

Metrological evaluation of efficiency and consumption of domestic gas cooking appliances

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Abstract. This study evaluates the results of efficiency and consumption tests on gas household appliances and their influence on the classification of the Brazilian Labeling Program. Historically, based on results in interlaboratory comparisons, there is a doubt concerning if the algorithms correct properly the differences among different altitudes. Data from efficiency and consumption tests were collected in two cities with different altitudes, and the proposed calculation methodology is compared with the traditional one. The results show that the arithmetic average, used in the calculation of the efficiency of the burners on the stove table, justifies being replaced by the weighted average, after evaluating the behaviour of the data and treating outliers. The uncertainty of the efficiency and consumption tests was not enough to change the classification range of the product's energy efficiency label. It is concluded that statistically a difference is observed between the results at sea level and at altitude above sea level; since the tests were applied by the same operator using the same apparatus, the only parameter that leaves a doubt is the algorithms for the correction of the altitude. Shortly, this study will be part of a revised Brazilian standard.

Keywords: Altitude / Brazilian standard / consumption / measurement uncertainty / thermal efficiency / stoves

1 Introduction

Brazil, following the example of developed countries, has been making a great effort in the implementation of product certification and labeling programs, mainly for those that have popular use and that bring some risk to the user. Currently, there are numerous products with compulsory certification, forcing manufacturers and importers of stoves to adopt measures to comply with the maximum levels of energy consumption and minimum energy efficiency (or energy performance). This ensures greater quality assurance for countless products, greater safety, excludes manufacturers that do not meet minimum quality and safety conditions, promotes greater competitiveness, and still opens space for exports, in addition to creating barriers for imported products without quality [1].

Gas stoves must comply with the Brazilian Policy for Conservation and Rational Use of Energy [2], in which

manufacturers must comply with increasingly rigid efficiency indexes, regulated by Brazilian Metrology Institute [3] and measured by means of tests following European technical standard [4].

Products linked to the use of fuels such as alcohol containers for domestic use, canisters of liquefied petroleum gas (LPG) and cylinders of natural gas (CNG), due to their high degree of risk of accidents, were prioritized in the certification programs. Meanwhile, domestic gas cooking appliances are labeled under the Brazilian Labeling Program, PBE.

PBE is an energy conservation program that, by means of informative labels, aims to guide the consumer regarding the energy efficiency of some products sold in the country. Its objective is to stimulate the rationalization of energy consumption by using products that are more efficient. Labeling allows the consumer to evaluate the various products in terms of their energy efficiency and select the ones that bring the greatest savings during use.

The labeling program for domestic gas cooking appliances, using more efficient stoves and ovens, aims

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to encourage the rationalization of gas consumption in general, especially LPG. Therefore, this program is in line with the goals of the Brazilian Energy Plan (PNE2030) [5] and the Brazilian Energy Efficiency Plan (PNEf) [6].

The labeling of domestic gas cooking appliances was instituted by an Brazilian Interministerial Decree [7], signed by the Brazilian Ministry of Industry, Foreign Trade and Services (MDIC), Brazilian Ministry of Mines and Energy (MME) and Brazilian Ministry of Science and Technology.

The labeling of gas stoves and ovens is mandatory and the Brazilian Energy Conservation Label – ENCE provides information on the Power, efficiency, consumption and internal volume of the oven. The standardization of this information allows a better evaluation and power of choice for the consumer, providing a natural process of incentive to manufacturers for technological improvement resulting in increased efficiency, operational safety and reduced cost of sale. Labeling is an important mechanism for industrial competitiveness and can also contribute to the success of other objectives aimed at economic and social development.

To receive ENCE, gas stoves and ovens need to be approved in all the defined and standardized criteria pertinent to the Conformity Assessment Regulation – RAC.

When the PBE of gas stoves and ovens started in Brazil 20 years ago, there were only two laboratories accredited by ISO / IEC 17025. Since, the results of the tests carried out by the laboratories did not converge statistically, the Technical Group for the study of the RAC met and decided that the problem was due to the corrections of the altitude parameter and that the mathematical models applied to the European standard [4] did not make the correct correction of atmospheric pressure. This working group decided to replace the existing algorithm in the standard, with the formula for the correction of the nominal Power contained in the European standard [8] without, however, an in-depth technical-scientific study. The standard has not been revised and the doubt persists nowadays, whether this correction is really adequate, because even after appropriate corrections, the results of interlaboratory plans do not converge if carried out at sea level or at other altitudes.

Therefore, aim of this study is to metrologically evaluate the results of the performance and consumption tests on domestic gas cooking appliances and their influence on the PBE classification, based on the statistical treatments of the data obtained in these tests.

2 Methodology

The stove is a relatively simple device for combustion. Its burner is a type of pre-mix and multi-hole door, and operates at low pressure (2.75 kPa), Surange et al. [9].

A gas burner is a device for generating a flame to heat products using fuels such as natural gas or liquefied petroleum gas. Some burners have an air inlet to mix the combustible gas with the air to make a complete combustion, Surange et al. [9]. At higher altitudes in

relation to sea level, the air has less oxygen per unit volume; therefore, the gas-burning rate must be adjusted to maintain adequate combustion of the fuel. This can be done by decreasing the size of the fuel injector orifice in the burner to reduce the equivalence rate. Wieser et al. [10] carried out a series of comparative experiments at different altitudes; that is, from 400 m to 3000 m and observed that with the increase in altitude, the burning rate is reduced because of the decrease in atmospheric pressure.

The heating capacity of the stove is also affected by the change in the air density, because due to the lower density, the air has less heat transport capacity, because the hot air has a lower density than the cold air, that by convection phenomenon, the hot air goes up and the cooler air goes down. Amell [11] studied the effect of energy in domestic atmospheric burners for LPG or natural gas (NG) in Colombian locations such as Santa de Antioquia (555 m), Medellín (1550 m) and Alto Bogotá (2600 m). The result of this study stated that the performance of an atmospheric burner decreases 1.5% by 304 m of altitude increase. An experimental analysis of thermal efficiency, power and emissions of liquefied petroleum gas in stoves at altitudes between 2200 and 4200 meters in Peru are presented [12]. The studies concluded that power, efficiency and combustion vary according to the altitude above sea level.

More recently, Zhou et al. [13] investigated the influence of altitude on power, thermal efficiency and emissions in domestic atmospheric burners for NG in the Chinese locations of Lhasa (3658 m) and Chongqing (4000 m). The study concluded that a change in fuel gas supply pressure could compensate for the energy loss that is produced with increasing altitude, that thermal performance increases as altitude increases, and that emissions increase by decreasing oxygen in atmospheric air at a higher altitude when compared to sea level.

Brazilian Metrology Institute, in the use of its attributions as regulator of the gas appliances sector, established in 2008, the specific regulation for the use of the national energy conservation label – ENCE. This regulation defines the technical and operational requirements imposed on the Brazilian system for the assessment of conformity for gas stoves and ovens produced and or marketed in Brazilian territory. The specific regulation was approved and instituted with the publication of joint ordinance 73, of April 5, 2002 [14]. In January 2008, Inmetro published Ordinance 018 [15] and revised specific Regulation 008, the same that was in force until 2012. In August 1, 2012, Inmetro Ordinance No. 400 [3] was published. The new regulation for conformity assessment (RAC), contained in this ordinance, emphasizes the types of devices covered by the scope, the indices, the classification ranges and in the annex, the control metrology required to ensure the quality of the required products and services. This document also sets the energy rating ranges for table and oven burners, Table 1.

On October 10, 2013, Inmetro published Ordinance No. 496 [16] in which it establishes the deadlines for extinction of old products in commerce on August 1, 2014 and determines that the deviations between the amount declared in the spreadsheet of the technical specification

Table 1. Energy rating for table and oven burners.

Average burner efficiency of the table, η (%)	Consumption index of the oven CI (%)	Classification PBE
$\eta \geq 63$	$CI \leq 49$	A
$61 \leq \eta < 63$	$49 < CI \leq 53$	B
$59 \leq \eta < 61$	$53 < CI \leq 57$	C
$57 \leq \eta < 59$	$57 < CI \leq 60$	D
$52 \leq \eta < 57$	$60 < CI \leq 63$	E

Table 2. Allowable nominal deviations in the initial test.

Burner table efficiency (η)	$\pm 3\%$
Oven consumption index (CI)	$\pm 5\%$
Oven volume (V)	$\pm 2\%$

of efficiency and of the appliance's energy consumption must comply with the limits specified in Table 2.

The determination, in accordance with the regulations described above, of table performance (η) and oven consumption (CI), follows the test procedure specified by [4] and [8]; measuring quantities for use as variables in the calculation equations of η and CI, described as follow.

Regarding the spread of measurement uncertainty, the combined uncertainty will be calculated according to [17], for both η and CI and considering the input quantities as not correlated with each other.

2.1 Efficiency measurement of domestic gas cooking appliances

The calculation of the efficiency (η), in %, equation (1), is expressed according to the test conditions.

$$\eta = \frac{\text{Heat absorbed}}{\text{Heat transferred}} = 100 \frac{MC(T_2 - T_1)}{V_n H_s} = 0.4186 \frac{M(T_2 - T_1)}{V_n H_s} [\%] \quad (1)$$

where:

Heat absorbed refers to the effective heating of the test vessel;

Heat transferred refers to the combustion energy of the volume of gas used;

C is the specific heat of the water, 4.186×10^{-3} MJ/kg °C;

T_1 is the initial temperature of the test vessel (20 ± 1) °C;

T_2 is the maximum water temperature after the flame is extinguished (90 ± 1) °C;

H_s is the gross calorific value of the gas used, if it is the reference gas, butane, it will be constant and equal to 126.21 MJ/m³, without associated uncertainty, i.e., negligible uncertainty [8].

M is the equivalent mass of the test vessel, equation (2);

$$M = M_1 + \frac{C_{\text{rec}}}{C} m = M_1 + 0.213m [\text{kg}] \quad (2)$$

where:

M_1 is the body of water used (inside the test vessel), in kg;

m is the mass of the test vessel and its lid, in kg;

C_{rec} is the specific heat of the test vessel (aluminium), in MJ/kg °C.

V_n is the volume of gas used, in m³, corrected to the reference conditions (101.33 kPa, 15 °C) of H_s by equation (3).

$$V_n = V \frac{P_a + P - W}{101.33} \frac{288.15}{273.15 + T_g} = 2.84368V \frac{P_a + P - W}{273.15 + T_g} [\text{m}^3] \quad (3)$$

where:

V is the volume read under the test conditions (P_a, P, T_g), in m³;

P_a is the local atmospheric pressure, in kPa;

P is the gas supply pressure in the meter, in kPa;

T_g is the gas temperature at the measurement point, in °C;

W is the saturation pressure of water vapor at temperature T_g , in kPa, equation (4).

$$W = W(T_g) = \frac{e^{\left(21.094 - \frac{5262}{273.15 + T_g}\right)}}{10} = 0.1 \exp\left(21.094 - \frac{5262}{273.15 + T_g}\right) [\text{kPa}] \quad (4)$$

By processing equations (1)–(4), a more detailed and explicit form of the efficiency equation is obtained in the dependent variables, equations (4) and (5) assists in the propagation of uncertainties of the input quantity V_n .

$$\eta = \eta_{(M, T_2, T_1, H_s, V, P_a, P, T_g)} = 0.4186(M_1 + 0.213m)(T_2 - T_1) \frac{1}{H_s} \frac{1}{V_n} [\%] \quad (5)$$

$$V_n = V_{n(V, P_a, P, T_g)} = 2.84368V \frac{P_a + P - W}{273.15 + T_g} [\text{m}^3] \quad (6)$$

The efficiency sensitivity coefficients in relation to M , T_1 , T_2 , and H_s depend only on equation (3) and are

described according to equations (7)–(10).

$$F_{\eta,M} = \frac{\partial \eta}{\partial M} = \frac{\eta}{M_1 + 0.213m} \quad [\%/kg] \quad (7)$$

$$F_{\eta,T_2} = \frac{\partial \eta}{\partial T_2} = \frac{\eta}{T_2 - T_1} \quad [\%/^{\circ}C] \quad (8)$$

$$F_{\eta,T_1} = \frac{\partial \eta}{\partial T_1} = \frac{-\eta}{T_2 - T_1} = -F_{\eta,T_2} \quad [\%/^{\circ}C] \quad (9)$$

$$F_{\eta,H_s} = \frac{\partial \eta}{\partial H_s} = \frac{-\eta}{H_s} \quad [\% \text{ kg } ^{\circ}C/MJ] \quad (10)$$

As V_n depends on V , P_a , P , T_g , and W , where W depends on T_g , there will be no sensitivity coefficient in V_n , but rather in V , P_a , P e T_g according to equations (11) and (14).

$$F_{\eta,V} = \frac{\partial \eta}{\partial V} = \frac{-\eta}{V} \quad [\%/m^3] \quad (11)$$

$$F_{\eta,P_a} = \frac{\partial \eta}{\partial P_a} = \frac{-\eta}{P_a + P - W} \quad [\%/kPa] \quad (12)$$

$$F_{\eta,P} = \frac{\partial \eta}{\partial P} = \frac{-\eta}{P_a + P - W} = F_{\eta,P_a} \quad [\%/kPa] \quad (13)$$

$$F_{\eta,T_g} = \frac{\partial \eta}{\partial T_g} = \frac{\eta}{273.15 + T_g} - \frac{5262W}{(273.15 + T_g)^2} F_{\eta,P_a} \quad [\%/^{\circ}C] \quad (14)$$

2.2 Measurement of consumption of domestic gas cooking appliances

The burner consumption test, P_c , referred to as “consumption” by [4], goes by means of an initial temperature stabilization step ($210 \pm 1^{\circ}C$) above room temperature, being then calculated by equation (15):

$$P_c = 0.278 \dot{V}_c H_s \quad [KW] \quad (15)$$

where:

P_c is consumption, in kW;

0.278 is the conversion factor of consumption, in kW/(MJ/h);

H_s is the higher calorific value of the gas used (if it is the reference gas, butane, it will be constant and equal to 126.21 MJ/m³, without associated uncertainty, i.e., negligible uncertainty [8].

\dot{V}_c is the volumetric flow, of the gas under the reference conditions (101.33 kPa and 15 °C), obtained from equation (16), in m³/h.

The volumetric flow corresponds to the measurement of a reference gas flow (99.99% pure butane m/m) under reference conditions, that is, assuming the gas is dry, at

15 °C and under a pressure of 101.33 kPa, as described by [8]. The purpose of equation (16) is to convert the volumetric flow measured in the test conditions (\dot{V}) for a flow value in the reference conditions (\dot{V}_c)

$$\dot{V}_c = \dot{V} \sqrt{\frac{101.33 + P}{101.33} \frac{P_a + P}{101.33} \frac{288.15}{273.15 + T_g} \frac{d_h(P_a, P, T_g)}{d_r}} \quad [m^3/h] \quad (16)$$

If a wet meter is used or if the gas used is saturated, the value d (relative density of dry gas in relation to dry air) shall be replaced by the value of the relative density of the wet gas d_h given by equation (equation 17):

$$d_h = \frac{(P_a + P - W_{(T_g)})d + 0.622W_{(T_g)}}{P_a + P} \\ = d + \frac{0.622 - d}{P_a + P} W_{(T_g)} \quad (17)$$

where:

\dot{V} is the gas flow measured in the test conditions, in m³/h; (P_a , P , T_g), in m³/h;

P_a is the local atmospheric pressure, in kPa;

P is the gas supply pressure in the meter, in kPa;

T_g is the temperature of the gas at the measurement point, in °C;

d is the relative density of the dry (or wet) test gas relative to dry air;

d_r is the relative density of the dry reference gas relative to dry air;

W is the saturation pressure of the water vapor at the temperature T_g (Eq. 4), in kPa.

Equation (15) for the burner consumption can then be rewritten to cover all the quantities measured in the test (Eq. 18).

$$P_c = P_c(\dot{V}_{c,H_s,P,P_a,T_g}) \\ = 0.278 H_s \dot{V} \sqrt{\frac{101.33 + P}{101.33} \frac{P_a + P}{101.33} \frac{288.15}{273.15 + T_g} \frac{d_h}{d_r}} \quad [kW] \quad (18)$$

$d_h = d_h(P_a, P, T_g)$, see equation (17)

$W = W_{(T_g)}$ [kPa], see equation (4)

The efficiency sensitivity coefficients in relation to \dot{V} and H_s depend only on equation (18) and are described according to equations (19) and (20).

$$F_{P_c, \dot{V}} = \frac{\partial P_c}{\partial \dot{V}} = \frac{P_c}{\dot{V}} \quad [kW h/m^3] \quad (19)$$

$$F_{P_c, H_s} = \frac{\partial P_c}{\partial H_s} = \frac{P_c}{H_s} \quad [g^{\circ}C/s] \quad (20)$$

As d_h depends on P_a , P , T_g , and W , where W depends on T_g , there will be no sensitivity coefficient of P_c in d_h , but in

Table 3. Summary of the steps of statistical processes.

Aim/Statistical test	Normal distribution	Non-normal distribution
Assessment of normality		Shapiro-Wilk
Outliers	Grubbs' test	Interquartile range (IQR)
Position measurement	$p_i = \frac{1}{\sigma_i^2}$ $\bar{x} = \frac{\sum_{i=1}^m x_i \cdot p_i}{\sum_{i=1}^m p_i}$	$p_i = \frac{1}{(\text{MAD}/_{0.6745})_i^2}$ $\text{MAD} = \text{Median}[x_i - \text{Median}(x_i)]$ $\text{Md} = \frac{\sum_{i=1}^m M_i \cdot p_i}{\sum_{i=1}^m p_i}$
Uncertainty Assessment	Law of propagation of uncertainties	It is not relevant in this study

P_a , P , and T_g according to equations (21)–(23).

$$F_{P_c, P_a} = \frac{\partial P_c}{\partial P_a} = \frac{1}{2} \frac{P_c}{P_a + P} \frac{d}{d_h} \quad [\text{W/Pa}] \quad (21)$$

$$F_{P_c, P} = \frac{\partial P_c}{\partial P} = F_{P_c, P_a} \left(\frac{P_a + P}{101.33 + P} \frac{d_h}{d} + 1 \right) \quad [\text{W/Pa}] \quad (22)$$

$$F_{P_c, T_g} = \frac{\partial P_c}{\partial T_g} = \frac{1}{2} \frac{P_c}{273.15 + T_g} \times \left(\frac{5262}{273.15 + T_g} \frac{d_h - d}{d_h} - 1 \right) \quad [\text{W/Pa}] \quad (23)$$

2.3 Calculation of the oven consumption index

The calculation of the furnace consumption index (CI), for stoves and liquefied petroleum gas (LPG) ovens, equation (24).

$$\text{IC}_{\text{GLP}} = \frac{C}{(0.93 + 0.035 \times V_F) \times 0.0726} \times 100 \quad (24)$$

where:

V_F is the volume in dm^3 ;

0.0726 is the local atmospheric pressure, in kPa;

C is the consumption of maintenance of the oven, where the amount of gas per unit of time supplied for combustion in the oven burner to maintain, in the geometric center of the empty oven, the temperature rise of 210°C above the ambient temperature. This quantity is expressed in kg/h, for LPG [3];

$(0.93 + 0.035 \times V_F)$ is consumption, expressed in kilowatts, and calculated on H_s .

2.4 Uncertainty of table efficiency tests and oven consumption

The combined standard uncertainties of efficiency and consumption are calculated by equation (25) and the expanded uncertainty will be equal to the combined standard uncertainty, multiplied by the coverage factor ($k = 2$; for infinite degrees of freedom) to obtain an interval with a confidence level of ($p = 95.45\%$), equation (26).

$$u_c^2(y) = \sum_{i=1}^N \left[\frac{\partial f}{\partial x_i} \right]^2 u^2(x_i) \quad (25)$$

$$U(y) = k \times u_c(y) \quad (26)$$

2.5 Statistical testing steps

This study proposes a methodology for the statistical treatment of data based on the assessment of data normality, the treatment of outliers and the calculation of the average efficiency based on the position measurement weighted by the measure of dispersion of each burner [18], Table 3.

Where: p_i is the weight and must be related to the variability of the data, and quantified by means of standard deviations, σ_i ; \bar{x} is average; Md is median; i is the index that refers to each of the experimental values available, x_i is the measure of efficiency, ISO GUIDE 35 [19].

3 Summary of test method and experimental data

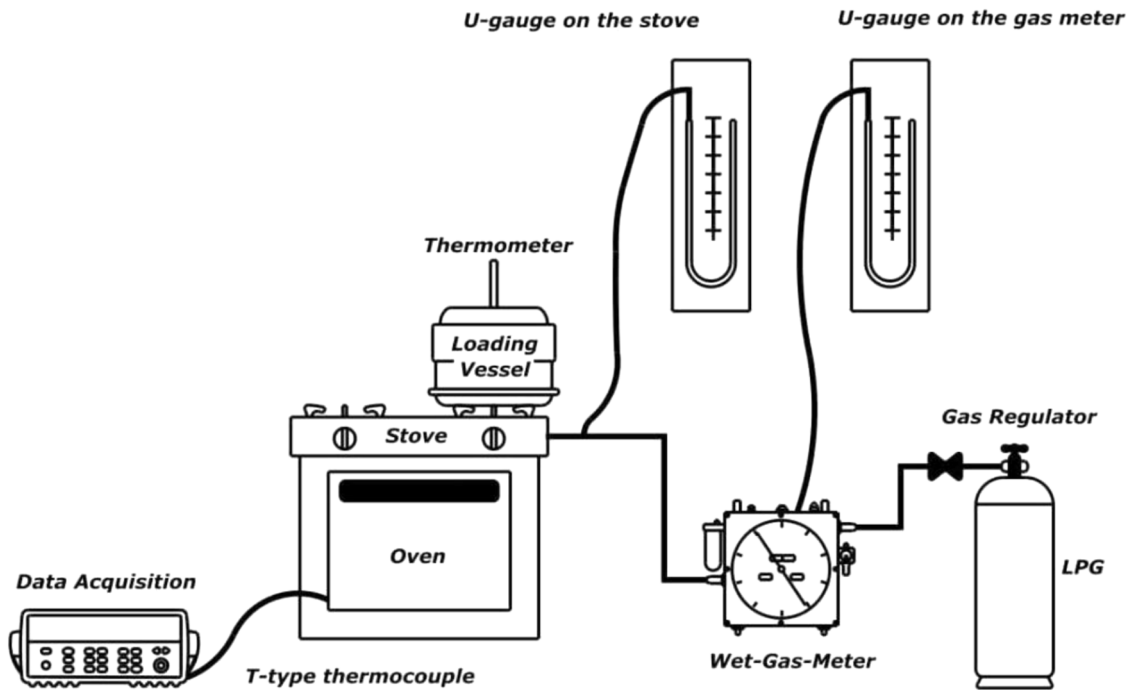
A table burner is covered with a 220 mm diameter container, containing 3.7 kg of water, which must be operated for 10 minutes at nominal power. Such a 220 mm container is removed and immediately replaced by the specific container to be used in the performance test.

Table 4. Mass of water as a function of the burner power.

Burner power about the H_s in (kW)	Internal diameter of container in (mm)	Body of water M_1 in (kg)
Between 1.16 and 1.64	220	3.7
Between 1.64 and 1.98	240	4.8
Between 1.99 and 2.36	260 ¹⁾	6.1
Between 2.37 and 4.20	260 ^{1),2)}	6.1

¹⁾If the container with a diameter of 260 mm cannot be used, the test must be conducted under the normal conditions of use of the appliance, using the 240 mm container with corresponding M_1 water mass, and the burner power must be adjusted to 1.98 kW (on H_s).

²⁾With a burner power setting to 2.36 kW (over H_s).

**Fig. 1.** Assembly configuration of the test bench.

For the performance test, a wet gas flow meter is used. It is a semi-submerged rotor meter, which controls the aspiration and escape of the gas whose flow you want to measure is done through the liquid, which has a sealing function. For flow measurement, one lobe has its outlet end submerged and that of the emerged inlet, aspirating gas, and the other has the submerged inlet and the emerged outlet, expelling gas. Therefore, this type of meter moistens the air, changing its relative density and leading to the need to use the term d_h/d_r in equation (16).

The initial water temperature must be $20\text{ }^\circ\text{C} \pm 1\text{ }^\circ\text{C}$ and the water temperature at the time of extinguishing the flame in the burner must be $90\text{ }^\circ\text{C} \pm 1\text{ }^\circ\text{C}$.

M is the equivalent mass of the test vessel, according to the indications in Table 4.

For the consumption test the oven burner is fed with reference gas (butane 99.9% m/m), regulated with a pressure of 2.75 kPa and the ambient temperature must remain throughout the test at $20\text{ }^\circ\text{C} \pm 5\text{ }^\circ\text{C}$.

With the empty oven, the flow of the register is adjusted, so that in the steady state the temperature rise, measured in the geometric center of the empty oven. This measurements is made by a thermocouple, is at $210\text{ }^\circ\text{C} \pm 1\text{ }^\circ\text{C}$ above the ambient temperature or, if the maximum possible temperature rise is less than $210\text{ }^\circ\text{C}$, corresponding to the maximum position of the thermostat or register, with the same tolerance. The temperature adjustment must be done by changing the position of the register and/or varying the nominal pressure of the reference gas by $\pm 5\%$.

In the measurement of the performance and consumption tests of domestic stoves, nine measurements were made on each burner (Q_i) of the stove table and nine measurements on the oven burner, by the same operator using the same apparatus, at sea level (Laboratory A) and above the level of the sea, 935 m (Laboratory B). The measurement configuration is described in Figure 1 and these results are available in Table 5.

Table 5. Experimental data.

Laboratory A					Laboratory B				
Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	Oven (kg/h)	Q1 (%)	Q2 (%)	Q3 (%)	Q4 (%)	Oven (kg/h)
63.9	67.7	66.7	62.0	0.117	62.3	64.5	64.2	60.3	0.106
62.6	67.0	66.3	61.4	0.122	60.6	64.6	64.2	60.0	0.100
64.1	67.4	66.2	62.3	0.122	63.4	67.1	66.2	60.3	0.115
62.5	67.9	67.1	61.2	0.120	62.5	67.6	66.3	60.0	0.110
65.5	68.4	67.2	62.6	0.119	63.3	64.9	65.6	60.4	0.112
63.9	68.8	65.7	62.1	0.122	62.9	65.8	66.4	60.3	0.114
62.0	68.6	66.8	61.9	0.116	63.0	67.9	66.9	60.7	0.115
64.4	68.3	66.8	61.9	0.118	63.1	67.2	66.2	60.8	0.112
63.6	68.0	66.4	62.2	0.119	63.9	67.7	66.7	60.9	0.112

4 Results and discussion

Data from Laboratories A and B are handled by two different approaches. The first approach is the traditional one that is based on [4]; that is, arithmetic mean of the data without analysis and treatment of the data. The second approach, here proposed, is based on the current statistical tests, Table 3.

The measurement uncertainty evaluation regarding the intermediate precision of the efficiency and consumption methods was calculated from the grouped standard deviation of the nine tests performed on each burner, repeated under the same conditions, so we are faced with a Type A uncertainty, whose standard uncertainty experimental average is given by $u(x_i) = \frac{s(x_i)}{\sqrt{n}}$, where $s(x_i)$ is the experimental standard deviation for n observations. Whereas the uncertainties contributions are type B assessments are provided by the calibration certificates:

- Efficiency: water and gas temperature (thermometer), atmospheric pressure (barometer), gas pressure (manometer) and gas volume (volumetric meter);
- Consumption: gas temperature (thermometer), atmospheric pressure (barometer), gas pressure (manometer) and gas volume (volumetric meter).

The calculation of the efficiency (η) is given by equation (1) and input quantities for the combined standard uncertainty are given by equations (5) and (6). The sensitivity coefficients (c_i) are presented from equations (8)–(14).

The calculation of the consumption (P_c) is given by equation (15) and input quantities for the combined standard uncertainty are given by equation (18). The sensitivity coefficients (c_i) are presented from equations (19)–(22).

4.1 Evaluation of the results of Laboratory A

Based on Shapiro Wilk's test, all efficiency and consumption results have a normal distribution:

After applying the Grubbs and IQR tests, respectively, for the efficiency and consumption tests, it was observed that no data sets have outliers.

The performance test data set showed a normal distribution; therefore, the estimate of the quantity, from the average, is weighted inversely proportional to their respective variances and finally, the average efficiency of the National Energy Conservation Label is calculated by the weighted average.

For this data set, one can infer from Table 6 that the means of the four burners compared cannot be considered equal. That is, there is a significant difference between the data sets ($F > F$ -critical), so that we cannot consider them as being samples from the same population. Anova shows that the use of the arithmetic mean of the four burners is not statistically compatible. Thus, the average weighted by the variance is justified.

Considering the specification range, according to Inmetro Ordinance 400 of August 1, 2012 [3], the efficiency according to the national energy conservation label, affixed to the equipment, is $63\% \pm 3\%$, that is, (61% to 65%). The result of Laboratory A is framed by the traditional approach, 65% (arithmetic average) and the proposed approach 65% (weighted average).

4.2 Evaluation of the results of Laboratory B

Based on Shapiro Wilk's test, with the exception of burner 3, all efficiency results have a normal distribution. In turn, the consumption results have a behaviour that departs from the normality:

After the treatment of outliers with the application of the Grubbs test in the performance test in Q1, Q2 and Q4, and IQR in the performance test in Q3, and also in the consumption test, it was observed with a new application of the Shapiro-Wilk test that all experimental data started to have a normal distribution.

The data set of the performance tests showed a normal distribution, therefore, the estimate of the quantity, from the average, is weighted inversely proportional to their

Table 6. Anova of the results of the burner efficiencies at sea level.

Anova (Single Factor)						
Group	Count	Average	Variance			
Q1		63.6	1.18			
Q2		68.0	0.34			
Q3	9	66.6	0.22			
Q4		62.0	0.19			
Origin of variation	SS	DF	MS	F	<i>p</i> -value	<i>F</i> -critical
Between groups	205	3	68.2	141.3	1.55E-18	2.9
Within groups	15	32	0.48			
Total	220	35				

SS = sum of squares; DF = degrees of freedom; MS = mean squares.

Table 7. Anova of the results of the burner performance above sea level.

Anova (Single Factor)						
Group	Count	Average	Variance			
Q1	8	63.1	0.26			
Q2	9	66.4	1.99			
Q3	4	66.3	0.0092			
Q4	9	60.4	0.11			
Origin of variation	SS	DF	MS	F	<i>p</i> -value	<i>F</i> -critical
Between groups	191.3	3	63.7	88.9	8.55E-14	2.9
Within groups	18.6	26	0.72			
Total	209.9	29				

SS = sum of squares; DF = degrees of freedom; MS = mean squares.

respective variances and finally, the average efficiency of the National Energy Conservation Label is calculated by the weighted average.

For this data set, one can infer from Table 7 that the means of the four burners compared cannot be considered equal. That is, there is a significant difference between the data sets ($F > F$ -critical), so that we cannot consider them as being samples from the same population. Anova shows that the use of the arithmetic mean of the four burners is not statistically compatible. Thus, the average weighted by the variance is justified.

Considering the specification range, according to Inmetro Ordinance 400 of August 1, 2012 [3], the efficiency according to the national energy conservation label, affixed to the equipment, is $63\% \pm 3\%$, that is, (61% to 65%). The result of Laboratory B is framed by the traditional approach, 64% (arithmetic mean) but it is not framed by the proposed approach 66% (weighted average).

4.3 Measurement uncertainty based on results from Laboratory A

The input quantities and sensitivity coefficients (c_i) for efficiency and its uncertainty budget are shown in Tables 8–10, respectively:

The uncertainty of efficiency measurement does not exceed 1.0%, Table 11, therefore it is not enough to change the classification range.

The relative contribution of each source of standard efficiency uncertainty is shown in Figure 2.

By analyzing Figure 2, it is possible to verify that the contributions of the uncertainty of the intermediate precision and the uncertainty of the gas temperature are dominant, while the uncertainties derived from the other components are practically insignificant. In the intermediate precision, the standard deviation of the nine efficiency measurements made is considered. This uncertainty source is relevant and since the burners Q1 and Q4 need manual adjustment during the test, probably it contributes to the variation in standard deviation, while burners Q2 and Q3 do not need adjustment, being their closest individual uncertainties. As for the gas temperature, the determining factor in increasing the uncertainty is the type B uncertainty of the instrument that has an analog resolution of 0.5 °C, however, even decreasing the resolution with another instrument, the gas temperature would still be dominant, as it depends directly on the water temperature inside the wet gas meter. Therefore, as a reference, the performance of the burners is in accordance with and within the tolerances allowed in the Inmetro Ordinance No. 400 of August 1, 2012 [3] and

Table 8. Input quantities for efficiency, Test 1, Lab A.

Quantities	Measurements				Units
	Q1	Q2	Q3	Q4	
T_1	19.4	19.9	20.2	20.0	°C
T_2	90.6	91.5	92.1	91.4	°C
P_a	101.5	101.5	101.4	101.4	kPa
P	2.77	2.74	2.75	2.78	kPa
V	0.02403	0.01786	0.01816	0.02465	m ³
T_g	23.0	22.4	21.6	21.8	°C
M	6.334	4.975	4.975	6.320	kg
H_s	126.21	126.21	126.21	126.21	MJ/m ³
W	2.78	2.68	2.56	2.59	kPa
η	63.9	67.7	66.7	62.0	%

Table 9. Sensitivity coefficients (c_i) for efficiency, Test 1, Lab A.

Sensitivity coefficients (c_i)	Q1	Q2	Q3	Q4	Units
$F_{\eta,M} = \frac{\partial\eta}{\partial M} = \frac{\eta}{M}$	10.0863	13.6101	13.4002	9.8102	kg ⁻¹
$F_{\eta,T_2} = \frac{\partial\eta}{\partial T_2} = \frac{\eta}{(T_2 - T_1)}$	0.8973	0.9457	0.9272	0.8684	(°C) ⁻¹
$F_{\eta,T_1} = \frac{\partial\eta}{\partial T_1} = \frac{-\eta}{(T_2 - T_1)}$	-0.8973	-0.9457	-0.9272	-0.8684	(°C) ⁻¹
$F_{\eta,H_s} = \frac{\partial\eta}{\partial H_s} = \frac{-\eta}{H_s}$	-0.5062	-0.5365	-0.5282	-0.4913	m ³ /MJ
$F_{\eta,V} = \frac{\partial\eta}{\partial V} = \frac{-\eta}{V}$	-2658.6	-3791.2	-3671.0	-2515.2	(m ³) ⁻¹
$F_{\eta,P_a} = \frac{\partial\eta}{\partial P_a} = \frac{-\eta}{P_a + P - W}$	-0.6295	-0.6667	-0.6562	-0.6103	(kPa) ⁻¹
$F_{\eta,P} = \frac{\partial\eta}{\partial P} = \frac{-\eta}{P_a + P - W}$	-0.6295	-0.6667	-0.6562	-0.6103	(kPa) ⁻¹
$F_{\eta,T_g} = \frac{\partial\eta}{\partial T_g} = \frac{\eta}{273.15 + T_g}$	0.3208	0.3369	0.3278	0.3057	kW/°C
$-\frac{526.2F_{\eta,P_a}}{(273.15 + T_g)^2} \exp\left(21.094 - \frac{5262}{273.15 + T_g}\right)$					

that recorded on the appliance's energy efficiency label (63% ± 3%).

The input quantities, the output quantities and sensitivity coefficients (c_i) for consumption, its uncertainty budget and expanded uncertainty are shown in [Tables 12–15](#), respectively:

The relative contribution of each source of standard consumption uncertainty is shown in [Figure 3](#).

By analyzing [Figure 3](#), one can see that the uncertainty of the gas temperature is the dominant one, while the uncertainties of the other components are practically insignificant. As for the gas temperature, the determining factor in increasing the uncertainty is the type B uncertainty of the instrument that has an analog resolution of 0.5°C, however, even decreasing the resolution with another instrument, the gas temperature would still be

Table 10. Uncertainty budget in efficiency, Test 1, Lab A.

Type	Source of uncertainty	Value (U)	Unit	Distribution	Divisor	u (xi)	V_{eff}	uc (xi)
B	Uncertainty of the thermometer – T_1	0.10000	°C	Normal	2	0.0500	∞	
B	Lower division of the thermometer – T_1	0.05000	°C	Triangular	$\sqrt{6}$	0.0204	∞	0.05401
B	Uncertainty of the thermometer – T_2	0.10000	°C	Normal	2	0.0500	∞	
B	Lower division of the thermometer – T_2	0.05000	°C	Triangular	$\sqrt{6}$	0.0204	∞	0.05401
B	Barometer uncertainty – P_a	0.06900	kPa	Normal	2	0.0345	∞	
B	Lower division of the barometer – P_a	0.00500	kPa	Triangular	$\sqrt{6}$	0.0020	∞	0.03456
B	Pressure gauge uncertainty – P	0.00007	kPa	Normal	2	0.0000	∞	
B	Lower division of the pressure gauge – P	0.00500	kPa	Triangular	$\sqrt{6}$	0.0020	∞	0.00204
B	Volume uncertainty of $Q_1 - V$	0.00021	m ³	Normal	2	0.0001	∞	
B	Lower division of the volume – V	0.00005	m ³	Triangular	$\sqrt{6}$	0.0000	∞	0.00011
B	Volume uncertainty of $Q_2 - V$	0.00015	m ³	Normal	2	0.0001	∞	
B	Lower division of the volume – V	0.00005	m ³	Triangular	$\sqrt{6}$	0.0000	∞	0.00008
B	Volume uncertainty of $Q_3 - V$	0.00016	m ³	Normal	2	0.0001	∞	
B	Lower division of the volume – V	0.00005	m ³	Triangular	$\sqrt{6}$	0.0000	∞	0.00011
B	Volume uncertainty of $Q_4 - V$	0.00021	m ³	Normal	2	0.0001	∞	
B	Lower division of the volume – V	0.00005	m ³	Triangular	$\sqrt{6}$	0.0000	∞	0.00008
B	Uncertainty of the gas thermometer – T_g	0.33000	°C	Normal	2	0.1650	∞	
B	Lower division of the gas thermometer – T_g	0.25000	°C	Triangular	$\sqrt{6}$	0.1021	∞	0.19401
B	Balance uncertainty – M	0.00200	kg	Normal	2	0.0010	∞	
B	Smaller scale division – M	0.00500	kg	Rectangular	$\sqrt{3}$	0.0029	∞	0.00306
A	Repeatability of Q_1	1.08679	%	Normal	$\sqrt{9}$	0.3623	8	0.36226
A	Repeatability of Q_2	0.58190	%	Normal	$\sqrt{9}$	0.1940	8	0.19397
A	Repeatability of Q_3	0.47376	%	Normal	$\sqrt{9}$	0.1579	8	0.15792
A	Repeatability of Q_4	0.43333	%	Normal	$\sqrt{9}$	0.1444	8	0.14444

Table 11. Summary of efficiency uncertainties in Test 1, Lab A.

Efficiency	k	u_η	$k \times u_\eta$	U %
Q_1	2	0.468659086	0.937318172	0.94
Q_2	2	0.374344631	0.748689261	0.75
Q_3	2	0.352109515	0.704219031	0.70
Q_4	2	0.322240467	0.644480933	0.64

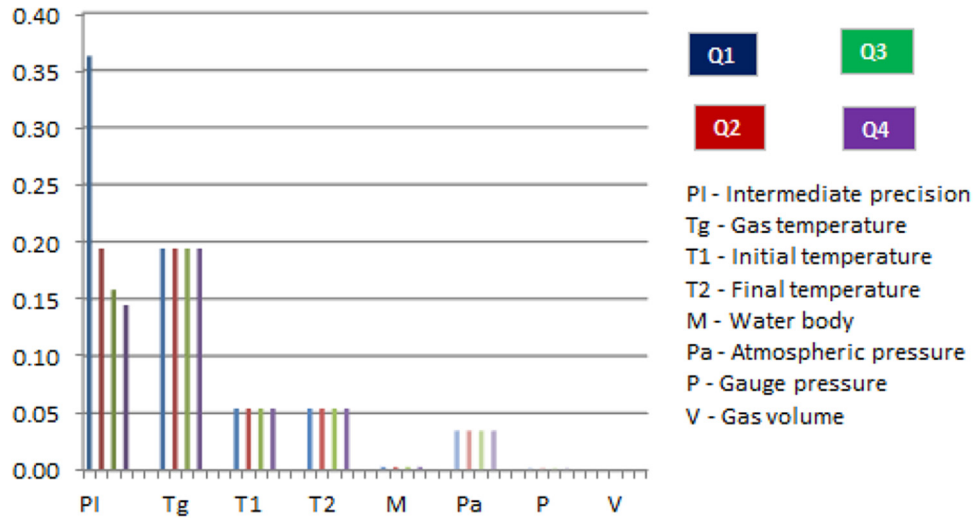


Fig. 2. Balance of contributions from uncertainties of efficiency in test number 1, Lab A.

Table 12. Input quantities for consumption, Test 1, Lab A.

Quantities	Measurements	Units
P_a	101.350	kPa
P	2.780	kPa
\dot{V}	0.04572	m ³ /h
T_g	22.4	°C
H_s	126.21	MJ/m ³
d	2.0788	—
d_h	2.0412	—
P_c	1.613	kW

Table 13. Sensitivity coefficients (c_i) for consumption, Test 1, Lab A.

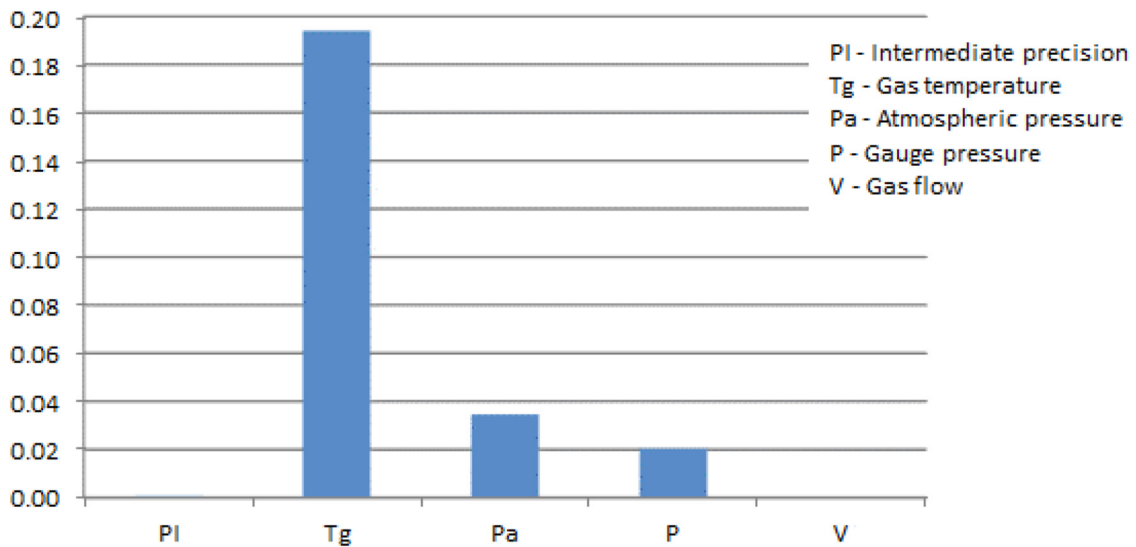
Sensitivity coefficients (c_i)	Results	Units
$F_{P_c.H_s} = \frac{\partial P_c}{\partial H_s} = \frac{P_c}{H_s}$	0.0128	kW/MJ.m ³
$F_{P_c.\dot{V}} = \frac{\partial P_c}{\partial \dot{V}} = \frac{P_c}{\dot{V}}$	35.2721	kWh/m ³
$F_{P_c.T_g} = \frac{\partial P_c}{\partial T_g} = \frac{1}{2} \frac{P_c}{273.15 + T_g} \left(\frac{5262}{273.15 + T_g} \frac{d_h - d}{d_h} - 1 \right)$	-0.0036	kW/°C
$F_{P_c.P_a} = \frac{\partial P_c}{\partial P_a} = \frac{1}{2} \frac{P_c}{P_a + P} \frac{d}{d_h}$	0.0079	kW/kPa
$F_{P_c.P} = \frac{\partial P_c}{\partial P} = \frac{1}{2} \frac{P_c}{101.33 + P} + F_{P_c.P_a}$	0.0156	kW/kPa

Table 14. Uncertainty budget in consumption, Test 1, Lab A.

Type	Source of uncertainty	Value (U)	Unit	Distribution	k	u (xi)	V_{eff}	u_c (xi)
B	Barometer uncertainty – P_a	0.06900	kPa	Normal	2	0.0345	∞	0.03456
B	Lower division of the barometer – P_a	0.00500	kPa	Triangular	$\sqrt{6}$	0.0020	∞	
B	Pressure gauge uncertainty – P	0.00007	kPa	Normal	2	0.0000	∞	0.00204
B	Lower division of the pressure gauge – P	0.00500	kPa	Triangular	$\sqrt{6}$	0.0020	∞	
B	Flow meter uncertainty – \dot{V}	0.00021	m^3 / h	Normal	2	0.0001	∞	0.00011
B	Lower division of the flow meter – \dot{V}	0.00005	m^3 / h	Triangular	$\sqrt{6}$	0.0000	∞	
B	Uncertainty of the gas thermometer – T_g	0.33000	$^{\circ}\text{C}$	Normal	2	0.1650	∞	0.19401
B	Lower division of the gas thermometer – T_g	0.25000	$^{\circ}\text{C}$	Triangular	$\sqrt{6}$	0.1021	∞	
A	Repeatability	0.00224	kW	Normal	$\sqrt{9}$	0.0007	8	0.00075

Table 15. Summary of consumption uncertainties in Test 1, Lab A.

	k	u_c	$k \times u_c$	U(kW)	U (kg/h)
U (Consumption)	2	0.007059232	0.014118464	0.141	0.0010

**Fig. 3.** Balance of contributions from uncertainties of consumption in Test 1, Lab A.

dominant, as it depends directly on the water temperature inside the wet gas meter.

4.4 Measurement uncertainty based on results from Laboratory B

The input quantities and sensitivity coefficients (c_i) for efficiency and its uncertainty budget are shown in Tables 16–19, respectively:

The uncertainty of measuring the yield does not exceed 1.0%, Table 19, therefore it is not enough to change the classification range.

The relative contribution of each source of standard efficiency uncertainty is shown in Figure 4.

By means of the analysis of Figure 4, one can verify that the contributions of the uncertainty of the intermediate precision and the uncertainty of the gas temperature are dominant, while the uncertainties of the other components are practically insignificant. The intermediate precision is relevant and since the burners Q1 and Q4 need manual adjustment during the test, probably it contributes to the variation in standard deviation, while burners Q2 and Q3 do not need adjustment, and their individual uncertainties should be closer, however due to the number of outliers in

Table 16. Input quantities for efficiency, Test 1, Lab B.

Quantities	Measurements				Units
	Q1	Q2	Q3	Q4	
T_1	19.7	20.6	19.8	19.5	°C
T_2	90.0	91.9	91.1	90.8	°C
P_a	91.0	91.1	90.9	90.8	kPa
P	2.79	2.83	2.83	2.79	kPa
V	0.02744	0.02066	0.0212	0.02868	m ³
T_g	23.2	21.3	24.1	24.6	°C
M	6.320	4.975	4.975	6.320	kg
H_s	126.21	126.21	126.21	126.21	MJ/m ³
W	2.82	2.51	2.97	3.06	kPa
η	62.3	64.5	64.2	60.3	%

Table 17. Sensitivity coefficients (c_i) for efficiency, Test 1, Lab B.

Sensitivity coefficients (c_i)	Q1	Q2	Q3	Q4	Units
$F_{\eta,M} = \frac{\partial \eta}{\partial M} = \frac{\eta}{M}$	9.8584	12.9646	12.8974	9.5367	kg ⁻¹
$F_{\eta,T_2} = \frac{\partial \eta}{\partial T_2} = \frac{\eta}{(T_2 - T_1)}$	0.8751	0.9046	0.8999	0.8453	(°C) ⁻¹
$F_{\eta,T_1} = \frac{\partial \eta}{\partial T_1} = \frac{-\eta}{(T_2 - T_1)}$	-0.8751	-0.9046	-0.8999	-0.8453	(°C) ⁻¹
$F_{\eta,H_s} = \frac{\partial \eta}{\partial H_s} = \frac{-\eta}{H_s}$	-0.4937	-0.5110	-0.5084	-0.4776	m ³ /MJ
$F_{\eta,V} = \frac{\partial \eta}{\partial V} = \frac{-\eta}{V}$	-2.270.6	-3.121.9	-3.038.1	-2.101.5	(m ³) ⁻¹
$F_{\eta,P_a} = \frac{\partial \eta}{\partial P_a} = \frac{-\eta}{P_a + P - W}$	-0.6849	-0.7055	-0.7071	-0.6658	(kPa) ⁻¹
$F_{\eta,P} = \frac{\partial \eta}{\partial P} = \frac{-\eta}{P_a + P - W}$	-0.6849	-0.7055	-0.7071	-0.6658	(kPa) ⁻¹
$F_{\eta,T_g} = \frac{\partial \eta}{\partial T_g} = \frac{\eta}{273.15 + T_g}$	0.3258	0.3266	0.3410	0.3234	kW/°C
$-\frac{526.2 F_{\eta,P_a}}{(273.15 + T_g)^2} \exp\left(21.094 - \frac{5262}{273.15 + T_g}\right)$					

the Q3 burner test, the metrological reliability may have been compromised. As for the gas temperature, the determining factor in increasing the uncertainty is the type B uncertainty of the instrument that has an analog resolution of 0.5 °C, however, even decreasing the resolution with another instrument, the gas temperature would still be dominant, as it depends directly on the water temperature inside the wet gas meter. Therefore, as a reference, the performance of the burners is in accordance

with and within the tolerances allowed in the Inmetro Ordinance No. 400 of August 1, 2012 [3] and that recorded on the appliance’s energy efficiency label (63% ± 3%).

The input quantities and sensitivity coefficients (c_i) for consumption, its uncertainty budget and expanded uncertainty are shown in Tables 20–23, respectively:

The relative contribution of each source of standard consumption uncertainty is shown in Figure 5.

Table 18. Uncertainty budget in efficiency, Test 1, Lab B.

Type	Source of uncertainty	Value (U)	Unit	Distribution	Divisor	$u(x_i)$	V_{eff}	$uc(x_i)$
B	Uncertainty of the thermometer – T_1	0.10000	°C/%	Normal	2	0.05000	∞	
B	Lower division of the thermometer – T_1	0.05000	°C/%	Triangular	$\sqrt{6}$	0.02041	∞	0.05401
B	Uncertainty of the thermometer – T_2	0.10000	°C/%	Normal	2	0.05000	∞	
B	Lower division of the thermometer – T_2	0.05000	°C/%	Triangular	$\sqrt{6}$	0.02041	∞	0.05401
B	Barometer uncertainty – P_a	0.06900	kPa/%	Normal	2	0.03450	∞	
B	Lower division of the barometer – P_a	0.00500	kPa/%	Triangular	$\sqrt{6}$	0.00204	∞	0.03456
B	Pressure gauge uncertainty – P	0.00007	kPa/%	Normal	2	0.00004	∞	
B	Lower division of the pressure gauge – P	0.00500	kPa/%	Triangular	$\sqrt{6}$	0.00204	∞	0.00204
B	Volume uncertainty of $Q_1 - V$	0.00024	m ³ /%	Normal	2	0.00012	∞	
B	Lower division of the volume – V	0.00005	m ³ /%	Triangular	$\sqrt{6}$	0.00002	∞	0.00013
B	Volume uncertainty of $Q_2 - V$	0.00018	m ³ /%	Normal	2	0.00009	∞	
B	Lower division of the volume – V	0.00005	m ³ /%	Triangular	$\sqrt{6}$	0.00002	∞	0.00009
B	Volume uncertainty of $Q_3 - V$	0.00018	m ³ /%	Normal	2	0.00009	∞	
B	Lower division of the volume – V	0.00005	m ³ /%	Triangular	$\sqrt{6}$	0.00002	∞	0.00009
B	Volume uncertainty of $Q_4 - V$	0.00025	m ³ /%	Normal	2	0.00012	∞	
B	Lower division of the volume – V	0.00005	m ³ /%	Triangular	$\sqrt{6}$	0.00002	∞	0.00013
B	Uncertainty of the gas thermometer – T_g	0.33000	°C/%	Normal	2	0.16500	∞	
B	Lower division of the gas thermometer – T_g	0.25000	°C/%	Triangular	$\sqrt{6}$	0.10206	∞	0.19401
B	Balance uncertainty – M	0.00200	kg/%	Normal	2	0.00100	∞	
B	Smaller scale division – M	0.00500	kg/%	Rectangular	$\sqrt{3}$	0.00289	∞	0.00306
A	Repeatability of Q_1	0.50709	%	Normal	$\sqrt{8}$	0.17928	7	0.17928
A	Repeatability of Q_2	1.41244	%	Normal	$\sqrt{9}$	0.47081	8	0.47081
A	Repeatability of Q_3	0.09574	%	Normal	$\sqrt{4}$	0.04787	3	0.04787
A	Repeatability of Q_4	0.32575	%	Normal	$\sqrt{9}$	0.10858	8	0.10858

Table 19. Summary of efficiency uncertainties in Test 1, Lab B.

Efficiency	k	u_η	$k \times u_\eta$	U%
Q_1	2	0.340586796	0.681173592	0.68
Q_2	2	0.560000900	1.120001800	1.1
Q_3	2	0.305801830	0.611603661	0.61
Q_4	2	0.300473614	0.600947229	0.60

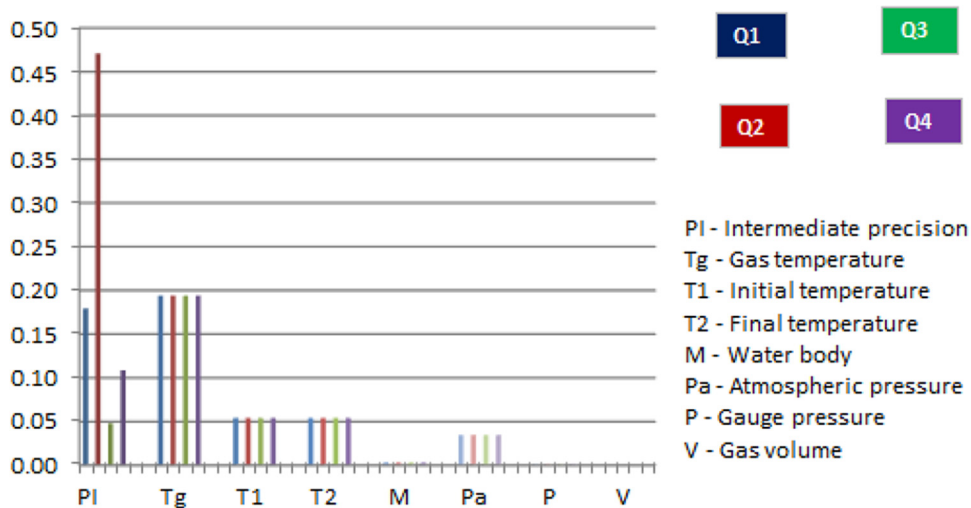


Fig. 4. Balance of contributions of efficiency uncertainties in Test 1, Lab B.

Table 20. Input quantities for consumption, Test 1, Lab B.

Quantities	Measurements	Units
P_a	90.748	kPa
P	2.633	kPa
\dot{V}	0.04415	m ³ /h
T_g	24.9	°C
H_s	126.21	MJ/m ³
d	2.0788	—
d_h	2.0302	—
P_c	1.464	kW

Table 21. Sensitivity coefficients (c_i) for consumption, Test 1, Lab B.

Sensitivity coefficients (c_i)	Results	Units
$F_{P_c.H_s} = \frac{\partial P_c}{\partial H_s} = \frac{P_c}{H_s}$	0.0116	kW/MJ.m ³
$F_{P_c.V} = \frac{\partial P_c}{\partial \dot{V}} = \frac{P_c}{\dot{V}}$	33.1509	kWh/m ³
$F_{P_c.T_g} = \frac{\partial P_c}{\partial T_g} = \frac{1}{2} \frac{P_c}{273.15 + T_g} \left(\frac{5262}{273.15 + T_g} \frac{d_h - d}{d_h} - 1 \right)$	-0.0035	kW/°C
$F_{P_c.P_a} = \frac{\partial P_c}{\partial P_a} = \frac{1}{2} \frac{P_c}{P_a + P} \frac{d}{d_h}$	0.0080	kW/kPa
$F_{P_c.P} = \frac{\partial P_c}{\partial P} = \frac{1}{2} \frac{P_c}{101.33 + P} + F_{P_c.P_a}$	0.0151	kW/kPa

Table 22. Uncertainty budget in consumption, Test 1, Lab B.

Type	Source of uncertainty	Value (U)	Unit	Distribution	k	u (xi)	V_{eff}	u_c (xi)
B	Barometer uncertainty – P_a	0.06900	kPa	Normal	2	0.0345	∞	
B	Lower division of the barometer – P_a	0.00500	kPa	Triangular	$\sqrt{6}$	0.0020	∞	0.03456
B	Pressure gauge uncertainty – P	0.00007	kPa	Normal	2	0.0000	∞	
B	Lower division of the pressure gauge – P	0.00500	kPa	Triangular	$\sqrt{6}$	0.0020	∞	0.00204
B	Flow meter uncertainty – \dot{V}	0.00038	m ³ /h	Normal	2	0.0002	∞	
B	Lower division of the flow meter – \dot{V}	0.00005	m ³ /h	Triangular	$\sqrt{6}$	0.0000	∞	0.00011
B	Uncertainty of the gas thermometer – T_g	0.33000	°C	Normal	2	0.1650	∞	
B	Lower division of the gas thermometer – T_g	0.25000	°C	Triangular	$\sqrt{6}$	0.1021	∞	0.19401
A	Repeatability	0.00163	kW	Normal	$\sqrt{7}$	0.0006	6	0.00062

Table 23. Summary of consumption uncertainties in Test 1, Lab B.

	k	u_c	$k \times u_c$	U (kg/h)
U (Consumption)	2	0.006401922	0.012803845	0.0009

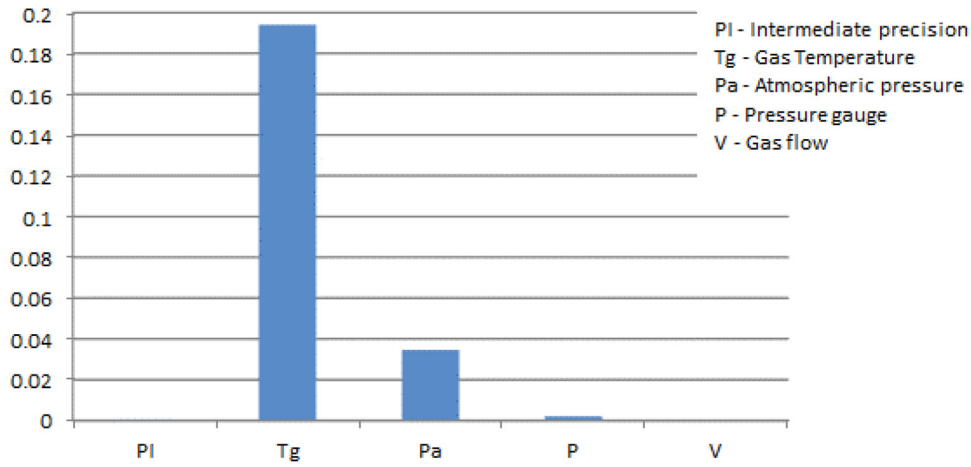


Fig. 5. Balance of contributions from uncertainties of consumption in Test 1, Lab B.

Table 24. Results of the nine performance tests (%), Lab A.

Q1 ± U	Q2 ± U	Q3 ± U	Q4 ± U	Average ± U	Arithmetic average ± U	Standard deviation	Weight	Weighted Average ± U
63.9 ± 0.9	67.7 ± 0.8	66.7 ± 0.7	62.0 ± 0.6	65.1 ± 0.4		2.6	0.1	
62.6 ± 0.9	67.0 ± 0.7	66.3 ± 0.7	61.4 ± 0.6	64.3 ± 0.4		2.7	0.1	
64.1 ± 0.9	67.4 ± 0.7	66.2 ± 0.7	62.3 ± 0.9	65.0 ± 0.4		2.3	0.2	
62.5 ± 0.9	67.9 ± 0.8	67.1 ± 0.7	61.2 ± 0.6	64.7 ± 0.4		3.3	0.1	
65.5 ± 0.9	68.4 ± 0.8	67.2 ± 0.7	62.6 ± 0.7	65.9 ± 0.4	65.0 ± 0.1	2.5	0.2	65.1 ± 0.1
63.9 ± 0.9	68.8 ± 0.8	65.7 ± 0.7	62.1 ± 0.6	65.1 ± 0.4		2.9	0.1	
62.0 ± 0.9	68.6 ± 0.8	66.8 ± 0.7	61.9 ± 0.6	64.8 ± 0.4		3.4	0.1	
64.4 ± 0.9	68.3 ± 0.8	66.8 ± 0.7	61.9 ± 0.6	65.4 ± 0.4		2.8	0.1	
63.6 ± 0.9	68.0 ± 0.8	66.4 ± 0.7	62.2 ± 0.6	65.1 ± 0.4		2.6	0.1	

By analyzing the graph, Figure 5, one can see that the uncertainty of the gas temperature is the dominant one, while the uncertainties of the other components are practically insignificant. As for the gas temperature, the determining factor in increasing the uncertainty is the type B uncertainty of the instrument that has an analog resolution of 0.5 °C, however, even decreasing the resolution with another instrument, the gas temperature would still be dominant, as it depends directly on the water temperature inside the wet gas meter.

4.5 Measurement uncertainty in performance and consumption tests at sea level and above sea level

The results in Sections 4.1 and 4.2 show the data set of the performance tests where the weighted average is obtained from the arithmetic average of the nine trials, removing their outliers. However, this item discusses the weighted average from the average of the burners in the stove table (Q1, Q2, Q3 and Q4) without removing outliers, according to the methodology followed by the international standard [8]. The uncertainty of the performance of the stove table from the uncertainties of each burner and from the large average of the nine tests was calculated, Tables 24 (Lab A) and 15 (Lab B).

As shown in Tables 24 and 25, one can verify that the uncertainty of the performance of the stove table in each of the nine tests, at sea level or at altitude above sea level is 0.4%.

In both conditions, the uncertainty was not enough to change the classification range of the product’s energy efficiency label, which varies according to Table 1. In addition, as shown in Table 26, we also found that the uncertainty of oven consumption in each of the nine tests, at sea level or at altitude above sea level is 0.0003 kg/h.

From the (grand) mean of the nine trials, a hypothesis testing was applied, Table 27.

As the hypothesis testing portrays, the averages are not compatible; therefore, as the tests were applied to the same sample, applying the same test conditions, with the same analyst and using the same instruments, the only variable observed is altitude, which allows us to infer that, perhaps, the algorithms are not correcting it properly.

5 Conclusions

The present work has metrologically evaluated the results of the efficiency and consumption tests on domestic gas cooking appliances and their influence on the Brazilian Labeling Program classification of these appliances.

Table 25. Results of the nine performance tests (%), Lab B.

Q1 ± U	Q2 ± U	Q3 ± U	Q4 ± U	Mean ± U	Grand mean ± U	Standard deviation	Weight	Weighted grand mean ± U
62.3 ± 0.9	64.5 ± 0.8	64.2 ± 0.7	60.3 ± 0.6	62.8 ± 0.4		2.6	0.3	
60.6 ± 0.9	64.6 ± 0.7	64.2 ± 0.7	60.0 ± 0.6	62.4 ± 0.4		2.7	0.2	
63.4 ± 0.9	67.1 ± 0.7	66.2 ± 0.7	60.3 ± 0.9	64.3 ± 0.4		2.3	0.1	
62.5 ± 0.9	67.6 ± 0.8	66.3 ± 0.7	60.0 ± 0.6	64.1 ± 0.4		3.3	0.1	
63.3 ± 0.9	64.9 ± 0.8	65.6 ± 0.7	60.4 ± 0.7	63.6 ± 0.4	63.9 ± 0.1	2.5	0.2	63.6 ± 0.1
62.9 ± 0.9	65.8 ± 0.8	66.4 ± 0.7	60.3 ± 0.6	63.9 ± 0.4		2.9	0.1	
63.0 ± 0.9	67.9 ± 0.8	66.9 ± 0.7	60.7 ± 0.6	64.6 ± 0.4		3.4	0.1	
63.1 ± 0.9	67.2 ± 0.8	66.2 ± 0.7	60.8 ± 0.6	64.3 ± 0.4		2.8	0.1	
63.9 ± 0.9	67.7 ± 0.8	66.7 ± 0.7	60.9 ± 0.6	64.8 ± 0.4		2.6	0.1	

Table 26. Results of consumption.

Laboratory A			Laboratory B		
Oven (kg/h)	U (kg/h)	Mean ± U (kg/h)	Oven (kg/h)	U (kg/h)	Mean ± U (kg/h)
0.117	0.0010		0.106	0.0009	
0.122	0.0011		0.100	0.0009	
0.122	0.0011		0.115	0.0009	
0.120	0.0011		0.111	0.0009	
0.119	0.0010	0.122 ± 0.0003	0.112	0.0009	0.111 ± 0.0003
0.122	0.0011		0.114	0.0009	
0.116	0.0010		0.115	0.0009	
0.118	0.0010		0.112	0.0009	
0.119	0.0010		0.112	0.0009	

Table 27. Comparing Labs A and B by a hypothesis testing.

	Grand mean efficiency		Mean consumption	
	Oven (kg/h)	U (%)	Oven (kg/h)	U (kg/h)
At sea level (x_1)	65.0	0.1	0.122	0.0003
Above sea level (x_2)	63.9	0.1	0.111	0.0003
Hypothesis Testing				
$ x_1 - x_2 \leq \sqrt{U_1^2 + U_2^2}$				
	1.1 ≤ 0.1		0.011 ≤ 0.0002	
	0.1		0.0002	

Here, based on international references, the efficiency and consumption algorithms concerning domestic gas cooking appliances are detailed.

It was possible to statistically compare two experiments, one at sea level and the other at altitude above sea level. The data sets suggest a new approach for calculating table burners, evaluating data behaviour, treating outliers and calculating the efficiency from the position measure,

inversely weighted by the measure of dispersion of each burner. These two different approaches were compared and not always, both the results reach the same conclusion, i.e., meet compliance/non-compliance to the specification. What one can guarantee experimentally is that the efficiency of table burners decreases with altitude and the performance of the furnace burner increases with altitude.

The results reveal that the measurement uncertainty of the tests does not affect the Brazilian Labeling Program classification of these devices. However, there is no statistical compatibility between the efficiency and consumption and their respective uncertainties, at sea level and at altitude above sea level.

Shortly, this study will be sent to the next revision of the standard test of the ABNT (Brazilian Association for Technical Standards) and the working group will evaluate the relevance of incorporating the methodology discussed here.

As a future study, this manuscript suggests shedding light on altitude correction algorithms.

Conflict of interests

The authors declare that they have no conflict of interest.

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