as interactions with specialists in Brazil and abroad, which allowed for an understanding of the origin of the problem and uncovering solutions to mitigate it.

Thus, we will start with *Energy efficiency measurement procedures and the circumvention problem overview*, giving an overview of the circumvention problem applied to energy efficiency measurement procedures. Then, *Brief Description of the PBE for Air Conditioners* provides a brief description of PBE for air conditioners, highlighting only the most relevant elements for enabling an understanding of the analyses and propositions contained in this paper. Afterwards, in *Products that consume more can result in a better performance index*, the problem will be explained in detail, including its causes and potential consequences. In *Options to overcome the problem,* we will discuss options for overcoming the problem, including the risks and impacts associated with each option. Finally, in *Conclusion and Discussion,* we will draw some conclusions with an emphasis on the international impact of Brazilian findings on the question.

ENERGY EFFICIENCY MEASUREMENT PROCEDURES AND THE CIRCUMVENTION PROBLEM OVERVIEW

Since energy test procedures are the technical foundation for energy standards, energy labels and other related programs, it must satisfy several goals regarding the interest of several stakeholders, such as manufactures, regulatory authorities, and consumers. Besides allowing repeatable and accurate results, Meier and Hill (1997) highlight that an ideal procedure should reflect actual usage conditions, be inexpensive to perform, be comparable with other test procedures, cover a wide range of products and be easily modified to accommodate new technologies or features. The authors say it is not easy to achieve all these goals together, because sometimes it is contradictory: to be more realistic, an energy test procedure is often more costly. However, a good energy test procedure must satisfy enough of those goals "to discourage excessive complaints".

Although there was great evolution on the energy test procedures and standards during the past years, some solutions are still under systematic analysis. Regarding the case of air conditioners, Palkowski et al (2019) criticized the current test standards to determine the seasonal cooling performance of variable speed appliances. The test script requires fixing of the compressor speed to achieve steady-state conditions. For the authors, this condition differs from the consumer's use, delivering results that are not relevant to them. In addition, it is very dependent on the data of the manufacturer, which makes it more difficult for regulatory authorities to carry out market surveillance. They suggest a new test procedure to address all these issues and also suggested to include a new criterion for a good energy efficiency test procedure: independency.

For Mavuri (2014), the difficulty "to conduct 'part-load' performances for air conditioners when no 'locked' instructions are available" can be considered a circumvention device, since it is defined as any control that alters the operating characteristic during any test procedure, resulting in measurements that do not represent an appliance's behaviour during normal use. As we will see in this paper, the dependency on the manufacturer to fix the air condition operation for the partial load test can be considered as circumvention in itself, and also increases the risk of there being other ways to manipulate testing results. Mavuri (2014) also develop an "unlocked" test method as an alternative and more realistic field behaviour assessment.

In that sense, Meier and Hill (1997) also emphasize that a good energy test procedure must be designed in such a way that it is difficult to the manufacturer to use technical loopholes to circumvent the intention of the procedure. As early as 1997, the authors also indicated the impact of microprocessors on energy test procedures. These controls can lead to a non-realistic test result in several ways, including circumvention. While controls provide energy-savings opportunities, on the other hand, it allows manufacturers to reduce a device's energy consumption during testing – and it is less costly for the manufacturer than implementing real product improvements. Meier (2015) affirms that the increasingly sophisticated microprocessor controls of energy-using equipment is the root of circumvention. Among some examples, Meier (2015) narrated the case of a mini-split air conditioner with logic controls that could recognize when the machine was under test conditions, moving the product to a more energy efficiency operation.

Circumvention deviates the energy test procedure from its proposal and therefore may qualify products as efficient when they are not. It means that circumvention promotes losses of potential primary energy savings. The 2021 Anti-Circumvention of Standards for Better Market Surveillance (ANTICSS) impact assessment revealed acts of circumvention in washing machines, dishwashers, ovens, refrigerating appliances and televisions in Europe that could sum up to significant losses of potential primary energy savings, from 395 TJ (in the lowest option of the more realistic scenario) to 5,982 TJ (in the more theoretical extensive scenario), corresponding to 13,300 up to 201,800 tons of CO_2 equivalents. Circumvention also causes market distortions, and impacts negatively on the credibility of labels and standards (ANTICSS, 2021; ECOS, 2018).

Strong regulatory provisions should come first as a measure to deal with circumvention, as it must be design to discourage it. Regulations can ban the element of design that achieves circumvention and define how a product must behave or not behave under test (ECOS, 2018). On this paper, we will see how regulation in Brazil implemented some criteria that allowed to identify if an air conditioner is behaving property when testing to obtain the cooling seasonal performance factor under the ISO 16358:2013 calculation method.

BRIEF DESCRIPTION OF THE PBE FOR AIR CONDITIONERS

The PBE for air conditioners is in a transition phase since the publication of Inmetro Decree nº 234 of 2020. This revision made in 2020 increased the stringency of the product's classification for energy efficiency and also introduced a new metric for calculating the efficiency rating, the Cooling Season Performance Factor (CSPF). From the 1st of January 2023, suppliers must only manufacture or import products that already comply with the new National Energy Conservation Label (ENCE for its initials in Portuguese) based on the CSPF.

The implementation of the new ENCE, however, may occur even before the referred deadline. In this transition phase the new ENCE based on CSPF can coexist with the old ENCE that is based on Energy Efficiency Ratio (EER), which was used until now to classify products. As part of this transition phase, the following two changes have started to be implemented:

a) First, products with variable speed (inverter type) compressors are also tested at partial capacity, allowing suppliers to highlight the advantages of inverter technology in energy saving compared to fixed speed (on-off type) compressor models; and

b) Secondly, the calculation of the energy consumption of the product considers the number of hours of use of the device in each temperature that typically occurs in the country, along an annual cycle (hence, the seasonal character of the CSPF). Table 1 shows the temperature bins, established by Inmetro ordinance, which relates the air conditioner usage hours with the temperatures in the country. Notice that greater weight is given to temperatures between 21 ºC and 30 ºC.

The CSPF calculation follows the method defined by the ISO 16358-1:2013 technical standard (Air-cooled air conditioners and air-to-air heat pumps – Testing and calculating methods for seasonal performance factors – Part 1: Cooling seasonal performance factor) and, for inverter products, this calculation is made based on energy consumption measured in the laboratory, under the following conditions:

1. Test 1: measurement of the energy consumption of the product configured at full load (100 % capacity) at an external temperature 35 °C. It is a mandatory test for inverter products.
2. Test 2: measurement of the energy consumption of the product configured at part load (50 % capacity) at an ex-

Table 1. Brazilian bin hours to calculate CSPF.

Bin hours																			
N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total
°C	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	-
h	130	167	231	271	253	226	189	149	128	111	84	60	38	22	12	5	3	1	2080

ternal temperature 35 °C. It is a mandatory test for inverter products.

3. Test 3: measurement of the energy consumption of the product configured at part load (50 % capacity) at an external temperature of 29 °C. It is an optional test for the inverter products.

If the supplier performs only the mandatory tests, the CSPF is calculated from the measurements made during the tests at 35 °C, at full and partial loads. If the supplier also chooses to test the product at 29 °C, under partial load, the CSPF can be calculated based on this test result as well. In this way, whenever the product carries more advanced components, such as an electronic expansion device and DC motors, which enable lower energy consumption at lower temperatures, it is advantageous to perform the test at 29 °C, as this increases the CSPF compared to the CSPF calculated based on only 2 points. The implementation of optional testing is intended to stimulate Brazilian manufacturers to supply the national market with more technologically advanced and efficient products.

Before proceeding, it is worth explaining that the partial load test of inverter type products depends on a "special configuration" made by the manufacturer on the laboratory premises so that the product delivers only half of the nominal refrigeration capacity (e.g., if the nominal capacity is 12,000 Btu/h, then at partial load the product must deliver 6,000 Btu/h). Of course, when the device is installed in the consumer's home, it is not possible to forcibly set it to partial capacity. In our homes, the inverter products are equipped with control strategies in such a way that they are able to decrease the compressor rotation frequency as the thermal load decreases and not turn off the motor when they reach the target temperature, which substantially reduces the device's energy consumption when compared to fixed speed products. However, the "special configuration" made by the manufacturer in the laboratory facilities is necessary to measure the energy consumption while simulating the operation of the product when it is delivering half of its cooling capacity, this being the measurement of energy consumption in partial load, a value used in the equations of the ISO 16358-1:2013 technical standard for calculating the CSPF.

In addition to the ENCE thresholds in 2023, as explained above, the revision also brought stricter thresholds for air conditioner ratings in 2026. In 2023, a product must have a CSPF of at least 5.5 to belong to category A, with this CSPF value increasing to 7.0 on January 1, 2026. This generates the necessary predictability for the industry to allocate its investments in new production lines and new product designs. As these improvements are implemented, we hope to lower national energy consumption by increasing the availability of more energy-efficient models in the national market and encourage consumers to purchase these more energy-efficient products. In March 2020, the Kigali Network presented a study of the energy benefits resulting from this revision, estimating an energy savings of more than 56 GWh by 2035 and a reduction in peak hour energy demand equivalent to three times the Santa Cruz thermoelectric plant in Rio de Janeiro.

Finally, we emphasize the importance of improving the PBE for Air Conditioner for other public policies that also impact the air conditioner industry. We are referring to the Basic Productive Process (PPB, for its initials in Portuguese), an industrial policy coordinated by the Ministry of Economy that governs the tax benefit given to the manufacturers located in the Manaus Free Trade Zone, and to the minimum energy performance standard (MEPS) established by the Management Committee for Energy Efficiency Indicators (CGIEE, for its initials in Portuguese), chaired by the Ministry of Mines and Energy. In relation to the PPB, the Inmetro has led a task force to test air conditioners manufactured in the country using inverter compressors produced domestically by Tecumseh. The air conditioning industry requests greater flexibility in the PPB to allow them to purchase imported inverter compressors, having requested a technical analysis from the Ministry of Economy, based on tests, to assess whether the compressors supplied by Tecumseh are truly capable of delivering the efficiency of an A-class product under the revised policy. The test protocol was designed based on the definitions, parameters, and criteria established in the PBE for Air Conditioners. In early 2022, the CGIEE put out a new MEPS proposal for public consultation based on CSPF and following the methodology defined in the Inmetro Ordinance.

PRODUCTS THAT CONSUME MORE CAN RESULT IN A BETTER PERFORMANCE INDEX

Problem overview

As mentioned above, even before the new ENCE becomes mandatory on January 1, 2023, it is now possible to display the new CSPF-based label. To inform the consumer which products are already labelled based on the new standard and also to encourage competition between companies, Inmetro has adopted the practice of publishing an Energy Efficiency Table based on CSPF (http://www.inmetro.gov.br/consumidor/tabelas.asp). The Table available on the website in September 2021 lists 43 different models, which indicates that the industry has already started moving to meet the new ENCE. Hopefully, by the 31st of December 2022, an estimated total of 300 models will be labelled based on CSPF.

The published Table includes the test results at each of the test points that are used for calculating the CSPF. As products are added to the Table, it is natural to observe the values ob-

Table 2. Comparison of the products that highlights the problem.

A	B	C	D	E	F	G	H	I	J	K	L
Product	Test 1 (35_total) Capacity (W)	Test 1 (35_total) Consumption (kWh)	Test 2 (35_partial) Capacity (W)	Test 2 (35_partial) Consumption (kWh)	Test 3 (29_partial) Capacity (W)	Test 3 (29_partial) Consumption (kWh)	COP 35_total	COP 35_partial	COP 29_partial	CSPF	Annual consumption (kWh)
#1	3516	975	1758	355	1758	275	3,61	4,95	6,39	6,20	469
#2	3516	1140	1758	587	1758	310	3,08	2,99	5,67	7,60	382,0

tained by the new models to get a feel for the evolution of the market. When comparing two products from different suppliers and with identical refrigeration capacity, an intriguing situation emerged: a model that consumed more energy in all three tests was able to obtain a higher CSPF than the one with lower energy consumption in these same three tests. This fact was brought to Inmetro in August 2021 by two companies in the sector, who requested confidentiality regarding their names. Table 2 allows for a comparison of these products and highlights the report brought by the companies.

Note that the models in question have the same nominal capacity (12,000 Btu/h or 3,516 W) and were configured to the same total and partial cooling capacity at the three test points (columns B, D and F). Product #2 consumed more energy at all test points (columns C, E and G) and, even so, achieved a 23 % better CSPF (column K), resulting in a lower estimated annual energy consumption (column L) than product #1. One could ask whether this phenomenon, however contradictory it may seem, could not reveal an acceptable situation. However, two observations make it more clear that the case is problematic:

1. In product #2, the EER (obtained as the ratio between the cooling capacity and consumption) of Test 2 (column I) was lower than the EER from Test 1 (column H). However, if an inverter product is designed to save energy at part load, it is to be assumed that a good design will result in an improved EER when the product is required to deliver less refrigeration (i.e., the EER of Test 2 needs to be higher than the EER of Test 1). We could even admit that product #2 was poorly designed, but if that were true, it would not have had a high EER in Test 3 (column J).
2. In Test 1, the increase in energy consumption of product #2 compared to product #1 occurred at the rate of 17 %; in Test 2, in 65 %; in Test 3, by 13 %. This is peculiar because, normally, one product tends to perform better or worse compared to another in a similar proportion across all the test points. The fact that this increase in energy consumption occurs more markedly in Test 2 draws attention to an unnatural situation.

It is also important to emphasize that the distortion of the CSPF between the models occurs when it is calculated based on the three test points (column K). If the CSPF of the products in Table 1 were calculated based only on mandatory tests 1 and 2, the situation would be the opposite. While product #1 would have an CSPF of 5.41, product #2 would achieve an CSPF of only 3.48, implying that the "problem" only occurs when the CSPF uses the third test point (at 29 °C, at part load). In light of these facts, we carried out an in-depth study of the CSPF calculation method defined by the ISO 16358-1:2013 technical standard, as well as the test reports of the products that, in addition to the product #2, listed in Table 2, also displayed this issue. With this, it was possible to understand the origin and causes of this situation, as explained below.

Origin and causes

The first step in understanding the source of the problem is to understand how the test results are used in the ISO method for calculating the CSPF. Let's start our analysis for the case of the CSPF being calculated based on Tests 1 and 2 (mandatory). Figure 1, prepared for product #1, shows that the energy consumptions measured at 35 °C at full load (Test 1) and at 35 °C at partial load (Test 2) are points through which the Power Consumed at Full Load (Pfull) and the Power Consumed at Partial Load (Phalf) curve pass both in function of the temperature bins (from 21 °C to 38 °C). In essence, the ISO method estimates the slope of these lines from the values measured in the tests. The energy consumed by the device over the course of the year is calculated by multiplying power consumption by the number of bin hours for the corresponding temperature (after all, energy is equal to the product of power and time). Remember that product #1 has a CSPF of 5.41, when calculated on the basis of mandatory test results only.

The grey columns at the bottom of Figure 1 represent the number of hours linked to each external temperature bin (according to Table 1), giving a notion of the "weight" given to the power consumption for the calculation of energy consumption as a function of the temperature bins. That is, the power consumption values at temperatures up to 29 °C are the most impactful on the CSPF. And when is it favourable to use the third test point at 29 °C at partial load? Figure 2, also referring to product #1, demonstrates the situation in which Test 3 becomes interesting to be performed by the product supplier for CSPF calculation purposes. Note that the difference between the power consumption of Test 2 (35 °C, part load) and the consumption of the energy obtained in Test 3 (29 °C, partial load) determines the slope of the straight line instead of the slope pre-established by the standard. Therefore, whenever the energy consumption measured in Test 3 is lower than that determined by the curve pre-established by ISO, the curve Phalf comes to represent lower values of power consumed for temperatures below 35 °C (which have greater weight in the calculation of energy!) and, with that, it becomes worthwhile to use the optional test point for the CSPF calculation.

With the use of the optional test point, the CSPF, which was 5.41, was increased to 6.2, representing a gain of 15 % over the CSPF calculated with just 2 test points. Let's notice that to achieve lower levels of energy consumption at lower tem-

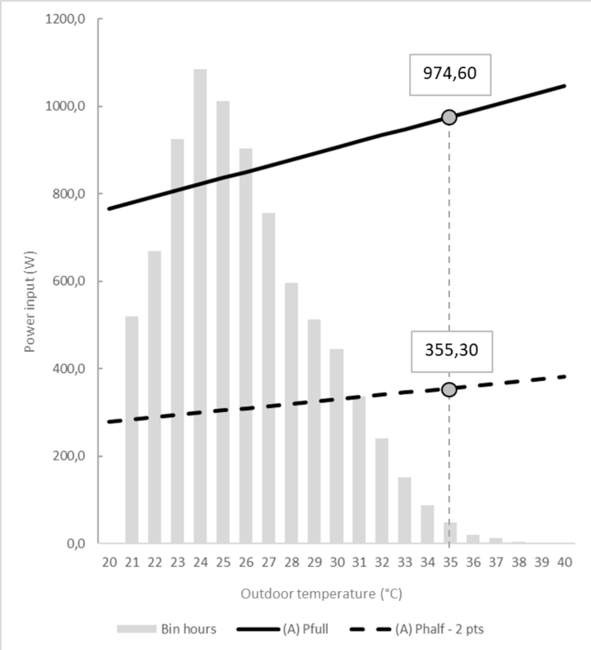

Figure 1. Pfull and Phalf curves (product #1).

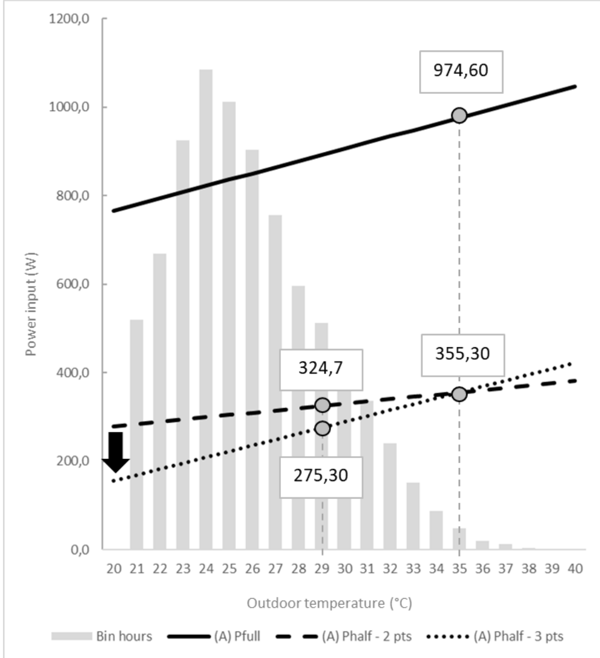

Figure 2. Test 3 effect on Phalf curve (product #1).

peratures, a more technologically advanced product is needed. Therefore, this increase in CSPF caused by Test 3 is welcomed and serves to stimulate suppliers to adopt more advanced technologies in inverter products so that they consume even less energy, especially at the temperatures with the greatest impact on annual consumption.

Before proceeding with the analysis, we need to mention that an important step for calculating the CSPF by the ISO method is the definition of the EER for each external temperature, based on the Phalf and Pfull curves, as shown in Figure 3, also prepared for the product #1. Note that Figure 3 is divided into 3 parts, as follows:

1. The first part occurs for the temperature range in which the cooling load demanded by the environment is less than the partial cooling capacity of the product. It is assumed that the device works between off state and partial load. Calculating the EER at a given temperature is based on dividing the estimated cooling capacity by the consumed power, using the Phalf curve to calculate the energy consumption with a penalty due to the fact that the air conditioner losses efficiency compared to Phalf curve, when switching ON and OFF to meet the cooling demand.
2. The second part occurs for the temperature range in which the cooling load demanded by the environment is between the partial and full cooling capacities of the product. It is assumed that the device works between partial load and full load. Therefore, both Phalf and Pfull curves are used to calculate the EER at a given temperature being calculated based on the assumption that the EER lineally decreases as the external temperatures and thermal load (cooling demand) increases.
3. Finally, we have the third part of the graph, which occurs for the temperature range in which the cooling load demanded by the environment is greater than the total cooling capacity. It is assumed that the device works at full load. The calculation of the EER at a given temperature is calculated by dividing the estimated cooling capacity by the consumed power, based on the Pfull curve.

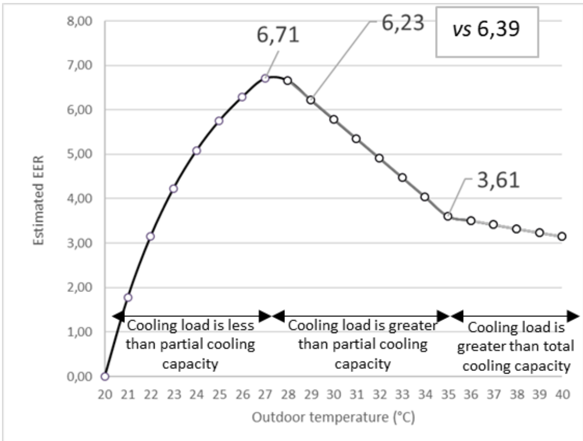

Figure 3. EER calculation as an intermediary step to calculate energy consumption (product #1).

Note that for product #1, while ISO estimated an EER at 29 °C equal to 6.23, this ratio was 6.39 in the laboratory. Notice that ISO standard calculates EER at 29 °C assuming an ambient thermal load of 60 % compared to the device's full load (i.e., the appliance is migrating from minimum load operation capacity towards the full load one), while the measurement of EER in the laboratory refers to a product delivering exactly 50 % of its cooling capacity. Thus, it is expected that the EER at 29 °C measured in the laboratory be greater than the one estimated by ISO, indicating a better efficiency when the cooling load is less demanding – which is a normal behaviour for the inverter air conditioner.

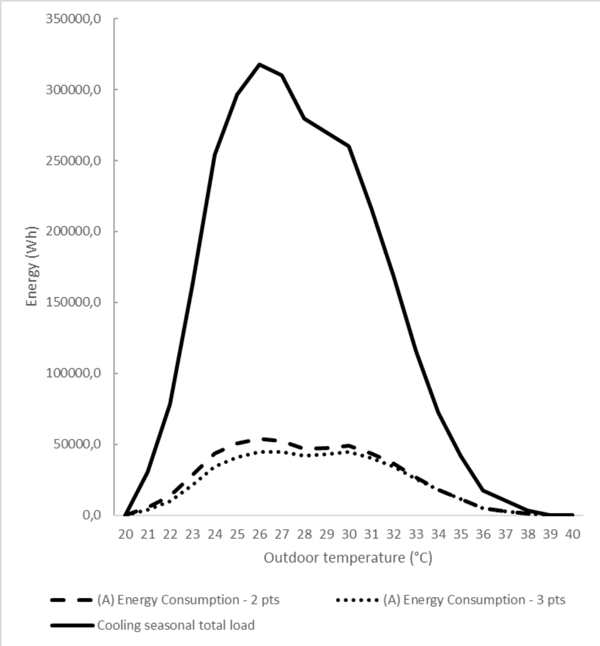

Figure 4. Seasonal Cooling Load by this Seasonal Energy Consumption (product #1).

The EER calculation step is essential for measuring the CSPF, because it allows for a single reference for power consumed for the temperature range in which the product's operation migrates from partial load to full load (2nd part of graph). Based on this estimated EER, it is possible to calculate the energy consumption of the appliance at each external temperature. The sum of consumptions in all temperatures results in Seasonal Energy Consumption. CSPF consists of dividing the Seasonal Cooling Load by this Seasonal Energy Consumption. Looking at Figure 4, it is as if we divided the area below the orange curve (Seasonal Cooling Load) by the purple curve, for 3 test points, or green, for 2 test points (Seasonal Energy Consumption). Note that the difference in area between the green and purple curves is just 15 % – a 15 % difference between the CSPF calculated based on 2 test points and the CSPF calculated based on the optional test point.

But could there be other ways to increase the slope of the Phalf line and, with this, improve the CSPF calculated in three test points? We verified that it is indeed possible, as happened with product #2. In this case, the increase in the difference between the power consumed at 35 °C under partial load and the power consumed at 29 °C at partial load is due not to the decrease in consumption at 29 °C, but to a disproportionate increase in consumption at 35 °C. The dotted lines in Figure 5 show the curves calculated for product #2 according to the ISO method, and the phenomenon that we'll call the "leverage" of the CSPF calculated using the results of the three test points. Continuous lines belong to product #1 results as in Figure 2.

In "leverage", it is possible to obtain lower power consumptions at part load, especially in the temperature ranges with greatest weight in the CSPF calculation. The case of product #2 is so emblematic that energy consumption even gives negative results at temperatures below 23 °C, as if the device were generating energy at the lowest temperatures! This "leverage" represents an artificial situation for an inverter, as the EER at 35 °C at partial load (2.99) is even worse than at full load (3.08), when the opposite should happen.

The EER calculation, as an intermediate step for calculating the Seasonal Energy Consumption, also presents anomalies. As it can be seen in Figure 6, the EER results in negative values (at temperatures where consumption resulted in negative values), bordering on infinity at a temperature of 23 °C.

Unlike what happens in product #1, the EER at 29 °C estimated by ISO (6.46) is better than that measured in the laboratory (5.67), which is inconsistent with the product's expected behaviour. After all, it is expected that EERs of the temperature range in which the product works between the minimum and partial load are better than the EERs of the temperature range in which the product is working from partial load to full load. Understanding this anomalous behaviour is the foundation for formulating the "lock" that potentially prevents "leverage" from occurring, as will be explained in item III.2 *Origin and causes* of this paper.

Finally, it is worth noting the effects of "leverage" in measuring Seasonal Energy Consumption, recorded in Figure 7. Note that the purple curve (related to the Phalf of three test points) even crosses to negative values at temperatures below 23 º C. The difference in the area of the green curve and the purple curve for product #2 is also much greater than for product #1. If the CSPF of product #2 were calculated on the basis of two test points, it would yield 3.48, against a CSPF of 7.6 for three test points (a difference of +118 %!).

Consequences

Making energy performance worse at 35 °C at part load is simple, fast, and cheap and it does nothing to increase the energy efficiency of the appliances, which is the fundamental objective of the PBE. In fact, the analysis of the test reports of the products contained in the Energy Efficiency Table that potentially benefited from the "leverage" revealed that a simple testing strategy was responsible for the artificial increase in consumption of the product's energy in Test 2. Note that this Test 2 is performed at partial load, with two possible ways for the supplier of the product to configure the device to deliver half of its cooling capacity, whether they are:

1. The supplier that wants the maximum reduction in the energy consumption of their product in Test 2 (which is to be expected) will configure the appliance so that the compressor runs at the lowest possible frequency to deliver 50 % of the refrigeration capacity. With that, the product consumes as little power as possible for that test point.
2. The supplier who wants to carry out the "leverage" is not interested in reducing the compressor rotation as much as possible, but rather wants the energy consumption to be as high as possible at this point. For this, the supplier will reduce the air flow (m3/h) to decrease the refrigeration capacity and only make a small adjustment in the rotation frequency of the compressor, without necessarily halving it. This is a trick that makes the appliance deliver only 50 % of its total cooling capacity with higher energy consumption (because the compressor will run on a frequency greater than really required), enabling the "leverage" that inflates the CSPF.

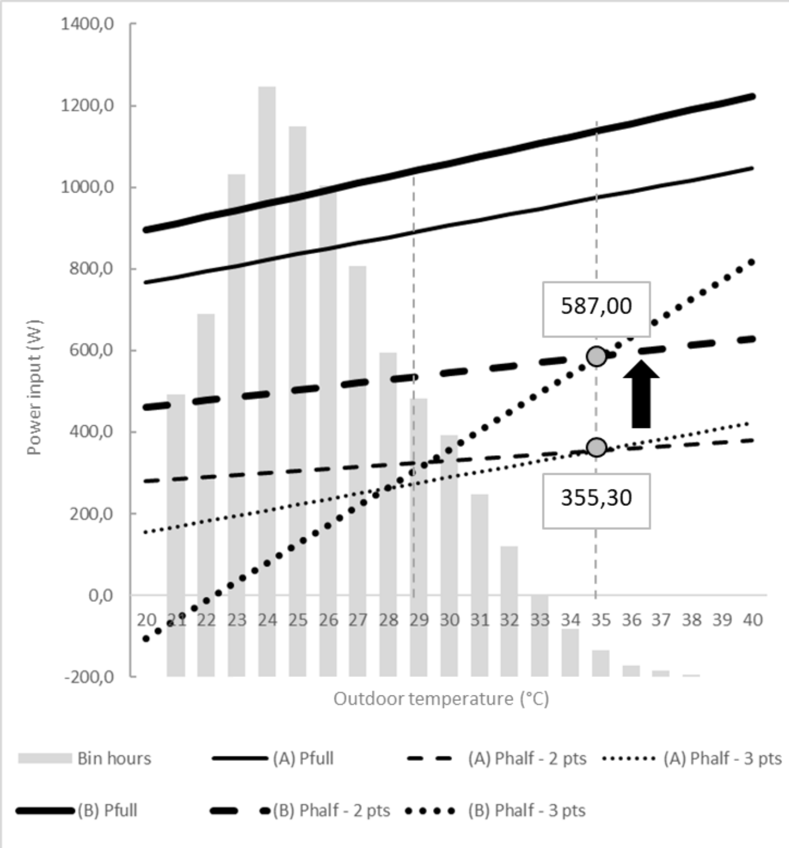

Figure 5. Pfull e Phalf curves (product #2 versus product #1).

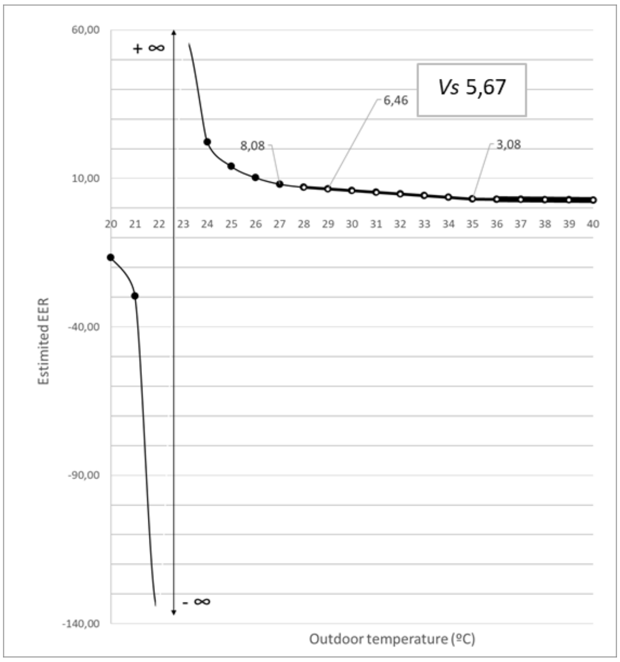

Figure 6. EER calculation as an intermediate step to calculate energy consumption (product #2).

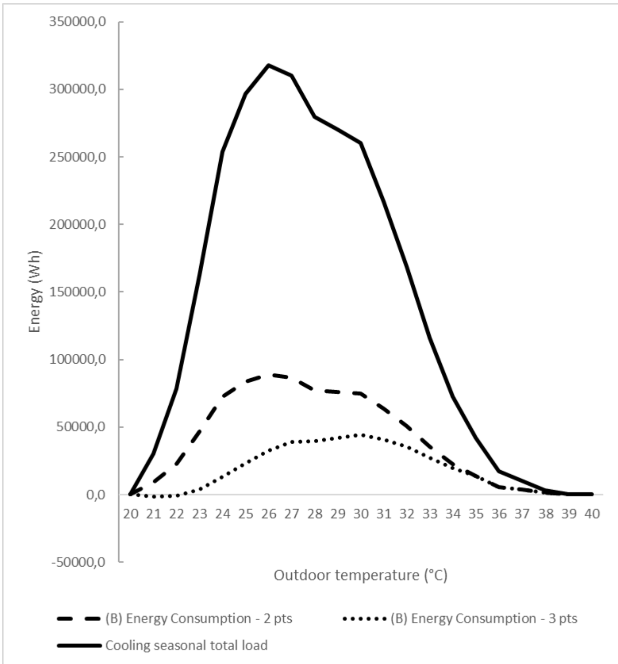

Figure 7. Seasonal Cooling Load by Seasonal Energy Consumption (product #2).

Table 3. Regulatory problem.

Cause	Problem	Consequences
Artificial increase of consumption power in Test 2	Products that consume more energy result in a better CSPF when the calculation is based on three test points	1) Suppliers will be discouraged from implement product solutions for real reduction in energy consumption. 2) Consumer will buy a product supposing it is more efficient when it is not.

Where we have examined test reports to verify the testing strategy, the flow reduction was performed only in Test 2, reducing the flow to half or even one-third of the maximum flow configured in Tests 1 and 3. Definitely, this or any other "leverage" cannot be allowed to be used to increase the CSPF. This strategy harms fair competition, to the detriment of suppliers who have implemented or want to implement technology in their products to make them truly more efficient. It also harms the consumer, who will buy a product thinking it is more efficient, when it is not. Table 3 summarizes the findings regarding the definition of the regulatory problem.

The PBE for Air Conditioners, therefore, needed to eliminate the root cause of this problem. Thus, the PBE team determined to make it impossible to use the strategy of artificially increasing energy consumption in Test 2 in order to unfairly increase the CSPF calculated on the basis of the three test points. Based on technical studies and research, alternatives were formulated and evaluated to achieve this objective, as explained in the following Section.

OPTIONS TO OVERCOME THE PROBLEM

CSPF only based on the two mandatory test points

As explained above, it is only "advantageous" to inflate the energy consumption in Test 2 when the CSPF is calculated based on at the three test points. If only the results of Tests 1 and 2 are used, the artificial increase in energy consumption in Test 2 becomes detrimental to the CSPF. Therefore, a solution to the problem presented would be to consider only the mandatory tests as a reference for calculating the index. The advantage of this alternative is, essentially, to solve the problem without incurring additional costs to the suppliers.

Without denying that this alternative would eliminate "leverage", it is necessary to point out some negative impacts and risks associated with it, namely:

a We would lose the opportunity to use labelling to stimulate the adoption of more sophisticated technologies in Brazilian products so that they are more efficient in the lower temperature ranges that are weighted more heavily in the CSPF calculation, with that greater weight being the result of those temperatures being more frequently observed in Brazil. With that, there is a risk of slowing down or even pausing the technological evolution of Brazilian products that would bring energy savings for the consumer and for the country.

b To achieve the 2023 and 2026 goals, negotiated with the productive sector during the revision process conducted between the years 2019 and 2020, suppliers had the possibility of improving their products' CSPF based on better product performance in the lower temperature ranges with greater weight in temperature bin distribution. Eliminating the possibility of using the Test 3 for calculating the CSPF could cause industry to demand that these goals to be reassessed, which would bring legal uncertainty and would destabilize the foundation for the definition of MEPS by the CGIEE.

Implementation of "lock" to prevent CSPF "leverage"

Another possible alternative is to implement an additional criterion that must be met in order to use the optional third test point for the CSPF calculation. We refer to the comparison between the EER at 29 °C at partial load measured in the laboratory and the EER at 29 °C estimated by ISO for calculating the Seasonal Energy Consumption. For the additional criterion, the EER at 29 °C at partial load measured in the laboratory must always be greater than the EER at 29 °C estimated by ISO.

The "lock" based on the EER at 29 °C mitigates the possibility of a malicious supplier artificially increasing the energy consumption in Test 2 to inflate the CSPF. The EER at 29 °C estimated by ISO for the CSPF calculation would be higher than the EER declared at Test 3 (29 ºC part load) and this should not be possible. The cooling demand at the bin temperature of 29 ºC is 60 % of full load capacity whereas the cooling capacity of the Test 3 at 29 ºC part load is exactly 50 %. We always expect to have a higher EER if we reduce the cooling demand for a fixed outdoor temperature. The opposite cannot happen naturally.

For example, in product #1, the EER at 29 °C at part load measured in the laboratory (6.39) is higher than the EER at 29 °C estimated by ISO (6.23) and therefore product #1 would go through the "lock". For product #2, the EER at 29 °C at partial load measured in the laboratory (5.67) is lower than the EER at 29 °C estimated by ISO (6.46) and therefore product #2 would not pass the "lock".

In addition to not causing a cost increase with new tests for suppliers, the use of the "lock" preserves the stimulus given by the ENCE for the adoption of more advanced technologies in Brazilian products so that they can be more efficient in the lower temperature ranges (which have greater weight in the distribution of hours of use at external temperatures). Another advantage is that it maintains the foundation negotiated with the productive sector and still allows for the use of the current references for the MEPS being prepared by the CGIEE.

As the main impact, we identified the need for products that do not comply with the "lock" to be re-declared (24 models of 43 currently listed in the table), which may lead to the need for new tests and some rework. The industry is not opposing to this rework because the impact would be worse if the problem were left unaddressed until a date closer to January 1, 2023 (when hundreds of products should already appear in the new Table, and not just 43).

Additional test

This alternative consists of implementing the Test at 29 °C at minimum load so that the energy consumption under these conditions be considered by the ISO method to measure the curve of Power Consumed at Minimum Load (Pmin). This curve would determine the estimated EER for the temperature range associated with the operation of the device at minimum load, eliminating the influence of the "leverage" Phalf from the CSPF calculation.

On one hand, it offers an additional test point based on laboratory measurement for CSPF determination purposes, making the CSPF calculation more accurate; on the other hand, there are major technical challenges for measuring energy consumption at minimum load, both for the manufacturers and the laboratories, as noted by laboratories and the industry during the technical discussions that took place between 2019 and 2020 for the improvement of the PBE. Because of these difficulties, with high probability, results in minimal load can have a significant error, affecting the credibility of the measures and making them irreproducible. In addition, the implementation of a test point implies an increase in the supplier's expenses and time for carrying out tests.

Establishment of a limit to the difference between CSPF calculated based only on the mandatory test points (both at 35 °C), and the one that considers the voluntary test point (at 29 °C)

This alternative was suggested by the Brazilian industry as a way to simplify the implementation of the alternative described at III.2 in *Origin and causes*. The idea is to designate 40 % as the maximum difference between CSPF measured based only on the mandatory test points (both at 35 °C), and the one that considers the voluntary test point (at 29 °C). The 40 % was chosen based on the performance of the air conditioners in the Brazilian market already labeled with CSPF (they are all listed on the Inmetro's Energy Efficiency Table). Although it seems to avoid the main cases of CSPF "leverage", it does not cover small leverages. Besides that, it can also punish "good" products that have a greater than 40 % difference between the CSPFs, which can limit innovation.

Do nothing

Finally, the remaining alternative would be to do nothing. With it, the problem continues along with all of its harmful consequences. That is, with high probability and severity, by keeping everything as it is, suppliers will be discouraged from implementing product improvements for real consumption reduction, since an artificial strategy would be enough to increase the CSPF. In addition, the consumer will be harmed and will guide their buying on the basis of false information, purchasing a product thinking it is more efficient than another, when this will not always be the case.

Comparison between alternatives and Inmetro's decision making rationale

After weighing the alternatives, Inmetro understood that the best cost-benefit is attached to alternative 2, with the establishment in Inmetro's labelling regulation of additional criterion to allow the use of the third test point in the calculation of the CSPF. We refer to the comparison between the EER at 29 °C at partial load measured in the laboratory and the EER at 29 °C estimated by ISO for calculating the Seasonal Energy Consumption. Under this additional criterion, the EER at 29 °C at part load measured in the laboratory must always be greater than the EER at 29 °C estimated by ISO.

When Inmetro presented to the manufacturers the additional criterion based on the EER at 29 °C, however, they highlighted the very technical aspect of the rule, which would make its implementation difficult to them. As an alternative to this criterion, the Brazilian industry claimed that a product should be considered compliant also when meeting the limit to the difference between CSPF calculated based only on the mandatory test points (both at 35 °C), and the one that considers the voluntary test point (at 29 °C) (alternative 4). We know that this limitation based on CSPF difference could restrict innovative products with very high efficiency at partial load operation that achieves a difference greater than 40%. But since this criterion would be used as an alternative to the EER criteria, this risk no longer exists. Also, a product conforming to this 40 % of difference could still have some circumvention. However, it is a very limited and known one, and since there are benefits of adopting this forth alternative from the industry point of view, Inmetro's regulation also introduced it as a criterion to authorize the product in the Brazilian market.

CONCLUSION AND DISCUSSION

The identification of the problem seems to be unprecedented in the world. Our team was unaware of this circumvention tactic being implemented anywhere in the world. With the problem now addressed in Brazil, we feel it is important for other policymakers around the world to be aware of this potential circumvention tactic and to carefully avoid allowing it. Towards this end, this issue has been duly reported to ISO. In order for product policies to continue advancing energy efficiency, they must address this issue where applicable.

Finally, we emphasize that it was only possible to identify the problem occurring among Brazilian products because Inmetro published on its website, the Energy Efficiency Table, with test results at all test points. We are not aware of a similar table being published, with this level of detail, by any other country, which may be why the international community has not identified such an occurrence in another place in the world so far (which doesn't mean it isn't happening or can't happen). This case demonstrates the advantage of transparency, because with it, we expand the possibility of social control and the participation of different actors in the monitoring of the Program and identification of opportunities for improvement.

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