DEVOTION
Journal of Research and Community Service
Volume 7, Number 6, June 2026
e-ISSN: 2797-6068 and p-ISSN: 2777-0915

The Effect of Variations in Temperature and Humidity Based on OIML R 111-1: 2004 on the Calibration of F1-Class Weighing Scale Weight Standards

Tri Surawan, Rudy Yulianto*, Nani Kurniawati, Fogot Endro Wibowo, Tony Sutrisno
Universitas Jayabaya, Indonesia
Email: tri.surawan@gmail.com, wahyurudyulianto@gmail.com*, nanikurniawati0104@gmail.com, fogotendro71@gmail.com, tonysutrisno0311@gmail.com

Keywords
mass calibration, f1 class weights, temperature, humidity, conventional mass, OIML R 111-1:2004

Abstract

The Effect of Variations in Temperature and Humidity Based on OIML R 111-1: 2004 on the Calibration of F1-Class Weighing Scale Weight Standards investigates the accuracy of mass measurement, which is an important aspect of modern commerce, particularly for consumer protection and the maintenance of orderly trade. The OIML R 111-1:2004 standard defines requirements related to environmental conditions and physical characteristics for weight standards and calibration processes. This study aimed to analyze the effects of temperature and humidity variations on the calibration results of F1-class weights based on the OIML R 111-1:2004 standard. The research was conducted by observing standard and test mass readings within a temperature range of 18.0 °C to 25.0 °C and relative humidity (RH) levels between 50% and 60%. The data were analyzed using a two-way analysis of variance (ANOVA) to test the significance of individual factors and their interaction effects between environmental variables. The results showed that increasing temperature linearly increased the balance reading values while decreasing air density from 1.19206 kg/m³ to 1.16081 kg/m³. Statistical analysis using ANOVA confirmed that variations in temperature and humidity had a highly significant effect on calibration results, with a p-value of 5.27×10^{-134} under conventional mass conditions. The interaction between temperature and humidity was also significant, with an F-value of 1001.78, far exceeding the critical F-value of 1.84. Despite environmental fluctuations, conventional mass correction methods remained effective in maintaining result stability, with very low variance values in the range of 10^{-10} to 10^{-11}. All conventional mass values remained below the Maximum Permissible Error (MPE) limit of 5.0 mg for a nominal 1 kg F1-class weight. This study concludes that the application of buoyancy correction in accordance with OIML R 111-1:2004 is essential to maintain calibration accuracy under varying environmental conditions that significantly affect measurement results.

INTRODUCTION

The Effect of Variations in Temperature and Humidity Based on OIML R 111-1:2004 on the Calibration of F1-Class Weighing Scale Weight Standards highlights that the modern era of commerce is increasingly competitive, where the accuracy of mass measurement is a critical aspect. Nearly all buying and selling activities—ranging from food commodities and industrial raw materials to pharmaceutical products—rely on weighing instruments (Arianti et al., 2023; Chachan et al., 2021; Slegers et al., 2020). In Indonesia and globally, legal metrology regulations emphasize the need for orderly measurement practices and fair trade. Measuring instruments used in transactions must be verified against established standards. Scales as mass-measuring devices must maintain a high level of accuracy so that measurement results can be trusted (Arief et al., 2018; Kaviyarasan & Jaisri, 2025). Mass standards used as references in accordance with international regulations must be calibrated properly. The international reference for calibration of weights is regulated under the recommendations of the Organisation Internationale de Métrologie Légale (OIML) R 111-1, which specifies requirements for weights of classes E, F, and M (OIML, 2004).

F1-class weights serve as calibration standards for medium to high-precision scales. Scale accuracy is influenced by environmental factors, particularly temperature and humidity. Temperature changes cause thermal expansion or contraction of the weighing material. Humidity affects air density and, consequently, buoyancy correction values. Variations in environmental conditions may lead to significant deviations in conventional mass, resulting in increased measurement uncertainty (Wang et al., 2015; Zemp et al., 2019). If left unaddressed, these deviations may harm consumers, create unfairness in trade transactions, and disrupt the implementation of orderly trade, which is a primary objective of legal metrology (Cafaggi & Iamiceli, 2018; Mambodallu, 2018; Offermanns & Tangkiriphimarn, 2024).

Based on the research background, the main focus of this study is to analyze the effect of temperature and air humidity variations on the conventional mass values of F1-class weights during the calibration process (Sayed et al., 2026; Yoon et al., 2022). Changes in environmental conditions are assumed to affect mass measurement results through variations in air density and other correction factors that contribute to measurement uncertainty (Hagan & Kroll, 2020; Malings et al., 2020; Peng et al., 2020). In addition, this study examines how the findings can support consumer protection and the implementation of fair trade practices through accurate, reliable measurements in accordance with applicable metrology standards.

This study aims to analyze the influence of temperature and air humidity variations on the mass calibration results of F1-class weights and to formulate technical recommendations for controlling environmental factors during the calibration process (Amirkhanov et al., 2026; Elida et al., 2024; Pasha et al., 2026). The findings are expected to provide a deeper understanding of the impact of environmental conditions on mass measurement accuracy, contribute to the scientific literature in metrology, and serve as a reference for calibration laboratories, metrology institutions, and future researchers in improving the quality and reliability of mass standard calibration.

To maintain research focus, this study was limited to 1000-gram F1-class weights as the research object. The environmental factors analyzed were restricted to air temperature and humidity, while other factors such as air pressure, vibration, and magnetic fields were not considered (Abikenova et al., 2023; Keshmiry et al., 2023; Shuangchen et al., 2017). Calibration was conducted using reference standards traceable to national and international standards in accordance with OIML R 111-1, under experimental conditions with temperature variations of approximately ±2–3 °C from the laboratory baseline temperature (20 °C) and relative humidity of 50–60% RH. The study focused on the influence of environmental conditions on conventional mass and measurement uncertainty without examining material characteristics or the service life of the weights.

METHOD

This study was designed to analyze the effect of temperature and relative humidity variations on conventional mass calibration results of F1-class weights. The research was conducted at a Mass Metrology Laboratory from August 2025 to January 2026. The laboratory was selected due to the availability of high-precision mass measurement facilities and environmental monitoring systems that supported the study requirements. Measurements were carried out repeatedly under varying temperature and humidity conditions to obtain consistent and reliable data for evaluating the influence of environmental factors on calibration results.

The instruments used included E2-class reference weights as calibration standards, 1000-gram F1-class weights as the test object, high-precision mass comparators, and thermohygrometers for monitoring laboratory temperature and humidity. Latex gloves were used as standard laboratory safety equipment. Computer systems and data processing software were also utilized for statistical analysis. All instruments were selected to ensure measurement accuracy and compliance with mass metrology requirements.

The experimental procedure began with conditioning the reference standards and test weights to achieve thermal equilibrium in accordance with OIML R 111-1:2004 requirements. The mass comparator was then stabilized through an appropriate warm-up process to ensure optimal performance. Calibration was performed using a substitution comparison method between reference standards and the test weights following standard procedures for F1-class measurements. Each measurement was recorded systematically and repeated to ensure data reliability. The resulting data were used to calculate conventional mass values while accounting for air buoyancy and environmental influences during measurement.

Data analysis was conducted by determining the conventional mass values based on measurement results and recorded environmental parameters. The data were then analyzed using analysis of variance (ANOVA) to assess the significance of temperature and humidity effects on calibration outcomes. This analysis was also used to identify dominant influencing factors and potential interactions between environmental variables. The findings were intended to provide scientific evidence regarding the impact of environmental conditions on mass calibration and to support technical recommendations for environmental control in order to improve measurement accuracy and strengthen consumer protection and trade reliability.

RESULT AND DISCUSSION

The study was conducted to determine the effect of temperature and relative humidity variations on the conventional mass of F1 class weights with a nominal value of 1000 grams. The calibration process is carried out in a calibration laboratory with environmental condition control in accordance with the provisions of OIML R111 and ISO/IEC 17025. The temperature variation used is 18°C-25°C, while the relative humidity variation is 50%-60%. For each combination of temperature and humidity, a mass measurement was carried out 30 times to improve the reliability of the data.

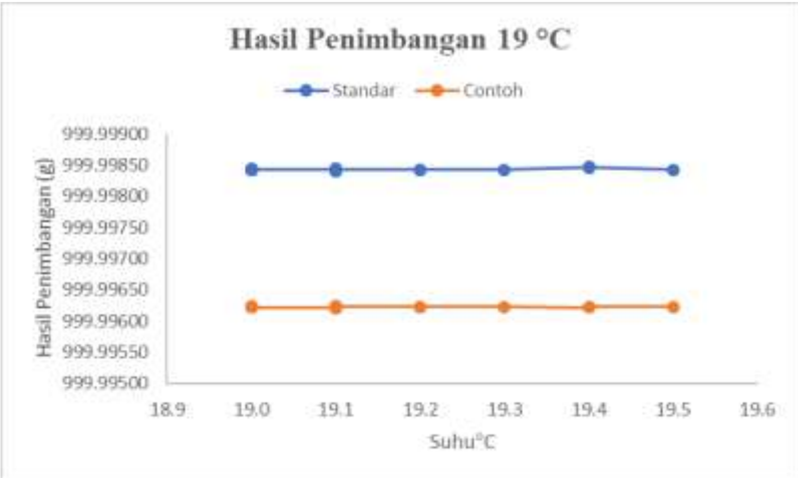
Measurement Results

The research was carried out by weighing standard tools and *unit under test* Using *mass comparator* MCM 1005. Standard tools use E2 weights with serial number 23429924 and *unit under test* using F1 weights with serial number G0611729. Mass data were collected from a range of temperature and humidity variations using direct comparison methods. The E2 standard is weighed 3 times and *unit under test* F1 class 2 times repetition with STSTS pattern. Data collection was carried out 30 times so that the results of the analysis could be represented. Varying temperature and humidity regulation performed in the laboratory. Based on OIML

R111-2004, the room temperature regulation must be in accordance with the characteristics of the weighing so that damage does not occur and accelerates corrosion. As for the temperature settings that vary from temperature [1]18°C, 19°C, 20°C, 21°C, 22-24°C and 25°C and humidity only with a range 50%-60%. following the temperature produced. Broadly speaking, the complete data is contained in appendix c. The data presented in the graph is figures 4.1 to 4.5 as follows:

Picture 1. Graphics *sEtting* Laboratory temperature: 18°C

This graph compares the mass weighing results between Standard (blue) and Example (orange) in the temperature range of 17.6°C to 18.4°C, where the standard scale object is consistently about 0.0022 g heavier than the example scale. The graph of the results of weighing 19°C is as follows:

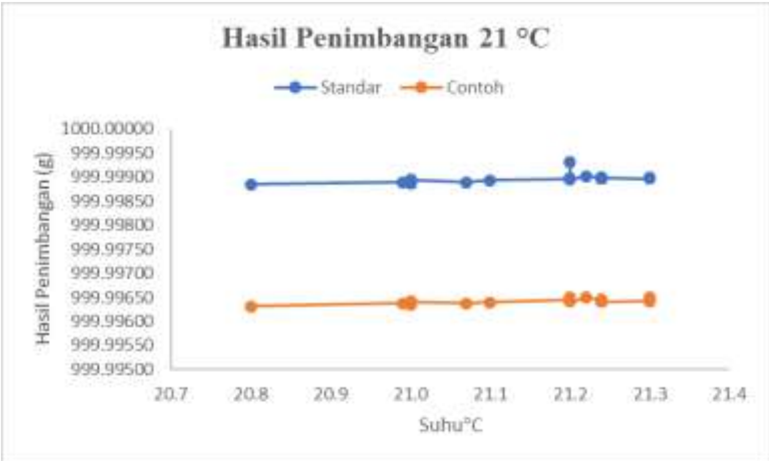


Picture 2. Graphics *Setting* Laboratory temperature: 19°C

This graph compares the mass weighing results between Standard (blue) and Example (orange) in the temperature range of 19.0°C to 19.5°C. The graph of the results of weighing 20°C is as follows:

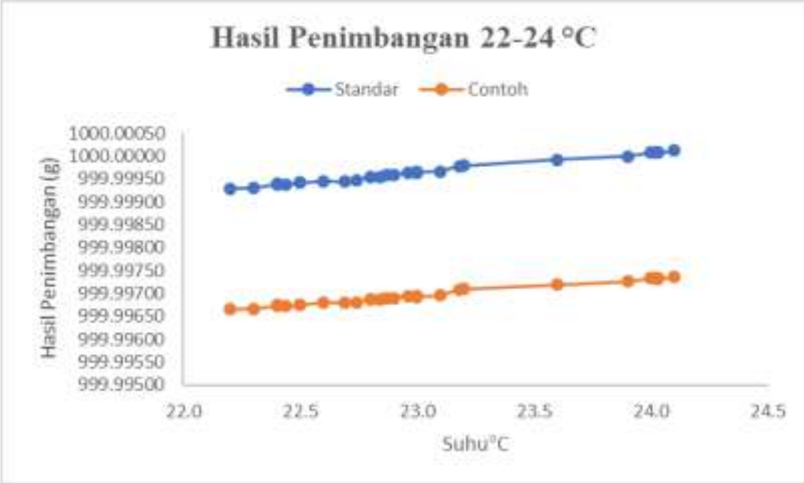
Picture 3. Laboratory temperature setting chart: 20°C

This graph compares the mass weighing results between Standard (blue) and Example (orange) in the temperature range of 21.0°C to 21.3°C. The graph of the results of weighing 21°C is as follows:



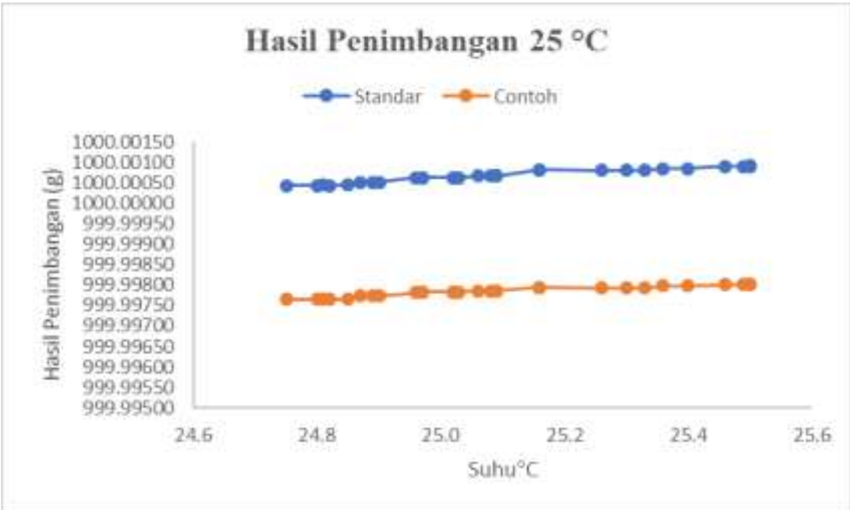
Picture 2. Graphics *Setting* Laboratory temperature: 21°C

This graph compares the mass weighing results between Standard (blue) and Example (orange) in the temperature range of 22.2°C to 24.1°C. The graph of the results of weighing 22-24°C is as follows:



Picture 3. Laboratory temperature setting chart: 22-24°C

This graph compares the mass weighing results between Standard (blue) and Example (orange) in the temperature range of 24.8°C to 25.5°C. The graph of the 25°C weighing results is as follows:



Picture 4. Laboratory temperature setting chart: 25°C

The weighing results according to figures 4.1 to 4.6 show that the higher the temperature, the higher the average weighing result. The average temperature rise is as follows:

Table 1. Average measurement of standard weights and

Average Temperature °C	Average RH %	Standard measurement average (g)	Average sample measurement (g)
18.0	58.9	999.99789	999.99572
19.1	56.5	999.99843	999.99623
20.2	53.9	999.99873	999.99626
21.1	52.1	999.99895	999.99641
22.4	51.2	999.99937	999.99672
22.9	51.2	999.99960	999.99692

24.0	51.3	1000.00005	999.99731
25.1	50.3	1000.00068	999.99785

The designation of measurement results from the temperature and humidity variations seen in table 1 has increased.

Results of Conventional Mass Calculation

The results of calculations from standard and test tool weighing data. Weighing is carried out in stages with the STSTS cycle (Standard, Test, Standard, Standard, Test) because it is only *unit under test* F1 class. The conventional mass is obtained by equation (2.1). The details of the equation are obtained on the average difference in the designation of scales between *Unit Under Test* and a reference standard, as shown in Equation:

$$\Delta I_i = I_{T_1 i} - \frac{(I_{S1} + I_{S2})}{2} \quad (4.1)\ [1]$$

with,

ΔI_i = Average number of repetitions

= the number of repetitions (1,2,3... n)i

The correction *of air buoyancy* can be calculated using the equation:

$$b = (\rho_a - \rho_b) x \left(\frac{1}{\rho_t} - \frac{1}{p_s}\right) \times m_s \quad (4.2)\ \text{(Badan Standardisasi Nasional [BSN], 2022)}$$

with,

b = *air buoyancy*

ρa = air density at calibration

ρb = air density at conventional mass measurements (1.2 kg/m3)

ρt = air density of the *unit under test*

ρs = air density of reference scales

mS = conventional mass of reference scales

The results of the calculation of the conventional mass of the weights use the measurement results in tables 4.1 to 4.6 using the same pattern. The following is a calculation for the conventional mass of each observed temperature

Conventional mass calculation

The variable sought is MT where the conventional mass is obtained from the mass of standard weights (Mstd) of class E2 is 1000.00032 g.

Known : Weighing 1 standard (I_{s1}) = 999.99798 g
Standard 2 weighing (I_{s2}) = 999.99802 g
Standard 3 weighing (I_{s3}) = 999.99802 g
Weighing 1 test (I_{T1}) = 999.99582 g
Weighing 2 tests (I_{T2}) = 999.99582 g
Temperature = 18.1°C
RH = 58.8%

Cast :

The conventional mass according to formula 2.1 is as follows:

$mT = mS_{\text{td}} ++ \Delta\text{m}\ b$

Before looking for the conventional mass of the *Under Test Unit* , first look for Δm and *b*. Where Δm is the difference from the average data of standard and *test* weighing and b is *buoyancy water.*

$$\Delta I_i = I_{T_i} - \frac{(I_{s1} + I_{s_2})}{2}$$

$$\Delta I_1 = I_{T_1} - \frac{(I_{s1} + I_{s_2})}{2}$$

$$= 999.99582 \text{ g} - \frac{(999.99798 \text{ g} + 999.99802 \text{ g})}{2}$$

= 999.99582 g - 999.99800 g

= -0.002180 g

$$\Delta I_2 = I_{T_2} - \frac{(I_{s2} + I_{s_3})}{2}$$

$$= 999.99582 \text{ g} - \frac{(999.99802 \text{ g} + 999.99802 \text{ g})}{2}$$

= 999.99582 g - 999.99802 g

= -0.002120 g

$$\text{DM} = \frac{(\Delta I_1 + \Delta I_2)}{2}$$

$$= \frac{((-0.002180 \text{ g}) + (-0.002120 \text{ g}))}{2}$$

= -0.002190 g

After the calculation of the average difference in weighing results, then calculate *the buoyancy water*. Before calculating *buoyancy water*, look for an unknown variable, namely ρa = air density at the time of weighing.

Known	:	Air density in conventional mass measurement (ρb)	= 1.2 kg/m3
		Air density of the *unit under test* (ρt)	= 7810 kg/m3
		Reference weight's air density (ρs)	= 8000 kg/m3
		Conventional mass of reference scales (mS)	= 1000.00032 g

Cast

Water Buoyancy can be calculated if all variables are met in such a conventional mass calculation. The calculation is as follows:

$$b = (\rho_a - \rho_b) x \left(\frac{1}{\rho_t} - \frac{1}{p_s}\right) \times m_s$$

$$A = \frac{0.34848\, p - 0.009\, hr\, x \exp(0.061\, t)}{273.15 + t}$$

$$A = \frac{(0.34848\, x\, 1000.4) - (0.009\, x\, 62.33)\ \exp(0.061\ 17.96)}{273.15 + 17.96}$$

$$= \frac{346.942}{291.11}$$

= 1.19179 kg/m3

$$b = (1.19179 - 1.2) x \left(\frac{1}{7810} - \frac{1}{8000}\right) \times 1000.00032 \text{ g}$$

$= 0.0000250$ g

After all the variables are known, the conventional mass calculation is as follows:

$$M_T = M_{Std} + \Delta m + b$$
$$= 1000.00032\ g + (-0.00219)\ g + 0.000025\ g$$
$$= 999.99816\ g$$

Subsequently, based on formulas and calculations, a table will be made to see the movement of conventional mass

Calculation data based on environmental factors

The manual calculation in subchapter 4.2.1 is detailed in the table based on a formula that has been calculated from the conventional mass. The following are the results of the calculation seen from the analysis of environmental factors.

Based on the calculation results based on the 4.1 graph image and the analysis of weighing data, the increase in ambient temperature shows a tendency to increase the weighing value read on the scale. This is due to the decrease in air density at higher temperatures, so that the buoyancy force acting on the weighs is reduced and causes the effective weight force received by the weighing system to be greater.

The results of the average conventional mass based on the variation of environmental factors, temperature and humidity are as follows:

Table 2. Average results of conventional mass calculations

Average Temperature °C	Average RH %	Average Conventional Mass Calculation (g)
18.0	58.9	999.99816
19.1	56.5	999.99815
20.2	53.9	999.99790
21.1	52.1	999.99785
22.4	51.2	999.99775
22.9	51.2	999.99773
24.0	51.3	999.99768
25.1	50.3	999.99768

The designation of the results of conventional mass calculations of temperature variations seen in table 2 decreases with the increase in temperature. Air humidity affects the weighing results indirectly through changes in air density and the surface condition of the scales. The increase in humidity causes the air density to decrease so that the buoyancy force of the air decreases and the weighing value tends to increase, although the effect is relatively small compared to the effect of temperature.

Research Statistical Analysis

The results of observation and research show that there is a variation in the weighing value of each change in environmental conditions. The change indicates that environmental factors have the potential to affect weighing results, although the magnitude of the influence differs for each parameter. An increase in temperature tends to be followed by an increase in the readability on the scale, while variations in humidity show a relatively smaller effect and are not always visually visible on the graph of the measurement results.

In this study, whether or not significant changes can be tested through statistics. The parameters are hypothesis testing; Statistical hypotheses, *two-way Analisys of Variance* (ANOVA) and correlation tests between the two allow evaluation of the influence of each factor as well as the interaction between temperature and humidity.

Uji Hypothesis

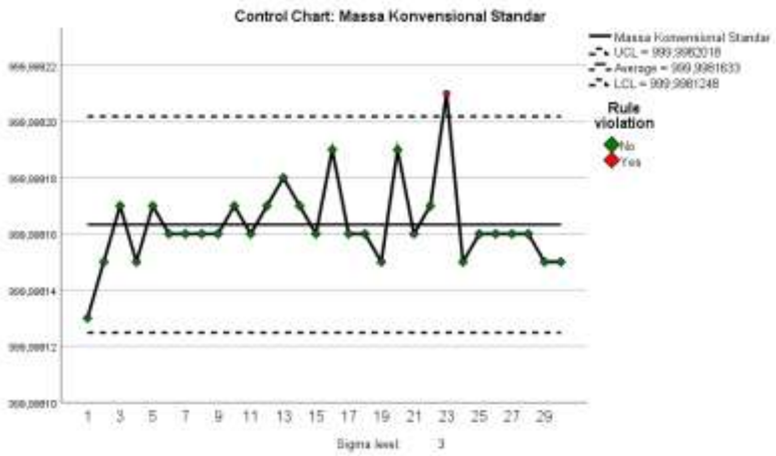
A temporary conclusion to a problem that is still presumptive because it still has to be proven to be true is a hypothesis test. The research hypothesis is as follows:

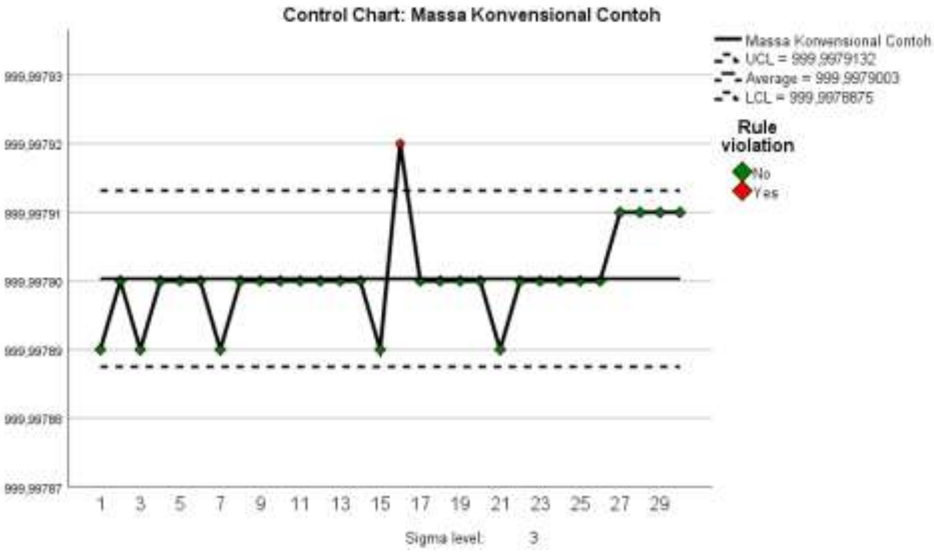
a) Research hypothesis with temperature variation factors
   H0: There is no significant difference in the average mass calibration with temperature variations.
   H1: There is a significant difference in the average mass calibration with temperature variations.
b) Research hypothesis with moisture variation factors
   H0: There is no significant difference in mean mass calibration with moisture variation.
   H1: There is a significant difference in average mass calibration with moisture variations.
c) Research hypothesis of the interaction between temperature and humidity factors
   H0: There is no interaction there is a significant difference in mass calibration with temperature and humidity variations.
   H1: There is a significant difference in interaction of mass calibration with temperature and humidity variations.

***Bidirectional Analysis of Variance* (ANOVA)**

Two-way ANOVA allows analysis of the influence of two factors at once and their interaction on dependent variables. Identify the dominant factors that affect the calibration results and assess the interaction between temperature and humidity. Before conducting *the Analysis of Variance* (ANOVA), there are several basic assumptions that must be met in order for the results of the analysis to be valid and accurate, namely normally distributed data, homogeneous variance, and independent samples. The tests are as follows:

1. Uniformity Test





Picture 5 Sample Uniformity Test Graph

Picture 7 is a uniformity test in which statistical testing is carried out to ensure that the data collected is uniform and comes from the same system. This test aims to identify data that is *out of control* due to extreme factors or errors in the data collection process.

2. Normality Test

Table 3. Normality Test Table

	Kolmogorov-Smirnova			***Shapiro-Wilk***		
	Statistic	**df**	**Say.**	**Statistic**	**df**	**Say.**
Residual Standar	0,137	180	0,054	0,920	180	0,050
Residual Sampel	0,194	180	0,055	0,890	180	0,051

The standard residual normality test was performed using *the Kolmogorov–Smirnov* and *Shapiro–Wilk* methods with a significance level (α) of 0.05. The test results showed that the standard residual variable had a *Kolmogorov–Smirnov* significance value of 0.054 and Shapiro–Wilk of 0.050. Meanwhile, the Temperature Influence variable showed a significance value of *Kolmogorov–Smirnov* of 0.055 and *Shapiro–Wilk* of 0.051.

Since the entire significance value (Sig.) is greater than or equal to 0.05 (Sig. ≥ 0.05), it can be concluded that the data is normally distributed. Thus, the assumption of normality has been fulfilled so that parametric statistical analysis can be continued.

Analysis of variations from temperature and RH factors to standard weighing, example and conventional mass

Table 4. ANOVA of temperature and RH factors against standard weighing

Summary	***Count***	***Sum***	***Average***	***Variance***
temperature 18; RH 58.9	30	29999.93683	999.9978943	2.10185E-08
Temperature 19; RH 56.5	30	29999.95298	999.9984327	1.30575E-10
Temperature 20; RH 53.9	30	29999.96194	999.9987314	2.17294E-09
Temperature 21; RH 52.1	30	29999.96856	999.998952	6.84886E-09
temperature 22-24; RH 51.3	30	29999.98963	999.9996543	6.63296E-08
Temperature 25 RH 50.3	30	30000.02054	1000.000685	2.56733E-08

ANOVA

Source of Variation	*SS*	*df*	*MS*
Standard Weighing	1.84E-06	29	6.35611E-08
Temperature Variation & RH	0.000146	5	2.91882E-05
Error	1.7E-06	145	1.17225E-08
Total	0.000149	179	

(connection)

Source of Variation	*F*	*P-value*	*F crit*
Standard Weighing	5.422129129	2.65697E-12	1.545812257
Temperature Variation & RH	2489.923422	1.2774E-138	2.276603348
Error			
Total			

Table 5. ANOVA of temperature and RH factors to sample weighing

Summary	***Count***	***Sum***	***Average***	***Variance***
temperature 18; RH 58.9	30	29999.93683	29999.8715	999.9957167
Temperature 19; RH 56.5	30	29999.95298	29999.88682	999.9962272
Temperature 20; RH 53.9	30	29999.96194	29999.88782	999.9962607
Temperature 21; RH 52.1	30	29999.96856	29999.89227	999.996409
temperature 22-24; RH 51.3	30	29999.98963	29999.90885	999.9969615
Temperature 25 RH 50.3	30	30000.02054	29999.9356	999.9978533

ANOVA

Source of Variation	*SS*	*df*	*MS*
Example weighing	1.34979E-06	29	4.65443E-08
Temperature Variation & RH	8.30258E-05	5	1.66052E-05
Error	1.2409E-06	145	8.5579E-09
Total	0.0000856	179	

(connection)

Source of Variation	*F*	*P-value*	*F crit*
Example weighing	5.438757939	2.41288E-12	1.545812257
Temperature Variation & RH	1940.330394	7.1487E-131	2.276603348
Error			
Total			

Table 6. ANOVA of temperature and RH factors relative to conventional mass

Summary	***Count***	***Sum***	***Average***	***Variance***
temperature 18; RH 58.9	30	29999.94492	999.9981639	2.18757E-10
Temperature 19; RH 56.5	30	29999.94454	999.9981514	1.15612E-10

Temperature 20; RH 53.9	30	29999.93703	999.9979011	4.01393E-11
Temperature 21; RH 52.1	30	29999.93537	999.9978455	1.96526E-09
temperature 22-24; RH 51.3	30	29999.93161	999.9977203	9.19436E-10
Temperature 25 RH 50.3	30	29999.92829	999.9976096	1.66333E-09

ANOVA			
Source of Variation	*SS*	*df*	*MS*
Conventional Mass Calculation	4.04294E-08	29	1.39412E-09
Temperature Variation & RH	7.57333E-06	5	1.51467E-06
Error	1.02324E-07	145	7.05685E-10
Total	7.71608E-06	179	

(connection)

Source of Variation	*F*	*P-value*	*F crit*
Conventional Mass Calculation	1.975550475	0.00469582	1.545812257
Temperature Variation & RH	2146.377642	5.2719E-134	2.276603348
Error			
Total			

Analysis of the interaction of temperature and RH factors with standard weighing, example and conventional mass.

Table 7. ANOVA of temperature and RH factors relative to conventional mass

ANOVA			
Source of Variation	*SS*	*df*	*MS*
Standard weighing, examples and conventional mass calculations	0.000557439	2	0.00027872
Temperature and RH Variations	0.000116087	5	2.32174E-05
Interaction	0.000120453	10	1.20453E-05
Within	6.27647E-06	522	1.20239E-08
Total	0.000800256	539	

(connection)

Source of Variation	*F*	*P-value*	*F crit*
Standard weighing, examples and conventional mass calculations	23180.47803	0	3.0129906
Temperature and RH Variations	1930.937766	0	2.231283218
Interaction	1001.781432	0	1.84883667
Within			
Total			

Correlation Test

Table 8. Correlation Test of Environmental Influence on Conventional Mass

		Standard Conventional Mass	Conventional Mass Examples
Environmental Impact	Pearson Correlation	1	-0.955**
	Sig. (2-tailed)		0.000
	N	180	180
Conventional Mass Examples	Pearson Correlation	-0.955**	1
	Sig. (2-tailed)	0.000	
	N	180	180

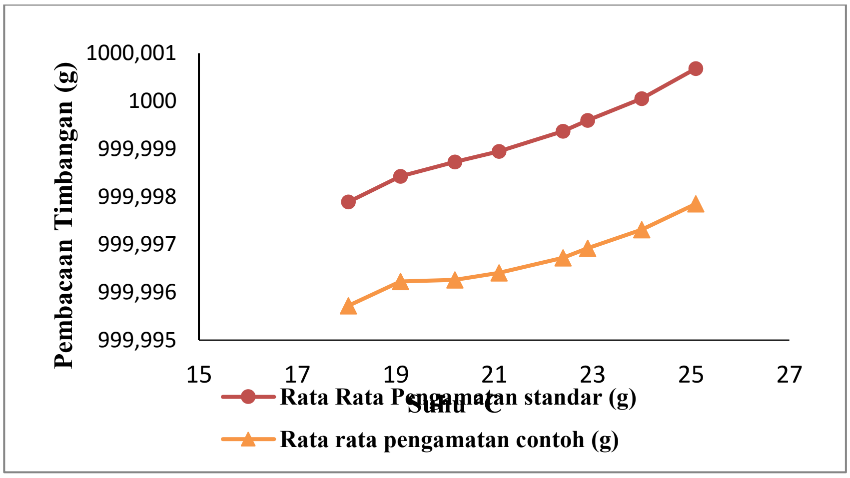
***. Correlation is significant at the 0.01 level (2-tailed).*

Based on the results of the Pearson correlation test in Table 4.8, the value of the correlation coefficient was -0.955. This shows that there is a very strong and negative relationship between environmental influences and conventional mass Examples. The significance value (Sig. 2-tailed) is 0.000, which is less than 0.01, so it can be concluded that the correlation is statistically significant at a 99% confidence level

Discussion of Measurement Results

The presentation of measurement results obtained from F1 class scale calibration activities carried out in the laboratory by paying attention to variations in environmental conditions, namely air temperature and humidity. Measurements were carried out using a comparison method with the standard of searchable mass, and were carried out at several predetermined temperature and humidity levels. Each observation point is carried out repeatedly to ensure the repeatability and stability of the measurement results.

The data taken are the results of standard and test measurements of weights. The measurement results are used as primary data for conventional mass calculations. In detail, the measurement results can be seen in tables 4.7 to 4.9 with the following graph:

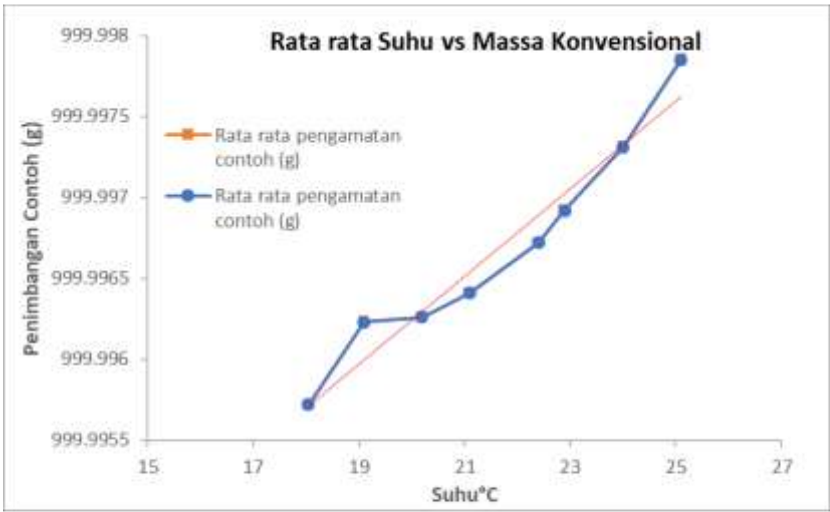


Picture 6. Comparison chart between temperature variation and scale readings

Based on Picture 4.8, there is a significant positive correlation between temperature increase and the results of scale readings. As the temperature increases from 18°C to 25°C, the average reading values of the standard observations (orange line) and the average sample observations (green line) show a consistent upward trend. At the lowest temperature of 18.0 °C, the standard reading was at 999.99789 g and the sample observation was 999.99572 g. As the temperature rises to a high of 25.1 °C, the reading increases to 1000.00068 g for standard and 999.99785 g for example. This phenomenon suggests that fluctuations in ambient temperature have a linear impact on thermal expansion or changes in sensitivity in the mechanical system of the measuring instrument.

Discussion of measurement results

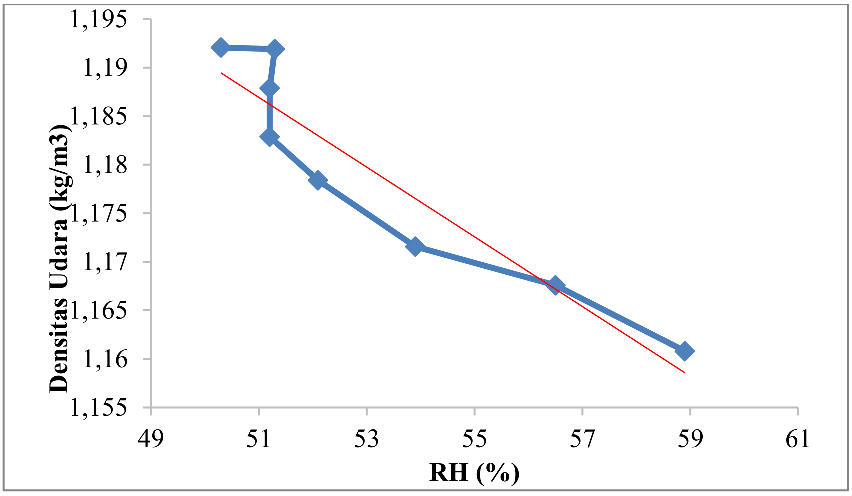
Calculation is secondary data taken from primary data, namely measurement data. As for conventional mass, in theory, there is no significant influence of the temperature factor, because the increase in temperature does not increase significantly with the conventional mass (OIML, 2004).



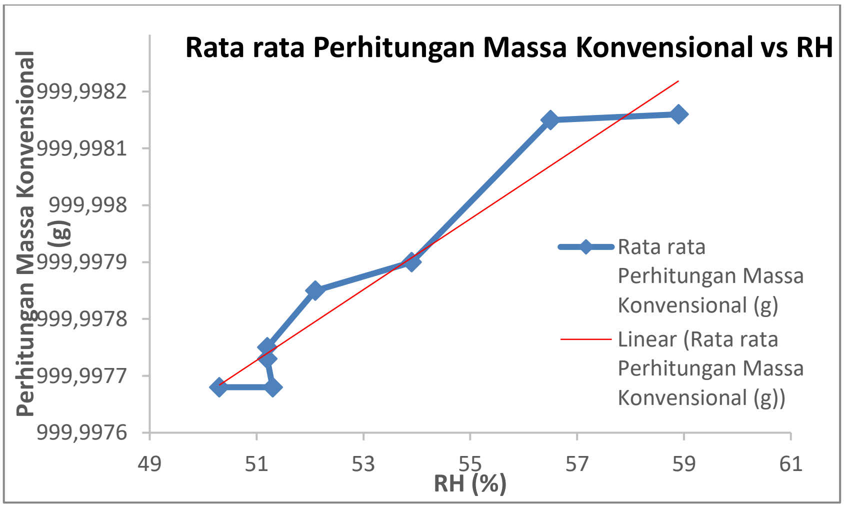
Picture 7. Comparison graph of average conventional temperature and mass variation

Based on the test results seen in Picture 4.9, there is a consistent effect of temperature on conventional mass values. In contrast to direct scale readings that increase as temperature rises, conventional mass values show a very sloping but linear downward trend. At 18.0 °C, the average conventional mass calculation was recorded at 999.99816 g. Along with the increase in temperature to 25.1 °C, the value decreased to 999.99761 g. This shows a difference of 0.00055 g or 0.55 mg along the temperature range of 7.1 °C.

In addition to temperature, the environmental influence is humidity affecting the air density at the time of calibration. The calculation process is based on the research method based on OIML R111 The following graph (figure 4.9) between humidity and air density.



Picture 8. Graph of the effect of air humidity on density



Picture 9. Graph Average of conventional mass with humidity (RH)

Influence of air humidity (*Relative Humidity*/RH) on the mass weighing process is closely related to changes in air density and the phenomenon of adsorption of water molecules. Humid air has a lower density than dry air at the same temperature. This is due to the fact that the water molecule (H_2O) has a lighter molar mass than a nitrogen molecule (N_2) or oxygen (O_2). Based on Figure 4.10, when RH drops from 58.9% to 50.3% (followed by an increase in temperature), there is a change in air density from 1.19206 kg/m³ to 1.16081 kg/m³ (Win et al., 2020). This decrease in density directly affects the buoyancy correction value (*buoyancy*) which must be applied to the scale reading. Air humidity affects the actual mass of an object through the layer of water that adheres to the surface. This phenomenon is called adsorption. The higher the humidity of the air, the thicker the layer of water molecules that are physically bonded to the surface of the test and standard specimens. This shows that in this experiment, the decrease in air density (due to temperature increase) had a greater impact on the increase in scale readings than the mass loss due to water desorption (release of the water layer) due to the decrease in RH (Win et al., 2020).

Discussion of *analysys of variance* (ANOVA)

The hypothesis discussion was carried out by comparing the statistical value of the calculation results (*F-calculate* and *P-value*) against the critical value (*F-critical*) and the significance threshold (α= 0.05). The summary and explanation are as follows:

Table 9. *Resume* hipotesis

Test Variables	F-*Calculate*	F-*Critical*	P-Value	Status Hypothesis
Standard Weighing	2489.92	2.27	1.27E-138	H1 Accepted
Example Weighing	1940.33	2.27	7.14E-131	H1 Accepted
Conventional Mass	2146.37	2.27	5.27E-134	H1 Accepted
Temperature & RH Interaction	1001.78	1.84	0.0000	H1 Accepted

1. Hypothesis of Temperature Variation Factors and RH for Standard Weighing

Based on the data in Table 4.4, the following results were obtained: The F-calculate value of 2489,923 far exceeded the F-critical value (2,276). In addition, the resulting P-value is 1.2774E-138, which is much smaller than 0.05. So the decision is that H0 is rejected and H1 is accepted, because F calculates > F table and P-value < 0.05. There are very significant differences in standard weighing results due to variations in temperature and humidity.

2. Hypothesis of Temperature Variation and RH Factors for Example Weighing

Based on the data in Table 4.5, the following results were obtained: The F-calculate value *was 1940,330 while the F-critical value* was 2,276. In addition, the resulting P-value is 7.1487E-131, which is much smaller than 0.05. So the decision is that H0 is rejected and H1 is accepted, because F calculates > F table and P-value < 0.05. Variations in temperature and humidity have a real and significant influence on the difference in mass readings on the test specimen (example).

3. Hypothesis of Temperature Variation and RH Factors to Conventional Mass

Based on the data in Table 4.6 (single factor), the following results were obtained: The F-calculate value was 2146,377 with an F-critical of 2,276. The P-value was recorded at 5.2719E-134. So the decision is that H0 is rejected and H1 is accepted, because F calculates > F table and the P-value < 0.05. Although conventional mass is used to correct for environmental influences, statistically the difference in temperature and humidity still exerts an influence on the final value of the mass calculation.

4. Hypothesis of the Interaction between Temperature and Humidity Factors

Based on the data in Table 4.7 (interaction analysis), the following results were obtained: The F-calculate value for the interaction between weighing and environmental variation reached 1001.781, far above the F-critical 1.848. The P-value is 0 (absolute zero in statistical rounding). So the decision is that H0 is rejected and H1 is accepted, because F calculates > F table and the P-value < 0.05. There was a significant interaction between temperature and humidity factors on the mass calibration results. This means that the magnitude of the effect of temperature changes on the mass value is highly dependent on the air humidity conditions at that time.

CONCLUSION

The Effect of Variations in Temperature and Humidity Based on OIML R 111-1:2004 on the Calibration of F1-Class Weighing Scale Weight Standards shows that variations in temperature and relative humidity affect the mass calibration results of F1-class weights in accordance with the OIML R 111-1:2004 standard. Increasing temperature causes a decrease in air density, which influences buoyancy correction and affects the measured conventional mass value. In addition, changes in relative humidity affect water vapor adsorption on the surface of the weights as well as air density characteristics, thereby contributing to variations in measurement results. These findings confirm the importance of controlling environmental conditions during the calibration process to maintain the accuracy and consistency of mass measurements.

Based on the study results, each 1 °C increase in temperature led to a decrease in the average conventional mass of 0.077 mg. However, all calibration results remained within the Maximum Permissible Error (MPE) limit of 5.0 mg for 1 kg F1-class weights. The largest observed deviation was 2.39 mg, indicating that the weights still met F1-class requirements and were suitable for use in trade applications. Therefore, calibration procedures based on OIML R 111-1:2004 ensure measurement traceability, support consumer protection, and strengthen fair and accurate commercial practices.

REFERENCES

Abikenova, S., Issamadiyeva, G., Kulmagambetova, E., Daumova, G., & Abdrakhmanova, N. (2023). Assessing occupational risk: A classification of harmful factors in the production environment and labor process. *International Journal of Safety & Security Engineering, 13*(5).

Amirkhanov, B., Kunelbayev, M., Amirkhanova, G., Nurgazy, T., Tyulepberdinova, G., & Tletay, S. (2026). Development of a digital twin for a bakery line with predictive analytics and adaptive control functions. *IET Collaborative Intelligent Manufacturing, 8*(1), Article e70056.

Arianti, F., Pauzi, M., Mughits, A., Nurdin, R., & Saad, A. Y. Q. (2023). Legality of agricultural products weight cutting as a cost of risk in trade. *JURIS (Jurnal Ilmiah Syariah), 22*(2), 355–365.

Arief, D. S., Shiddiq, M., Prayitno, A., Badri, M., Nugraha, A. S., & Muflihana, A. (2018). Calibration of 40 kg capacity digital scale on automatic machine measurement mass and dimension based on Arduino Uno using CSIRO-NML: 1995 method. *Proceeding of Ocean, Mechanical and Aerospace-Science and Engineering, 5*(1), 97–102.

Badan Standardisasi Nasional. (2008). *SNI ISO/IEC 17025:2008 standar nasional Indonesia persyaratan umum kompetensi laboratorium pengujian dan laboratorium kalibrasi*. Badan Standardisasi Nasional.

Cafaggi, F., & Iamiceli, P. (2018). *Unfair trading practices in the business-to-business retail supply chain: An overview on EU member states' legislation and enforcement mechanisms*.

Chachan, S., Kishore, A., Kumari, K., & Sharma, A. (2021). Trends of food adulteration in developing countries and its remedies. In *Food chemistry: The role of additives, preservatives and adulteration* (pp. 165–187).

Elida, E., Putri, A. O., Nugraha, D., Vresdian, D. J., Manfaluthy, M., & Pratama, L. P. (2024). Prototype of automatic calibration system based on IoT for weights using conveyor scale. In *2024 FORTEI-International Conference on Electrical Engineering (FORTEI-*

ICEE) (pp. 272–277).
Hagan, D. H., & Kroll, J. H. (2020). Assessing the accuracy of low-cost optical particle sensors using a physics-based approach. *Atmospheric Measurement Techniques Discussions, 2020*, 1–36.
Kaviyarasan, S., & Jaisri, J. (2025). Design and development of a 6-axis robotic arm with integrated weight measurement system. In *2025 4th International Conference on Automation, Computing and Renewable Systems (ICACRS)* (pp. 455–460).
Keshmiry, A., Hassani, S., Mousavi, M., & Dackermann, U. (2023). Effects of environmental and operational conditions on structural health monitoring and non-destructive testing: A systematic review. *Buildings, 13*(4), 918.
Malings, C., Tanzer, R., Hauryliuk, A., Saha, P. K., Robinson, A. L., Presto, A. A., & Subramanian, R. (2020). Fine particle mass monitoring with low-cost sensors: Corrections and long-term performance evaluation. *Aerosol Science and Technology, 54*(2), 160–174.
Mambodallu, A. (2018). *Growth related challenges facing Islamic banking windows in Kenyan conventional banks* [Thesis, KCA University].
Offermanns, C. B., & Tangkiriphimarn, A. (2024). *Mode 4 plus: International economic migration reform through the lens of cosmopolitan law*. Thammasat University.
Pasha, A., Hasan, M. A., Afroze, M., & Hossain, M. (2026). ISO/IEC 17025-compliant calibration of biomedical equipment: Frameworks, methods, and measurement uncertainty assessment. *International Journal of Research and Innovation in Applied Science (IJRIAS), 11*(5).
Peng, C., Wang, J., & Wu, D. (2020). Impacts of air density fluctuations toward the mass measurements of a 1 kg silicon sphere. *IEEE Access, 8*, 140840–140847.
Sayed, B. M., Zahra, O., & Eltawil, A. A. (2026). Design control and investigation of a two-axis robotic platform for high precision fifty kilogram mass calibration. *Discover Mechanical Engineering, 5*(1), 63.
Shuangchen, M., Jin, C., Kunling, J., Lan, M., Sijie, Z., & Kai, W. (2017). Environmental influence and countermeasures for high humidity flue gas discharging from power plants. *Renewable & Sustainable Energy Reviews*.
Slegers, P. M., Olivieri, G., Breitmayer, E., Sijtsma, L., Eppink, M. H. M., Wijffels, R. H., & Reith, J. H. (2020). Design of value chains for microalgal biorefinery at industrial scale: Process integration and techno-economic analysis. *Frontiers in Bioengineering and Biotechnology, 8*, 550758.
Wang, Y., Li, J., Jing, H., Zhang, Q., Jiang, J., & Biswas, P. (2015). Laboratory evaluation and calibration of three low-cost particle sensors for particulate matter measurement. *Aerosol Science and Technology, 49*(11), 1063–1077.
Yoon, K.-T., Lim, H., Bae, J.-H., Lee, W. K., Kim, D., & Choi, Y.-M. (2022). Novel multi-electromagnetic-force-compensation weighing cell with axis-symmetric structure. *IEEE/ASME Transactions on Mechatronics, 27*(6), 6018–6023.
Zemp, M., Huss, M., Thibert, E., Eckert, N., McNabb, R., Huber, J., Barandun, M., Machguth, H., Nussbaumer, S. U., & Gärtner-Roer, I. (2019). Global glacier mass changes and their contributions to sea-level rise from 1961 to 2016. *Nature, 568*(7752), 382–386.